ECO-PHYSIOLOGICAL ASPECTS OF CHENGAL SEEDLINGS PLANTED IN LOGGED-OVER FOREST IN TEKAI FOREST RESERVE, JERANTUT, PAHANG

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ABSTRACT

The replanting of chengal, an endemic Malaysian hardwood for rehabilitation has gained much prominence lately due to its high economic value. Planting stocks production generally aims to produce quality seedlings that can exhibit good survival and growth after outplanting in a logged-over forest. In this study, the effect of light, age and fertilizer requirements on the growth performance of chengal seedlings raised in the nursery at the Forest Research Institute Malaysia (FRIM) up to planting in a logged-over forest at the Tekai Forest Reserve, Pahang, were determined. Results showed that in the nursery, chengal potted seedlings under 50 % light intensity (LI) treated with NPK Blue fertilizer recorded the highest increment for growth, biomass allocation, plant mineral, soil mineral and physical content as well as physiological parameters compared to 30 and 100 % LI with organic fertilizer applied singly and without any fertilizer application. Meanwhile, in the field it was observed that 1 year 8 month old chengal seedlings given a combination of slow release fertiliser (SRF) and organic fertilizer, showed significantly higher growth, biomass and soil physical content compared to 6-month seedlings treated with either SRF or organic fertilizer after 44 months of planting. On the contrary, 6 months old seedlings exhibited higher soil mineral nutrient and physiological parameters throughout, compared to 1 year 8 month seedlings. Results from this study has provided new insights on the relationship between growth performance in chengal and biomass allocation, soil physical and mineral characteristics and its physiological processes, from nursery stage up to after outplanting in a logged-over forest.

Keywords: chengal, seedlings, growth, physiology, logged-over forest

ASPEK EKO-FISIOLOGI ANAK POKOK CHENGAL YANG DITANAM DI HUTAN SIMPAN DIBALAK DI HUTAN SIMPAN TEKAI, JERANTUT, PAHANG

ABSTRAK

Penanaman semula chengal, kayu keras endemik di Malaysia bagi pemulihan di hutan simpan yang dibalak banyak mendapat perhatian kerana nilai ekonominya yang tinggi. Pengeluaran stok anak pokok chengal bagi penanaman bertujuan untuk menghasilkan stok berkualiti dan dapat bermandiri dengan pertumbuhan yang baik selepas ditanam di hutan simpan yang telah dibalak. Dalam kajian ini, kesan cahaya, umur dan keperluan baja bagi meningkatkan prestasi pertumbuhan anak pokok chengal telah dijalankan di tapak semaian Institut Penyelidikan Perhutanan Malaysia (FRIM) sehingga penanaman di hutan simpan yang telah dibalak di Hutan Simpan Tekai, Pahang. Hasil kajian menunjukkan bahawa di tapak semaian FRIM, anak pokok chengal di bawah keamatan cahaya 50% dengan pembajaan *NPK Blue* merekodkan nilai tertinggi bagi pertumbuhan, agihan biomass, mineral tumbuhan, mineral tanah dan kandungan fizikal dan juga ciri-ciri fisiologi seperti kadar fotosintesis, transpirasi, konduktan stomata dan keluasan saiz daun berbanding dengan keamatan cahaya 30 dan 100% yang dirawat dengan baja organik secara tunggal dan tanpa pembajaan. Chengal berumur 1 tahun 8 bulan yang diberi *slow release fertilizer* dan baja organik menunjukkan pertumbuhan tertinggi ketara bagi biomass dan kandungan fizikal tanah berbanding dengan chengal berumur 6-bulan yang dirawat dengan *slow release fertilizer* secara tunggal atau baja organik secara tunggal selepas 44 bulan ditanam. Sebaliknya, chengal berumur 6-bulan mencatatkan nilai tertinggi dari segi nutrien mineral tanah dan ciri-ciri fisiologi berbanding dengan chengal berumur 1 tahun 8 bulan. Kajian ini telah dapat menyumbangkan pengetahuan baru tentang hubungan prestasi pertumbuhan dan proses fisologi bagi anak pokok chengal yang ditanam di hutan simpan yang telah dibalak.

Kata Kunci: chengal, anak pokok, pertumbuhan, fisiologi, hutan simpan balak

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LIST OF SYMBOLS AND ABBREVIATIONS

°	:degree
%	:percent
1 y 8 m	:1 year 8 month
6-m	:6 month
24-h	:24 hour
AGB	:above-ground biomass
AFP	:Allied Forest Product
ANOVA	:analysis of variance
BD	:basal diameter
Ca	:calcium
C	:carbon
CO_2	:carbon dioxide
CEC	:cation exchange capacity
cm	:centimeter
DBH	:diameter at breast height
DMRT	:Duncan's Multiple Range Test
FAO	:Food and Agriculture Organization
FR	:forest reserve
FRIM	:Forest Research Institute of Malaysia
IFER	:Forest Ecosystem Research
FACE	:Forests Absorbing Carbon dioxide Emissions
Rd	:dark respiration
GLM	:generalized linear model
g	:gram
ha	:hectare
Infapro	:Innoprise-Face Foundation Rainforest Rehabilitation Project
IPCC	:Intergovernmental Panel of Climate Change
ITTO	:International Tropical Timber Organisation
IUCN	:International Union for Conservation of Nature
K	:kalium
kg	:kilogram
LAI	:leaf area index
LMA	:leaf mass area

LSD	:least significant difference
LCP	:light compensation point
LI	:light intensity
LRC	:light response curve
LSP	:light saturation point
Mg	:magnesium
MTC	:Malaysian Timber Council
MUS	:Malayan Uniform System
A_{max}	:maximum photosynthetic rate
m	:meter
MAI	:mean annual increment
Mg	:Megagram
Pn	:net photosynthetic rate
N	:nitrogen
ns	:not significant
PRF	:permanent forest reserve
P	:phosporus
PPF	:photosynthetic photon flux
QE	:quantum efficiency
RCBD	:randomized complete block design
R&D	:research and development
SPF	:research station nursery
SMS	:Selective Management System
SRF	:slow release fertilizer
SLA	:specific leaf area
SD	:standard deviation
SPSS	:Statistical Package for the Social Sciences
TAGB	:total above-ground biomass
TAGC	:total aboveground carbon
TDW	:total dry weight
Ev	:transpiration rate
UNDP	:United Nations Development Programme
WUE	:water use efficiency

CHAPTER 1 : INTRODUCTION

1.1 General introduction

The tropical forest coverage in Asia has been declining at an alarming rate for several decades. Large areas of forest are either being lost to conversion for agriculture or degraded through poor logging practices without regard to sustainability and biodiversity. A report by Asia Forest Partnership (AFP) stated that these large areas of degraded forest are now best known as logged over forest, which can be defined as a forest in which most or all of the merchantable timber has been cut (AFP, 2005). In Malaysia, in the 1940's, the Malayan Uniform System (MUS) was introduced for converting virgin tropical forest to a lesser even-aged forest containing a greater proportion of commercial species (Okuda et al., 2013). During the 1970's, the Selective Management System (SMS) was implemented for the management of hill dipterocarp forests. This was based on preliminary and indicative growth rates of logged over forest obtained from studies conducted by the UNDP and Food and Agriculture Organization (FAO), to ensure a second cut in 25 – 30 years (FAO, 2010). For the understanding of the status and quality of logged over forest, the SMS is currently being practiced for hill dipterocarp forests in Peninsular Malaysia whereby timber harvesting is carried out using the conventional ground-based crawler-tractor logging method. This harvesting technique, which requires the construction of logging roads, skid trails, and decking sites, often leads to excessive opening of the forest canopy and significant soil disturbance. As a result, logged-over forests have a high density of roads and large gaps are created within logging areas. These areas will be colonised by bamboo, palms, ferns (i.e. *Gleichenia linearis*), wild bananas and small-sized and less commercial pioneer species, such as *Trema orientalis, Pometia* sp., and *Eugenia s*pp., after years of logging

(Raja Barizan & Shamsudin, 2001, 2008). Thus, the sites need to be treated with suitable silviculture treatments. One option is to increase the stocking and productivity of the sites through planting high quality timber species such as chengal.

Chengal or *Neobalanocarpus heimii* (King) Ashton is from the family Dipterocarpaceae. It synonyms with *Balanocarpus heimii* King, *B. wrayi* King, *B. accuminatus* Heim. and *Pierrea penangiana* Heim ex Brandis. Its vernacular or common names include, *chengal* (trade name); *penak, chengai* (Malaysia); *takhian-chan, takhian-chantamaeo, chi-ngamat* (Thailand). Chengal is a very big tree up to 60 m tall, producing a heavy hardwood with a well-deserved reputation for durability, traditionally the best known and most highly valued timber in the country. However, its timber supply is getting scarce as it has been heavily logged and this species has been listed as vulnerable (Okuda et al., 2013). FAO (2010) noted that the species has been over-exploited and has poor regeneration. There was a measured decrease in volume per hectare and number of hectare for trees over 45 cm in diameter in both virgin and logged over forests. Unless necessary steps are taken to replant them, it is anticipated that this tree species will face serious extinction threat and severe genetic loss because the demand for its wood is increasing every year and best ones are harvested on priority.

Chengal seedlings are capable of surviving for a very long period under dense shade, but light is required for development and it is only in association with felling gaps that well established young trees can appear without assistance. During its early stages of growth, the young chengal seedlings are sensitive to over exposure of high irradiance and drought. Some shade is required during its early developmental stages. However, being in the shade during the early stages of growth makes the seedlings slow to respond to an opening in the canopy and can readily become smothered by more responsive, rank growth. As a result of this and the very slow growth rate of chengal, there needs to be a way or technique to increase the growth performance of chengal seedlings to ensure its survival. Enrichment planting is a technique that has been employed for promoting artificial regeneration of forests in which seedlings of preferred timber trees are planted in the under-storey of existing logged-over forests and then given preferential treatment to encourage their growth (Paquette et al., 2009; Lamprecht, 1986). This technique was implemented by the Forestry Department during the MUS era and gained momentum in the late 1960's and early 1970's and continued during the SMS period. However, the survival and growth rate of seedlings under the enrichment planting programme was very poor and high cost of maintenance, due to the need for repeated post-planting treatments (Kamaruzaman & Dahlan, 2008; Appanah & Weinland, 1993; Tang & Wadley, 1976). As a result, a new improved planting technique was applied so that the plants can sustain excellent growth with minimum post-planting tending (Raja Barizan & Shamsudin, 2001). The new enrichment planting techniques has also been reported to be the best way to boost the growth performance of chengal (Raja Barizan & Shamsudin, 2008).

Growth measurements of 319 stands of 22 years old planted chengal trees at the Forest Research Institute Malaysia (FRIM), has shown that it has a mean girth of 370 mm and a mean annual increment of 17 mm (Hassan, 2014; Marzalina et al., 2001). Whereas, measurement of 5370 trees in Negeri Sembilan and Pahang gave an annual increment of 10 mm, indicating that in its natural state, it probably takes about 80 years to reach a girth of 1530 mm, and 120 years to reach a girth measurement of 2300 mm (Krishnapillay et al., 2007). Kenzo et al. (2011) conducted a study in a degraded secondary forest and reported that the height and diameter of chengal seedlings were 390 cm and 33 mm, respectively, 4 years after planting. It is assumed that these rates can be improved further with the use of an ideal fertilizer application, light exposure, from as early as at the nursery stage up to planting in the field.

Light is an essential perquisite factor for plant growth and development. It is one of the most important environmental factors owing to its fundamental role in photosynthesis and plant metabolism. Physiologically, light has both direct and indirect effects. It affects on metabolism directly through photosynthesis, and indirectly through growth and development (Dai et al., 2009). Photosynthesis is an important physiological process in plants that results in the production of carbohydrates initially, followed by amino acids, proteins, fatty acids, lipids and nucleic acids ultimately (Kenzo et al., 2015; Mishra & Dubey, 2005; Kozlowski & Pallardy, 1997; Moss et al., 1984; Kramer & Kozlowski, 1979). The process is essential for plant growth and production. Photosynthetic productivity, which may be described as the carbon balance of a plant over a period of time, depends on internal and environmental factors. Rates of photosynthesis vary widely among species, between sun and shade leaves during the day and according to the growing season (Kenzo et al., 2011, 2015; Dreccer, 2006; Kozlowski et al., 1991). The differences are due to the interactions of various plant and environmental factors, such as leaf age, stomatal behavior, light and temperature. Other than that, leaf eco-physiological traits related to photosynthesis are important signs for tree light adaptation ability and growth. The reason is mainly because of environmental adaptation and carbon assimilation which is important in leaf photosynthesis (Kenzo et al., 2007, 2008; Larcher, 2003). A study conducted by Kenzo et al. (2011) on the growth and photosynthetic response of chengal seedlings under different light conditions in Ayer Hitam Forest Reserve, Selangor, a degraded secondary forest, indicated that the chengal seedlings showed maximum growth and physiology parameters namely photosynthetic, transpiration, stomatal opening and light saturation at a relatively low canopy openness (less than 50%).

There has been relatively few studies of nutrient limitation of dipterocarp seedling growth in the field, the last being Turjaman et al. (2006). Nursery studies using potted seedlings have shown that the addition of both nitrogen and phosphorus may enhance the growth of dipterocarp seedlings (Brearley et al., 2007; Turjaman et al., 2006; Bungard et al., 2000; Gunatilleke et al., 1997; Yap & Moura-Costa, 1996). However, a few studies on these mineral applications reported the contrary results (Turner, 1993; Burslem et al., 1995). Whether these results reflect nutrient limitations in the field is unknown. Forest departments in Malaysia routinely apply nutrients to dipterocarp seedlings when they are planted in secondary, degraded forests (Krishnapillay, 2002; Krishnapillay et al., 2007; Appanah & Weinland, 1993), but whether the nutrient effects are species-specific or site-specific remains largely untested. The few field experimental studies that have been conducted suggest that nutrient limitation may be common in enrichment planting conditions.

Correspondingly, biomass that leads to carbon stock quantification of the earth's terrestrial ecosystem is mainly contributed by forests and their soils. Any changes in the trend of tree growth performance can affect and give huge impacts to climate change and biodiversity. Many studies and research have reported an increment in biomass across many forest types (McMahon et al., 2010). In tropical forest regions, forests may recover rapidly from agricultural fields, logged stands, or areas cleared due to natural disturbances. The period of recovery consists of a rapid increase in above-ground biomass (AGB). This rate of biomass pattern varies across stands depending upon nutrient availability and species composition. Principally, there are five primary carbon pools in a forest i.e, above-ground biomass, below-ground biomass, deadwood, litter and soils which accumulate and in some cases release carbon (Hamdan et al., 2015). However, about 98% carbon stored in a forest comprises of tree components (aboveground and belowground) living biomass, deadwood and litters and the remaining is stored in soils. As described by Hamdan et al. (2015), in a lowland dipterocarp forest in Pahang, trees with a diameter of breast height (DBH) < 10 cm are considered as saplings. In his study, results indicated that the biggest portion of biomass carbon was in the living trees, which was estimated to be about 79% (188.2 Mg ha^{-1}) of the total carbon pools in the forest. It was followed by below-ground living biomass carbon, which was estimated to be about 19% (45.2 Mg ha^{-1}). Deadwood and litter contributed about 1% (2.3 Mg ha^{-1}) and lastly, saplings contributed 1% (2.46 Mg ha^{-1}) of the total AGB in the forest. In Malaysia, generally in Pasoh Forest Reserve, a logged-over forest, the estimated total above-ground biomass density (TAGB) was 536 Mg ha^{-1} (Niiyama et al., 2010). However, research conducted by Tara (2012), on tropical forest carbon stock in Temenggor Forest Reserve, Perak, Malaysia reported that the average carbon in aboveground biomass was 149 Mg(C)/ha. There was not a significant difference in carbon content among individuals of the same species, but there was a significant difference in carbon content between different tree species.

Currently little information is available on chengal seedlings with regard to its growth performance, physiology and carbon stock, in relation to different fertilizer applications, light intensity and age from nursery to transplantation in a logged-over forest. A better understanding of the relationship between environment and its physiological effects on seedling growth and development would greatly improve chengal seedlings planting practices in the nursery and plantations, and this would in turn ensure successful regeneration of these trees. This would help in the management and manipulation of the forest to favour the regeneration of chengal in accordance to its tolerance. In fact, the primary objective of this investigation is to propose favorable and ideal treatments for chengal potted and planted seedlings in order to obtain the optimum conditions for its regeneration in our forests. In this study, chengal seedlings growth were monitored in the nursery and in the field as early as five months after planting to 44 months after planting under different light and fertilizer treatment regimes. The relationship between the growth performance of these seedlings to its physiology, age and biomass, as well as predicting the carbon stock value from nursery to field were also studied.

1.2 Hypothesis and Research Questions

In this study, we hypothesize that the growth performance, physiology and carbon stock of chengal seedlings in the nursery and logged-over forest will show a significant difference under different light, fertilizer and age treatments.

How does light intensity affect the growth of chengal seedlings in the nursery?

Will different type and amount of fertilizer applications enhance the growth of chengal seedlings in the nursery and in the field?

What is the relationship between light intensity, age, nutrient application and physiological parameters in chengal seedlings grown in the nursery and transplanted into the field?

1.3 Research objectives

1) To study the effect of light on the physiological parameters and growth of chengal potted seedlings in the nursery

2) To examine the effect of different fertilizer treatments on the physiological parameters and growth of chengal potted seedlings in nursery and after outplanting in a logged over forest.

3) To discover the effect of age on the physiological parameters and growth of chengal seedlings in a logged over forest.

4) To deduce the relationship between age, light and different fertilizer applications on physiological parameters and growth of chengal seedlings, in the nursery and in the field

1.4 Scope and limitations of study

This study focuses on chengal seedlings. The optimum level of light, ideal amount and type of fertilizer applications as well as best age group of chengal seedlings, which have significant importance on survival and growth performance of these seedlings raised in nursery and after out-planting in a logged-over forest were studied.

The growth, biomass quantification, carbon stock, soil mineral and physical properties as well as the physiological components as affected by different light, fertilizer and age treatments were analysed. Data collections included a one year measurement in the nursery in FRIM and 44 months throughout planting period in logged-over forest of Tekai, Jerantut, Pahang.

Limitations of the study would be the accessibility to the site. Since the study site is located at depth of the Tekai Forest Reserve which is located 13 km from the main roads, any collapsed logging roads along the route to the site would restrict and delay data collections. All data collections conducted should be planned and scheduled concurrent with logging activities done at nearest areas, so that loggers would fix and make logging roads for logs to be transferred out.

CHAPTER 2 : LITERATURE REVIEW

2.1 Scientific and Common Names

Chengal is scientifically known as *Neobalanocarpus heimii* belonging to the family Dipterocarpacaceae. Chengal is also known by its vernacular or common names in Malay language as, *penak, chengal* or *chengai* and in Thai language as *takhian-chantamaeo, takhianchan* or *chi-ngamat*.

2.1.1 Botanical Description

Chengal is a large tree, sometimes more than 60 m tall with a diameter of 1 m or more (Ng, 2014). The bole is straight and branchless for 30 m. The young twigs are lenticellate, resinous, with prominent buttresses. The bark is characteristically dark and scaly, exuding an almost colourless resin (Figure 2.1). Leaves are simple, alternate and bistipulate, leathery, elliptical-lanceolate, 7-17 cm long by 2.3-5 cm wide, apex long acuminate (Figure 2.2). First two leaves are opposite, or first two pairs are opposite, or first three or four leaves whorled. Subsequent leaves are alternate. Stipules are small, dropping early. Growth in flushes, with the terminal bud aborting at the end of each flush, and sylleptic branches developing at the upper leaf axils. Petioles are 5-10 mm long and stipules narrowly oblong, about 12 mm long. Flowers are bisexual, broadly ovate, outside caducous puberulent with 5 elliptic, creamy-white or greenish-yellow petals. Stamens 15, glabrous; connectives short, curved, slightly exceeding the anthers; ovary ovoid, glabrous with long slender style. Fruit an acorn-like wingless nut, blanceolate, oblong and cylindrical, 4-5 cm long by 2-2.5 cm wide at the base (Figure 2.3). At the time of maturity, the fruits begin to turn from green to brown. Seed shaped

Figure 2.1: Chengal tree bark aged 70 years (*source: Chengal FRIM Levy Project FRIM Field 12)*

Figure 2.2: Chengal leaves and branch source (a) *herbarium specimen from Tropical Forest Seeds, Seedlings and Tree; Malaysian Forest record No. 52 by F. S. P Ng, 2014*; (b) *Chengal FRIM Levy Project*

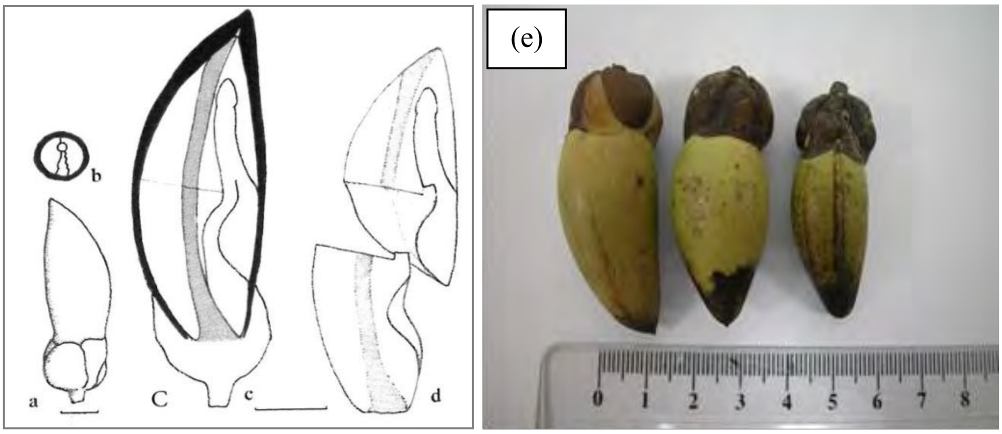


Figure 2.3: (a) Fruit (b) Fruit t.s (c) Fruit l.s (d) Longitudinal half of embryo showing the vertical positioning of one cotelydon above the other *(source: Tropical Forest Seeds,Seedlings and Tree; Malaysian Forest record No. 52 by F. S. P Ng, 2014)*
(e) Seeds collected from mother trees at FRIM field 12 *(Chengal FRIM Levy Project)*.

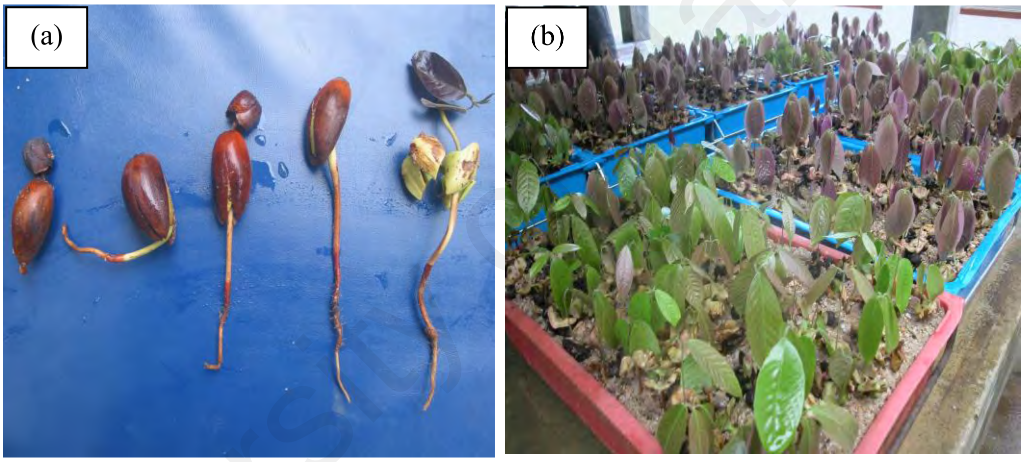


Figure 2.4: (a) Chengal seed phase; (b) Chengal seeds germination *(source: Chengal FRIM Levy Project FRIM, seeds collected from FRIM Field 12)*

like the fruit and a few mm shorter and green at maturity. Chengal fruit with persistent but unwinged sepals at the base. During germination, the fruit splits into three equal valves when the radicle elongates. Cotyledons fleshy, one positioned on top of the other in vertical alignment (Figure 2.4a or b). Germination epigeal (9 to 45 days). Cotyledons emergent, fleshy, bilobed, unequal. Hypocotyl elongated. Vertical growth is continued by the development of an accessory bud just below the aborted apex after a period of delay, during which time branch development is emphasized over upper branch leader development. The branches also grow in flushes and abort terminally. Chengal is closely related to the genus *Hopea*, whose species have similar leaf characteristics, wood anatomy, biochemistry and habit (Ng, 2014).

2.1.2 Natural Distribution

Chengal trees produce a heavy hardwood timber which is highly valued for its strength, durability and workability. Chengal is regarded by the timber trade as a 'primary hardwood', but the Malaysian government has banned its export in round log form. According to unpublished information from the Forest Department of Peninsular Malaysia, the largest specimen of chengal in Malaysia is in Pasir Raja Forest Reserve in Dungun, Terengganu. This tree is 65 m tall, with a girth of 16.75 m and a diameter at breast height of 5.33 m. Chengal is found in mixed dipterocarp tropical lowland forests, especially on undulating lands, in swampy areas and sometimes in dryer areas of swamp forests (Marzalina, 2013)

Under the the International Union for Conservation of Nature (IUCN) red list for threatened species, chengal is listed as extinct in Singapore and faces a high risk of extinction in southernmost peninsular Thailand. In peninsular Malaysia, chengal can still be found in protected areas in most states, except Perlis, Penang and Malacca (Tnah et al., 2012; Wong et al., 1994). It is the second most dominant species in the Pasoh Forest Reserve in Negeri Sembilan, although it accounts for only 1% of all trees (Marzalina, 2013). It is often found growing on undulating, well-drained areas with soils of average fertility but occurs less frequently at higher elevations. It has been reported that it was often found at low densities (fewer than five trees per hectare) in natural stands (Marzalina, 2013; Wyatt-Smith, 1987; Ashton, 1982).

According to Wong et al. (2005), this species is much rarer now than it was in the early 20th century. Its endemism and limited distribution justify conservation measures to safeguard the remaining populations. In view of the demand for this and other timber species, the Malaysian government has taken steps to implement conservation measures and sustainable management practices in remaining forest areas. Most areas populated by chengal in Malaysia's virgin jungle reserve system have been designated as research plots. The largest plot is in the Balok Forest Reserve, Compartment 8 in Pahang (Marzalina, 2013; Saw & Raja Barizan, 1991).

A great deal of experience in cultivating chengal has been gained since the era of gutta-percha extraction around 1900-1913 (Krishnapillay et al., 2007; Appanah & Weinland, 1993; Ashton, 1982). This information is considered adequate for current planting efforts. The limited availability of seed sources, however, is still a constraint to conservation programmes for this species.

2.1.3 Phenology

Most dipterocarp species tend to flower and fruit erratically. Such behaviour limits the supply of reproductive materials, especially seeds. It has been estimated that, in the aseasonal zones of Southeast Asia, the majority of dipterocarp species flower at intervals of 2-5 years. Approximately every 3–8 years, trees undergo a reproductive event. Some species flower annually, but only a few mother trees within the population bear fruit (Sakai et al., 1999, 2006; Curran et al., 1999; Medway, 1972; Appanah, 1993, 1995; Ashton et al., 1988).

Kondo et al. (2011) reported that dipterocarps appear to be strongly cross-pollinated, a feature which could account for poor seed production, if flowering trees of the same species occur infrequently and are widely dispersed. This appears to be the case in chengal, as natural regeneration beneath parent trees is rarely abundant despite annual fruiting (Aminah et al., 2013; Kamaruzaman & Dahlan, 2008). Given that seeds are the only feasible method of propagating and regenerating chengal, future supplies of timber are likely to be seriously affected.

Several studies have been carried out to determine the ecology and biology of flowering in chengal and to attempt to predict flowering events. It has been reported that a fall in minimum temperatures sustained for at least 5-8 days caused flowering events to be delayed eight to nine weeks later (Sakai et al., 1999, 2006; Curran et al., 1999; Medway, 1972; Appanah & Weinland, 1993; Appanah & Rasol, 1995; Ashton et al., 1988). Data from 20 years of phenological observations of chengal has been analyzed and the results showed that chengal flower gregariously almost every year (Sakai et al., 2006). Flowering was observed to occur either annually or biannually, and to peak between March and May, and between September and November. The flowering behaviour of chengal is a typical compared with other dipterocarps.

2.1.4 Biophysical Limits

Chengal is usually found at an altitude of 0-1000 m with an optimum mean annual temperature of around 24-27ºC and a mean annual rainfall of 2000-4000 mm. Chengal grows well on a wide range of soils from sandy granitic soils, red clay over shale to well-drained dark basic volcanic soils.

2.1.5 Products

Chengal produces a very durable and heavy timber, with an air-dry density of 915-980 kg/m^3. The sapwood is pale-yellow, heartwood light-brown, darkening on exposure. The wood is moderately lustrous with prominent ripple marks. It is suitable for all forms of heavy construction, particularly boat-building, bridges, railway sleepers, sawn power line posts, heavy flooring, rubber coagulating tanks and many other uses where great strength and durability are required (Hashim et al., 2015; Marzalina, 2013). Like teak, the timber contains preservative compounds that protect the heartwood and even under exposed conditions the timber can last about 100 years. The breaking strength is several times higher than that of oak, both radially and horizontally. The species is over-exploited, has poor regeneration and is in need of *in situ* conservation especially in Malaysia. A good quality resin is produced from chengal, known as *dammar penak* and has been used in the manufacture of varnishes (Hashim et al., 2015; Marzalina et al., 2001).

2.1.6 Chengal Pest and Disease Infestation

Chengal is known to flower almost annually, during most months. The population of flowers is in synchrony for about 2 weeks. Anthesis is matinal, and insect visitors (*Apis* and *Trigona* spp.) are seen foraging at dawn itself for nectar and pollen. The fruit ripen after about 6 months following the first appearence of flowering. Planted trees have been known to bear fruit at ages below 10 years (Sakai et al., 1999, 2006; Appanah & Weinland, 1993; Medway, 1972). The fruits are heavy and wingless, and fall below the parent tree. Seeds germinate readily but need heavy moisture conditions. Despite copius fruiting, established seedlings are not abundant. Supressed seedlings are usually found beneath the parent tree. The seedlings are capable of surviving under shade for many years, and are sensitive to over-exposure and drought but will not grow at all without light. Light is required for development as well as to establish young trees, which are only found in association with gaps. Saplings are frequently sympodial in growth, the leading shoot droops over and is replaced by a shoot from the lateral bud.

The fallen fruits of chengal are attacked by the seed beetle, *Coccotrypes graniceps* (Scolytidae, Coleoptera). Compared to the mast fruiting dipterocarps, fruits of chengal are less heavily predated. Protection for this annual fruit tree may be conferred by an unusual amount of resin in the fruit. The shoot borer, *Laspeyresia* (Tortricidae, lepidoptera) causes severe damage to young seedlings between 1 and 3 m in height. The pin hole borer, Diapus (Platypodidae, Coleoptera) attacks live trees (Jacobst, 2013; Marzalina et al., 2001).

2.1.7 Growth Performance of Chengal

Although chengal has been planted in the early years in several places, observations and records were not maintained during this period. In a review of planting quality timber by Appanah and Weinland (1993), it was reported that chengal grows slowly at the start but rapid growth takes place after it is 25 cm in diameter, and the fast growth is maintained until the tree is over 80 cm. They calculated it would be 100 years for the tree to reach a 40 cm in diameter of breast height. These are the estimations from trees in the natural forests, under considerable competition. If grown under more favourable conditions, better growth should be obtainable. The mean annual diameter increment of a 12-year old chengal sapling in the Kepong plantation was 1.2 cm, as fast as some of the balau trees (Shono et al., 2007). On this basis, Marzalina (2013) quoted a study undertaken by Symington where he projected it is possible to attain a 70 cm diameter tree in slightly over 70 years. In the Kepong plantations, early growth was slow, and seedlings were attacked by a borer. However later, the seedlings grew faster, but not uniformly (Marzalina, 2013).

A small scale plantation project entitled ‘Multi-storied Forest Management in Malaysia’ was carried out from November 1991 to October 2001. The project was implemented in two phases with the objective of establishing a multi-storied forest management system in order to promote forest plantations activities while yielding high quality timber species, namely chengal. The project established a total of 427 ha of multi-storied forest plantation with 375 ha in the Chikus Forest Reserve and and 52 ha in the Bukit Kinta Forest Reserve, both in Perak. Permanent plots were set up with 100 seedlings in each plot. The first measurements were done one month after planting with subsequent measurements carried out basically every 6 months after planting until 1999 and every 12 months thereafter (Table 2.1).

Table 2.1: Mean growth performance of chengal with different age planted, 10 years after planting in Chikus Forest Reserve, Perak

Species	Age (months)	Height (cm)	Basal diameter (mm)	Survival rate (%)
Chengal	66	334/(275-371)	47/(35-51)	44/(24-68)
	87	308/(264-350)	41/(29-49)	5/(3-9)
	95	489/(394-550)	70/(45-94)	55/(32-80)

Note: In an expression of A(B-C), A,B and C represent the average of plots’ mean value, minimum plot’s mean value and maximum plot’s mean value, respectively. (Source: Multi-storied Forest Management in Malaysia)

2.1.8 Status of Chengal in Dipterocarp Forest in Malaysia

Malaysia has a total forested area of 19.48 million ha or almost 60% of the total land area in 2005 (MTC, 2016). Out of this, 14.55 million ha or about 74% has been designated as Permanent Forest Reserved (PRF) to be sustainably managed. The forest areas in Malaysia comprises of dipterocarp forests, which makes up almost 82% (16 million ha) of the available resources. Other major forest types include peat swamp (7.8%), mangrove (3%) and planted (7%) forests.

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 characterized by the predominance of the family Dipterocarpaceae. Dipterocarpaceae is a family of 17 genera and approximately 500 species of mainly tropical lowland rainforest trees. The family name, from the type genus *Dipterocarpus*, is derived from Greek (*di* = two, *pteron* = wing and *karpos* = fruit) and refers to the two-winged fruit. The largest genera are *Shorea* (196 species), *Hopea* (104 species), *Dipterocarpus* (70 species), and *Vatica* (65 species). Many are large forest emergent species, typically reaching heights of 40–70 m tall, with some even over 80 m (in the genera *Dryobalanops*, *Hopea* and *Shorea*), with the tallest known living specimen (*Shorea faguetiana*) 88.3 m tall. Dipterocarpaceae is the dominant timber family in the dipterocarp forests and it is considered as 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 and 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 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.) (Wyatt-Smith & Kochummen, 1999).

2.1.9 Natural Seedling Regeneration of Dipterocarp

Knowledge on the regeneration of dipterocarp forests, including chengal species, in Peninsular Malaysia is adequate for the formulation of appropriate management systems for these forests. Many of the dipterocarps, which form the bulk of timber trees of these forests, possess characteristics (e.g. gregarious fruiting, dense seedling populations, quick response by seedlings to light openings, relatively fast growth, excellent form, gregarious stands and more) that allow foresters to manipulate these forests at little cost in order to produce a sustained yield of timber and other forest products. However, with the dwindling of timber and forested areas, rehabilitation through planting may be one of the ways for preserving these rich and productive forests, especially chengal.

The natural regeneration of dipterocarp forests depends largely on the flowering, fruiting and presence of seedlings on the forest floor before and after logging. The rule among canopy species, including the majority of dipterocarps in Peninsular Malaysia, is to flower and fruit gregariously, massively at about 2 to 10 year intervals. Isolated or sporadic flowerings of dipterocarps do occur, but at low intensities and the fruiting is poor. Most of the fruits are poorly dispersed by wind, and the majority remains within 60 m of the mother tree (Ashton & Hall, 2011; Burgess, 1972). The seeds of the gregarious fruits are heavily parasitized by predators, this parasitism being much higher during isolated fruiting years (Ashton & Hall, 2011; Burgess, 1972).

Some dipterocarps have been shown to be pollinated by tiny, fecund, common, flower-feeding insects, such as thrips and probably other similar group of insects (Kondo et al., 2011). The dipterocarps pollinated by these groups of insects which have been investigated are mostly outbreeders and breeding clumps are needed for high fruit set (Kondo et al., 2011; Chan & Appanah, 1980). Many of the canopy species that flower more regularly (e.g. *Dryobalanops* and chengal species) are pollinated by highly energetic insects, and may not have such dominance.

The behaviour of dipterocarp regeneration has been studied by only a few foresters, Hattori et al. (2013), Brown and Lugo (1990) and Liew and Wong (1973). The density of dipterocarp seedlings fluctuates within both virgin and logged over 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 survives to contribute to the tree regeneration. Hattori et al. (2013) reported that about 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 can approach almost a state of dormancy in an undisturbed virgin forest (Pallardy, 2010). Growth height of dipterocarp seedlings has been reported to be much greater under an extensive opening of the canopy, due to logging operations, than in virgin forest treated with a light liberation only (Hattori et al., 2013; Liew & Wong, 1973). Shono et al. (2007) 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 exposed conditions (Hattori et al., 2013; Liew & Wong, 1973). In order to maintain forest production, it is preferable to manage the regenerating forest than planting dipterocarp trees in open areas. However, a regenerating forest will not grow into stands of commercially sized trees by the next cutting cycle unless silvicultural treatments can release the understorey saplings.

2.1.10 Artificial Seedling Regeneration of Dipterocarp

Since the 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 the dipterocarp regeneration process. Limited experiments on artificial regeneration were carried out as early as the 1930's (Watson, 1935; Walton, 1932) and were subsequently followed by others (Kettle, 2010; Paquette et al., 2009; Tang & Chew, 1980; Tang & Wadley, 1976; Ismail, 1964). Enrichment planting is a technique for the promotion of artificial regeneration in which seedlings of the preferred timber trees are planted in the understorey of logged forest and then given preferential treatment to encourage their growth (Kettle, 2010; Paquette et al., 2009; Lamprecht, 1989).

2.1.11 Silviculture Implications through Forest Plantation

The large-scale, mechanized logging that is currently practiced tends to produce huge gaps in the forest canopy, and the resulting succession of pioneers can retard the regeneration of primary species by as much 2 decades. The heavily compacted or scraped soils remain barren and are vulnerable to erosion and loss of nutrients. Furthermore, present day logging techniques cause extensive damage to residuals, and can render the forests lacking a variety of saplings and seedlings of commercial timber species (Reynolds et al., 2011; Shono et al., 2007). Where natural regeneration can no longer be relied upon for the renewal of the timber crop, artificial regeneration has to be sought, namely reforestation (forest plantation).

As presently practiced, 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 for the production of a better biological forest, by taking away the fully matured trees and allowing the younger trees and saplings to have more space for growth. 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 ≥ 5 m in length are poison-girdled and climbers cut. Forest rehabilitation and development operations in Peninsular Malaysia have been implemented on a substantial scale by the Forestry Department.

Previously the traditional MUS of forest management was successfully applied to lowland dipterocarp forests but was found to be unsuitable for hill dipterocarp forests because of the more difficult terrain, uneven stocking and the sparse natural regeneration (Raja Barizan & Shamsudin, 1998). As a result the preferred silvicultural and management alternative for hill dipterocarp forests, the SMS, was 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 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.

With proper planning, forest plantations fulfill many of the productive and protective roles of the natural forest. It helps to stabilize and improve the environment (sequestering carbon and enhancing water and air quality), combat desertification, minimize erosion, and restore soil fertility. It is believed that in shorter time, forest plantations could provide a high yield of volume wood per unit area and definitely would meet the timber requirement in the future. In the early 1950's, a few plantation trials were conducted in peninsular Malaysia, especially using exotic and fast growing species (Raja Barizan & Shamsudin, 1998). The planting of teak in forest plantation for commercial purposes started in 1957 at the northern states of Perlis and Kedah. After the late 1960's and 1970's, the plantation efforts focused at planting fast growing tropical pines to produce long fibre pulp with an aim to set up a local pulp and paper mill. Meanwhile, in the states of Johor, Negeri Sembilan, Pahang Darul Makmur and Selangor Darul Ehsan, approximately 6,754 ha were planted with *Pinus caribea, Pinus merkusii* and *Araucaria* spp.

A shortage in timber supply was experienced in peninsular Malaysia by the middle of the 1990's due to an increase demand for timber and timber products mainly owing to population growth rising and living standards (Chong, 1979). One of the approaches to meet the problem was to cut down the size of harvested areas. Therefore, a step was taken by the National Forestry Council under the Tenth Malaysian Plan

(2011-2015), to decrease harvested areas to 47,450 ha (Forestry Departments, Peninsular Malaysia, Sabah & Sarawak, 2015). Another step was to establish forest plantation using fast growing species, which was launched in 1982. The forest plantations reflected a reclamation approach, even though the main aim of establishing forest plantations was to meet the future demands of timber, namely chengal.

2.2 General Description of Improved Planting /Enrichment Planting

It has been a few decades since measures were taken to rehabilitate forests after logging in Peninsular Malaysia. Enrichment planting is one of the potential rehabilitation measures under silvicultural management, which rehabilitate poorly stocked logged-over forest without eliminating the existing individuals. It is essentially a process of supplementing the natural regeneration with seedlings of commercial species (Krishnapillay et al., 2007; Appanah & Weinland, 1993). Usually indigenous species are planted in enrichment planting. It is applied to degraded patches of the forests for successful rehabilitation with species such as, kapur (*Dryobalanops aromatica*), meranti tembaga (*Shorea leprosula*), balau kumus (*Shorea laevis*), meranti seraya and mahogany (*Swietenia macrophylla*).

A study done by Safa et al. (2004) on enrichment planting, has shown that it resulted in better growth rate, with greater height and diameter increments in dipterocarp seedlings, in selected plots that were more than 24 years old. The areas under study were planted with indigenous species such as meranti rambai daun (*Shorea accuminata*), meranti tembaga (*Shorea leprosula*), meranti sarang punai (*Shorea parvifolia*), chengal (*Neobalanocarpus heimii*), kapur (*Dryobalanops aromatica*) and keladan (*Dryobalanops oblongifolia*) with the help of the Forestry Department. The growth of the trees was better, although some trees failed to survive due to natural courses. The observed growth performance of the trees in the EPSP (Enrichment Planting Sample Plot) was compared to the growth of indigenous tree species reported in other plantation and planting trials by Shono et al. (2007) and Zuhaidi and Weinland (1995). From this growth assessment, it was reported that individual trees exhibited good growth performances in terms of diameter and height, with Mean Annual Increment (MAI) in diameter ranging from 0.5 cm to 1.8 cm per year at more than 30 cm diameter at breast height.

2.2.1 Improved Planting Techniques

One of the challenges facing reforestation or forest plantation described above, is the planting technique employed, particularly when using saplings. Larger holes in the ground for better aeration and space for virile root growth need to be considered, in addition to the use of slow release fertilizers to aid degraded, logged-over forests to attain subsequent productive levels. This new approach to rehabilitation does not require frequent, repeated returns to the forests for silvicultural treatments, thus saving costs which compensates for the use of the more expensive slow-release fertilizers, bigger tree saplings and mechanized planting.

Current logging in the hill dipterocarp forests in Peninsular Malaysia employs the crawler-tractor method for clearing and tree felling, which causes excessive damage to the forest structure and soil. This is particularly due to the extensive logging road networks and skid trails, which have to be constructed within logging areas and the need for log landing sites and the numerous tree fall gaps, all of which make the soil highly compact, resulting in poor regeneration of commercial tree species. New planting techniques require digging larger holes (0.9-1.0 m width and 0.9-1.0 m depth) to plant tree saplings (of ± 2 m height and ± 2 cm diameter). Mechanical augers (the track tires skid steer loader model 753 or 773 attached with a 36-inch hydraulic auger is best) are used to dig holes in the ground. These machines are portable and workable even in difficult terrains, such as steep (maximum gradient of 28 degrees) and slippery slopes, soft earth in hilly logged-over forest and are easily operable by untrained workers. Another plus point is the minimal site preparations required, since clearing for line planting and canopy openings are not required (Raja Barizan & Shamsudin, 2001, 2008).

2.3 Physiological Factors on Plants

A great number of tree species grow in tropical rain forests, and their structure are extremely complex (Oshima et al., 2015; Whitmore, 1984). The dipterocarps are the main representative of timber tree species in Malaysia (Marzalina, 2013; Symington, 1943). The ability of individual species to tolerate different environmental conditions in its distribution zone must reflect physiological characteristics of the species. The photosynthetic characteristics, especially the photosynthetic rate, stomatal conductance and transpiration rate of species like chengal is little known. The knowledge would enable us to better understand the growth of this species.

2.3.1 Photosynthetic Rate/ Stomatal Conductance/Transpiration

Photosynthesis is the conversion by plants of solar energy into several forms of chemical energy via a series of reactions which represents the largest synthetic process on earth and is the main source of energy for all living things. As photosynthesis fixes carbon dioxide from the atmosphere into macromolecules such as starch, sucrose and eventually amino acids and fatty acids which leads to the formation of the four major macromolecules in living cells, carbohydrates, proteins, lipids and nucleic acids, its rate in plants can be said to be synonymous with its growth. Nevertheless the rate of photosynthesis of a plant is determined by several factors such as, the amount of light, carbon dioxide concentrations, temperature, water and mineral availability.

On the other hand, transpiration is the loss of water in the form of water vapor from plants (Pallardy, 2010; Kozlowski & Pallardy, 1997). Rapid transpiration on bright and sunny days can be very significant that could lead to the loss of turgor in cells of young leaves especially in dry areas which consequently results in stomatal closure leading to a reduction in photosynthesis and eventually growth (Pallardy, 2010; Kozlowski & Pallardy, 1997).

A study done by Juliana et al. (2009) and Ang and Maruyama (1993), on early survival and growth of dipterocarp seedlings in Pasoh Forest Reserve showed that there is a relationship between growth and physiological parameters of *Shorea* species. *Shorea platycaldos* and *Shorea assamica* exhibited higher net photosynthesis than *Hopea nervosa* and *Shorea macroptera. Shorea assamica,* especially, maintained a high net photosynthesis and transpiration rate (Table 2).

Table 2.2: Mean photosynthesis (P_n) /transpiration (Ev) ratio of the four open planted dipterocarps (Ang et al., 1993)

Species	Sample size (n)	Net photosynthesis (Pn) umol m^2 s^{-1}	Transpiration (Ev) mmol m^2 s^{-1}	Pn/Ev Ratio (x 10^{-3})
Shorea platyclados	6	10.19±0.45	4.69 ±0.10	2.191 ±0.125
Shorea assamica	6	11.66 ± 0.90	6.10±0.12	1.908 ±0.143
Shorea macroptera	6	7.1 5 ±0.52	5.68±0.21	1.2621±0.090
Hopea nervosa	5	2.15 ±0.41	2.7910.43	0.7801±0.071

A higher net photosynthetic rate, stomatal conductance and transpiration rate could contribute to a higher survival rate and better growth. The superiority in photosynthetic efficiency could be the main factor that contributes to a successful establishment under open conditions (Fitter & Hay, 2012; Ang & Maruyama, 1993). However, there is a lack of research data and information on chengal species with regard to its net photosynthetic rate, stomatal conductance and transpiration rate and how this relates to its survival in open planting. Hence, this study hopes to generate new knowldege on this subject.

2.3.2 Stomatal Conductance

Stomata are the primary structures in leaves that allow the exchange of water and CO_2 between plants and the atmosphere. Therefore, stomatal conductance is an important factor in the cycling and balancing of water, CO_2 and energy between plants and the atmosphere. Stomatal conductance is the measure of the rate of passage of carbon dioxide or water vapor through the stomata in leaves. Stomata are small pores on the top and bottom of a leaf that are responsible for taking in carbon dioxide and expelling moisture from and to the outside air, respectively (Konrad et al., 2008; Ainsworth & Rogers, 2007).

The degree of opening of stomata, as measured by the stomatal conductance is a vital parameter that determines the rates of photosynthesis and transpiration by all types of plants including those found in natural forests. A charateristic feature of natural forest is the heterogeneity and variability of the environmental conditions experienced by the plants, both spatially and temporarily. The way that different species co-exist within a forest respond to the above variation and heterogeneity of the environment and determines their survival and the degree of dominance that they would achieve in the succession process (Maruyama & Kuwagata, 2010; Ueno & Seiwa, 2003). The ability of the stomata to respond rapidly to variations in environmental factors such as light intensity, temperature, humidity and wind make them ideal organs through which forest plants respond and adjust their functioning to rapid fluctuations in the environment. This ability is especially crucial for the survival and growth of natural forest plant species because key physiological processes such as photosynthesis occur under rapid-fluctuating transient environmental conditions rather than stable, steady state conditions (Guangxiu et al., 2009; Katul et al., 2003).

The primary determinant of stomatal movements at the cellular level is the water content of the guard cells. Guard cell water content is determined by the leaf water status, which is in turn determined by the transpiration stream through the soil-plant-atmosphere continuum. Hence, it is hypothesized that leaf water status, measured as the leaf water potential, may play a crucial role in determining stomatal conductance in a variable environment (Lamaud et al., 2009; Guangxiu et al., 2009).

Therefore, it is important to investigate the environmental factors that determine the stomatal conductance, photosynthetic and transpiration rates and leaf water potential of chengal species in the natural forest and in the nursery.

2.3.3 Photosynthetic Light Response Curve

The photosynthetic light response curve (LRC) describes the relationship between leaf net photosynthetic rate and the photosynthetically active photon flux density arriving at the leaf surface. LRC is important in predicting carbon fixation in nature because variation in the light environment of a leaf is one of the most important factors affecting photosynthetic rates. Previous work on photosynthetic LRC has shown that different plants (even different leaves on the same plant) show differences in the shape of their LRC, which reveals characteristics of the underlying photosynthesis processes including the light-dependent and light-independent reactions, the efficiency at which light is utilized by photosynthesis, and even the rate of O_2 uptake (Halik & Hirsch, 2011; Kenzo et al., 2008, 2011; Valladares & Niinemets, 2008; Larcher, 2003). The response curve can be divided into two phases. Under low-light levels, the rate of photosynthesis increases as the irradiance level increases whilst at high light intensities there is little or no further increase in photosynthetic rate.

The vertical structure of a forest is complex and multi-layered, resulting in great variation in light availability and with height (Kenzo et al., 2008; Kimmins, 1997). Most canopy trees experience diverse light conditions during their lifetime, starting from seedlings on the poor lit forest floor and gradually gaining access to the well-lit canopy layer at maturity. Many trees exhibit different photosynthetic capacity at light saturation (A_{max}), according to their growth stage or light conditions, or both, as a result of differences in leaf morphology, physiology and biochemistry (Larcher, 2003). It is well known that sun leaves have higher leaf nitrogen and leaf mass per area (LMA), corresponding to higher A_{max}, than shade leaves. Shade leaves have a higher leaf chlorophyll content and are thinner and thus have a lower dark respiration and light compensation point (LCP) than sun leaves (Kenzo et al., 2008; Lambers et al., 1998).

Other than the above factors, the response of dipterocarp seedlings and their subsequent establishment in a lowland forest, especially in logged over forest, may also be influenced by the availability of other resources, such as nutrient availability.

Nutrition addition, in particular nitrogen availability, has been shown to influence the susceptibility of plants to photodamage and the non-photochemical quenching mechanism by which plants acclimate to high irradiance (Oguchi et al., 2011; Bungard et al., 2002; Khamis et al., 1990). The importance of nitrogen in response to high irradiance reflects the central role that the N plays in the photosynthetic mechanism of plants from being a major element in chlorophylls *a* and *b* and proteins, to the enzymes of the Calvin cycle or the so called 'dark reactions' of photosynthesis, such as Rubisco, that are involved in the rate-limiting steps of carbon fixation (Kenzo et al., 2008; Field & Mooney, 1986). A study by Kenzo et al. (2007) on *Shorea* species found that the light compensation point was higher in the nursery and dropped after planting in the field. Fertilizing the seedlings from nursery level up to the field contributed to an increased N in the leaves and directly increased the chlorophyll content. Applying higher N supply has been shown to accommodate better N ratios in the leaves, that directly influenced all physiological parameters values both in the nursery and field. A large leaf chlorophyll content helps maintain low light compensation and acclimatize to the open conditions in the field (Larcher, 2003).

Understanding that leaf physiology changes with tree size and age is important because the changes influence the carbon gain in certain species. Numerous structural and physiological characteristics change with tree size and age including net assimilation rate and stem hydraulic conductance (Mullin et al., 2009; Niinemets, 2002) as well as foliar dry mass per unit area (Niinemets, 2002). These profound adjustments in leaves have an impact on tree growth and forest net primary production due to their direct influence on photosynthetic carbon gain (Mullin et al, 2009; Ryan et al, 1997). An understanding of changes in leaf physiology and leaf anatomy, morphology and chemistry that affect foliar photosynthesis with tree size and age is important for scaling single leaf measurements to the whole plant and stand level. However, there is not much information on the influence of plant age on LRC in dipterocarp trees (Reich et al., 2009; Bruce et al., 2005; Langenheim, 2003). Reich et al. (2009) reported that gradual changes in physiology parameters of photosynthetic capacity and transpiration were observed to be influenced by the age of a tree. Age related changes in photosynthetic components derived from LRC, namely light compensation, light saturation and quantum efficiency were reported by Langenheim (2003) for species of Amazonian rainforest tree species, namely *Hymenaea courbaril* and *Hymenaea parvifolia*. The rates in young leaves were 47 and 31 % higher compared to older leaves in *Hymenaea courbaril* and *Hymenaea parvifolia,* respectively. Another study by Bruce et al. (2005) on *Phaseolus vulgaris*, reported an A_{max} rate of (5.5 and 2.17) µmol m^{-2} s^{-1} respectively for young and old leaves of the seedlings. The A_{max} of younger leaves was higher by nearly 60% compared to the older leaves. However, currently there is little information available on the variation of leaf photosynthetic, morphological and biochemical parameters in the leaves of dipterocarp seedlings.

2.4 Effects of Mineral Nutrients on Plant Growth

Plants use inorganic minerals for nutrition, whether grown in the field or in a nursery. There are actually 20 mineral elements necessary or beneficial for plant growth (Jones Jr, 2012). Carbon (C), hydrogen (H), and oxygen (O) are supplied by air and water. The six macronutrients, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) are required by plants in large amounts. The rest of the elements namely boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), sodium (Na), zinc (Zn), molybdenum (Mo), and nickel (Ni) are required in trace amounts (micronutrients). Previously, plant growth was thought of in terms of soil fertility or how much fertilizer should be added to increase soil levels of mineral elements (Marschner, 2011). Most fertilizers were formulated to account for deficiencies of mineral elements in the soil. The use of soilless mixes and increased research in nutrient cultures and hydroponics as well as advances in plant tissue analysis have led to a broader understanding of plant nutrition. Plant nutrition is a term that takes into account the interrelationships of mineral elements in the soil or soilless solution as well as their role in plant growth. This interrelationship involves a complex balance of mineral elements essential and beneficial for optimum plant growth.

There have been relatively few studies conducted on nutrient limitation in dipterocarp seedling growth in the field (Turner et al., 2006; Raja Barizan & Shamsudin, 1998). Nursery studies using potted seedlings have shown that the addition of both nitrogen and phosphorus (Brearley et al., 2007; Turjaman et al., 2006; Bungard et al., 2000; Gunatilleke et al., 1997; Yap & Moura-Costa, 1996) may enhance the growth of dipterocarp seedlings. However, a few studies have reported variations in their results with regard to mineral applications (Turner et al., 1993, 2006; Burslem et al., 1995). Whether these results reflect nutrient limitations in the field is not clear as Forest departments in Malaysia routinely apply nutrients to dipterocarps when planted in secondary, degraded forests (Krishnapillay, 2002; Krishnapillay et al., 2007; Appanah & Weinland, 1993). Whether the nutrient effects are species or site-specific remains largely untested. The few field experimental studies that have been conducted suggest that nutrient limitation may be common in enrichment planting conditions.

Few studies on phosphorus applied to potted seedlings have been shown to have a significant positive effect on seedling performance following out-planting in two dipterocarp species in Peninsular Malaysia (Turner et al., 2006; Raja Barizan et al., 2000; Nussbaum et al., 1995). Raja Barizan et al. (2000) reported strong growth responses of *Shorea* and *Hopea* species to nutrient addition on very low fertility, heavily compacted, log-landing sites with no topsoil. Seedlings grown in the same sites with the topsoil replaced exhibited growth rates similar to plots with added nutrients suggesting that in logged areas outside of compacted areas, seedling growth may not be as severely nutrient limited. Further work is needed to assess whether nutrient limitation is widespread in enrichment planting conditions, and more generally which components of below-ground resources are limiting to seedling growth during tree establishment.

Most plant physiologists consider potassium as second to nitrogen in importance for plant nutrition with tissue levels ranging between 1% to 3% by weight. As a trivia, potassium is the only essential plant nutrient that is not a constituent of any plant part (Sringarm et al., 2009). Potassium is a key nutrient important in plant tolerance to stresses such as cold/hot temperatures, drought, wear and pest problems. Furthermore, potassium acts as catalyst for many of the enzymatic processes in plants that are necessary for plant growth to take place. Another key role of potassium is the regulation of water use in plants (osmoregulation). Osmoregulation affects water transport in the xylem, maintaining high daily cell turgor pressure, which affects water tolerance, affects cell elongation for growth and more importantly it regulates the opening and closing of the stomates which affect transpirational cooling and carbon dioxide uptake for photosynthesis (Wang et al., 2013; Cheng & Fuchigami, 2000).

Leaf photosynthetic rate has been shown to vary with potassium status in several crop species and although the relationship between leaf nitrogen and phosporus concentration and leaf photosynthetic response have been studied extensively in fruit tree species, the relationship between leaf potassium concentration and leaf photosynthesis has received less attention particularly in forest tree species of dipterocarps (Farooq et al., 2009; Osaki et al., 1993).

2.5 Biomass and Carbon Stock

Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-based materials. Wood remains the largest biomass energy source to date and includes forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. Generally, changes in biomass stock or annual volume increment are used in determining the change in biomass carbon stocks in forests. Increasing the growth rate of the tree crop relatively increases the carbon absorbed. Carbon stock as stated by Chave et al. (2005) is 50% of biomass. Tree biomass is defined as the total mass of living organic matter in tree produced by photosynthesis and can be expressed as oven dried biomass per unit area. An accurate estimation of biomass is essential especially for scientific studies in relation to environment, such as, eco-system productivity, energy, nutrient flows, carbon sequestration, carbon stocks and evaluating the impact of changes in tropical forest to the global carbon cycle (Basuki et al., 2009). Principally, there are five primary carbon pools in a forest which are above-ground biomass, below-ground biomass, deadwood, litter and soils that accumulate and in some cases release carbon (Hamdan et al., 2015). However, about 98% carbon stored in a forest comprises tree components, namely, aboveground and belowground living biomass, deadwood and litters and the remaining are stored in soils. As described by Hamdan et al. (2015) in a lowland dipterocarp forest in Pahang, trees with a DBH < 10 cm are considered as saplings. In his study, results indicated that the biggest portion of biomass carbon is in the living trees, which comprised about 79% (188.2 Mg ha^{-1}) of the total carbon pools in the forest. It was followed by below-ground living biomass carbon, which consisted of about 19% (45.2 Mg ha^{-1}). Deadwood and litter contributed to 1% (2.3 Mg ha^{-1}) and lastly saplings contributed to 1% (2.46 Mg ha^{-1}) of the total AGB in the forest. A study by Laumonier et al. (2010) on biomass has shown a 5% (18.03 Mg ha^{-1}) contribution of total biomass (above and belowground) for saplings with a diameter range 1.0 – 9.9 cm in a lowland dipterocarp forest of Indonesia. Another study by Ngo et al. (2013) in the secondary forest of Singapore, indicated that saplings of 1-10 cm DBH contributed to 11.53 Mg ha^{-1} of total AGB.

Many studies have reported an increment of biomass across many forest types (McMahon et al., 2010). In tropical forest regions, forests may recover rapidly from agricultural fields, logged stands, or areas cleared due to natural disturbances. The period of recovery consists of a rapid increase in above-ground biomass of a forest. This rate of biomass pattern varies across stands because of nutrient availability and species composition. The databases on estimating biomass and carbon stock of dipterocarp forests, mainly on dipterocarp species are very few (FAO, 2005).

A research conducted by Tara (2012), on tropical forest carbon stock in Temenggor Forest Reserve, Perak, Malaysia has found that the average carbon in aboveground biomass was 149 Mg(C)/ha. There was not a significant difference in carbon content among individuals of the same species, but there was a significant difference in carbon content between different tree species (standard deviation ±1.04, $p<.001$). Percentage carbon ranged from 43.489% to 48.537%, with a mean percentage carbon of 46.292% (Table 3).

2.6 Rehabilitation for Carbon

Many studies and research have been done and are being conducted with regard to carbon and rehabilitation in Malaysia as well as throughout Southeast Asia. One of the rehabilitation projects on forest carbon inventory was done in Sabah in 2007 where Face Foundation commissioned a forest carbon inventory in the Infapro rehabilitation project area. This carbon monitoring campaign was a joint effort carried out by the Institute for Forest Ecosystem Research (IFER), Innoprise-Face Foundation Rainforest Rehabilitation Project (INFAPRO) and Forests Absorbing Carbon dioxide Emissions Foundation (FACE). The project started in 1992 with the objective to rehabilitate 25,000 ha of heavily degraded rainforest with liberating the remaining forest matrix and with enrichment planting of indigenous dipterocarps, fast growing pioneers and forest fruit trees. The technique was used to promote artificial regeneration of seedlings in the existing logged rainforest and preferable silvicultural treatments were given to encourage the growth of these seedlings. The objective of planting indigenous fruit tree species was to increase the biodiversity of the planting compartments and to attract wildlife. Up to now about 11,000 ha have been rehabilitated. Qualified trees from the rehabilitated area (30, 413 ha) were chosen and the growth parameters were measured for carbon stock quantification. The carbon stock held in trees was also expressed separately for different forest types, planting year and tree type. The carbon stock held in the aboveground and belowground tree biomass was estimated to be 1,912,300± 251,700 tons, with a confidence interval of ± 13.2 %. This corresponds to an average carbon stock of 92.5 ± 12.3 tons per hectare held in trees. This value was considered low compared to a study done by Tara (2012), where she recorded 149 tons per hectare for tropical forest carbon stock in Temenggor Forest Reserve, Perak. This shows that rehabilitated forest areas have a lower carbon stock compared to a forest reserve. The effect of excessive commercial logging would have decreased the number of species diversity and very likely caused the regeneration of lower-valued pioneer plant species, causing a decrease in carbon stocks.

Table 2.3: Database of species-specific carbon content by % dry weight in Temenggor Forest Reserve Perak, Malaysia (Tara, 2012)

Tree species	%C	Tree species	%C
Aglaia tomentosa	46.544	*Lithocarpus sundaicus*	47.611
Artocarpus komando	43.489	*Macropanax maingayi*	44.687
Artocarpus nitidus	45.185	*Mallotus dispar*	44.670
Atuna racemosa	46.267	*Mallotus subpeltatus*	47.501
Baccaurea brevipes	46.595	*Nephelium costatum*	46.402
Casearia clarkei	46.130	*Payena lucida*	46.173
Chisocheton ceramicus	47.084	*Pentaspadon velutinus*	47.110
Dacryodes rostrata	46.776	*Shorea leprosula*	46.560
Dialium platysepalum	47.543	*Scorodocarpus borneensis*	48.537
Elateriospermum tapos	46.905	*Pseuduvaria macrophylla*	46.384
Semecarpus curtisii	45.907	*Ptychopyxis caput-medusae*	46.057

CHAPTER 3 : GROWTH PERFORMANCE OF CHENGAL SEEDLINGS UNDER DIFFERENT LIGHT, FERTILIZER AND AGE TREATMENT FROM NURSERY TO FIELD

3.1 Introduction

Production of planting stocks in the nursery generally aims at preparing quality seedlings that will establish and grow well after outplanting. Planting stock quality generally carries the implication of the seedling inherent performance potential. The main factors which affect seedling quality in the nursery and field are mainly the quality of the seedlings to be fit, light intensity and fertilizer application. The quality of planting stock is one of the main factors influencing initial survival and subsequent development in any rehabilitation of logged-over forest. Hence, in raising seedling stock for the purpose of replanting in degraded forest areas, the need for optimum light and fertilizer application for seedlings at the nursery is of paramount importance. A Manual on Grading of Nursery seedlings stated that the judgment of nursery stock quality at the time of planting may be based on the growth and physiological characteristics of the seedlings (FDPM & ITTO, 2006). Although the knowledge on the best light and fertilizer treatment on seedlings have been well researched and documented, very little is known with regard to the chengal species. Chengal, a heavy hardwood timber is known to be shade tolerant and has a slow growth rate (Tnah et al., 2012; Wong et al., 1994; Appanah & Weinland, 1993).

Enrichment planting is a technique for promoting artificial regeneration of forests in which seedlings of preferred timber trees are planted in the under-storey of existing logged-over forests and then given preferential treatment to encourage their growth (Paquette et al., 2009; Lamprecht, 1986). However, previous studies have shown that the survival and growth rate of seedlings under the enrichment planting programme has been very poor and the costs of maintenance was high, due to the need for repeated post-planting treatments (Kamaruzaman & Dahlan, 2008; Appanah & Weinland, 1993; Tang & Wadley, 1976). As a result, an improved planting technique was applied so that the plants can sustain excellent growth with minimum post-planting tending (Raja Barizan & Shamsudin, 2001; Raja Barizan et al., 2008). Enrichment planting techniques has also been reported to be the best way to boost the growth performance of chengal (Raja Barizan & Shamsudin, 2001; Raja Barizan et al., 2008).

Light is one of the most important environmental factors affecting plant survival, growth, reproduction and distribution. Light intensity affects photosynthesis which in turn, affects the growth performance of plants especially of seedlings. Moreover, to sustain higher photosynthetic capacity or survival, plants modify their morphology under different light conditions (Tuba & Lichtenthaler, 2011; Larcher, 2003; Den & Oosterbeek, 1995). For example, plants grown under low light intensities exhibit slower growth (Lentz & Cipolinni, 1998; Devkota et al., 2010; Kenzo et al., 2008). However, different species, respond differently to light intensity. It has been reported that shade increases shoot growth at the expense of root growth, hence decreasing the extent of the absorption surface in the roots relative to the transpiration surface in the leaves (Portsmuth & Niinemets, 2007). As for chengal species, it is well known that at a younger stage, it is shade tolerant. However as it grows, it requires more light.

There have been relatively few studies on nutrient limitation of dipterocarp seedling growth in the field (Turner et al., 2006). Nursery studies using potted seedlings have shown that the addition of both nitrogen (N) and phosphorus (P) enhanced the growth of dipterocarp seedlings (Brearley et al., 2007; Turjaman et al., 2006; Bungard et al., 2000; Gunatilleke et al., 1997; Yap & Moura-Costa, 1996). Nevertheless to get healthy seedlings, all the necessary nutrients must be supplied in the proper proportions (Afa et al., 2011). If a given nutrient is deficient, seedlings may compensate to some extent by increasing their capacity to take up the deficient ion (Afa et al., 2011). However more commonly, such stress will be reflected by reduced growth. There are reports that indicate both positive and negative effects of nursery fertilizer applications on subsequent seedling growth and survival. Both Saner et al. (2011) and Turjaman et al. (2006) reported positive growth responses after outplanting in the field for seedlings fertilized with various levels of nitrogen in the nursery. A study by Raja Barizan (1998) on planted *Hopea odorata* and *Dryobalanops oblongifolia* in the Berkelah Forest Reserve, Pahang showed that the survival and growth of the seedlings were affected significantly by the level of fertilizer applied, whereby fertilizing the seedlings significantly improved and increased the mean percentage of seedlings growth. A restoration program conducted by Heriansyah et al. (2013) in Tekai Forest Reserve, Pahang concluded that S*horea leprosula* stands planted in tropical degraded forest land, without applying organic material, resulted in poor growth rate and biomass accumulation. They suggested organic material application to be one of the requirement treatments needed for better growth performance.

Not many studies have been done to determine the best age of planting stock, especially on chengal species that will be optimal for planting in the field. In any planting trial, the homogenous size of planting stocks at planting is very critical. As far as the age of the planting stock is concerned, Shaharudin (2011) and Yamada et al. (2014), found that for most of the dipterocarp species, a planting stock between 3 and 8 months old is the best. They studied *Dryobalanops aromatica, Shorea leprosula* and *Shorea pauciflora*. Similarly, Skarpe & Hester (2008) and Hodgson & Eggers (1937) concluded that planting stock only a few months old is more likely to survive than older material. Raja Barizan & Shamsudin (2001, 2008) recommended big saplings with height and diameter of 1 m and 1 cm, respectively, as the optimum size for field planting. However little information is available on chengal species, regarding the ideal age and size of planting stock, best used for planting in a degraded forest.

As has been explained earlier, there is a lack of information regarding the optimum light intensity and fertilizer level treatment required at nursery level for optimal growth of chengal potted seedlings, as well as the best age and fertilizer treatment for chengal stands to be planted in a degraded forest. The study in this chapter was carried out to determine the optimum light intensity and fertilizer treatment for the growth of potted chengal seedlings in the nursery and the best age and fertilizer treatment for the growth of this endangered species in the field.

3.2 Methodology

3.2.1 Nursery site selection

The Forest Research Institute Malaysia (FRIM) nursery, established in 1963, was chosen as the location for the nursery experiments. It occupies an area of about one hectare. The FRIM nursery lies between the latitude of 3° 14´13” N and longitude 101° 38´16” E, at an elevation of 97 m above sea level.

3.2.2 Meteorological aspect

The rainfall, air temperature and relative humidity (RH) data for the year 2009 to 2010 were obtained from the Meteorological Department, Petaling Jaya, Selangor.

3.2.2.1 Rainfall

The annual rainfall at the FRIM nursery, as evident from rainfall data from 2009 to 2010, was 3,077 mm and 3,228.5 mm, respectively. The nursery received the lowest amount of rainfall in July and the highest in November. The average annual number of raindays for 2009 and 2010 were 136 days and 134 days, respectively (Figure 3.1).

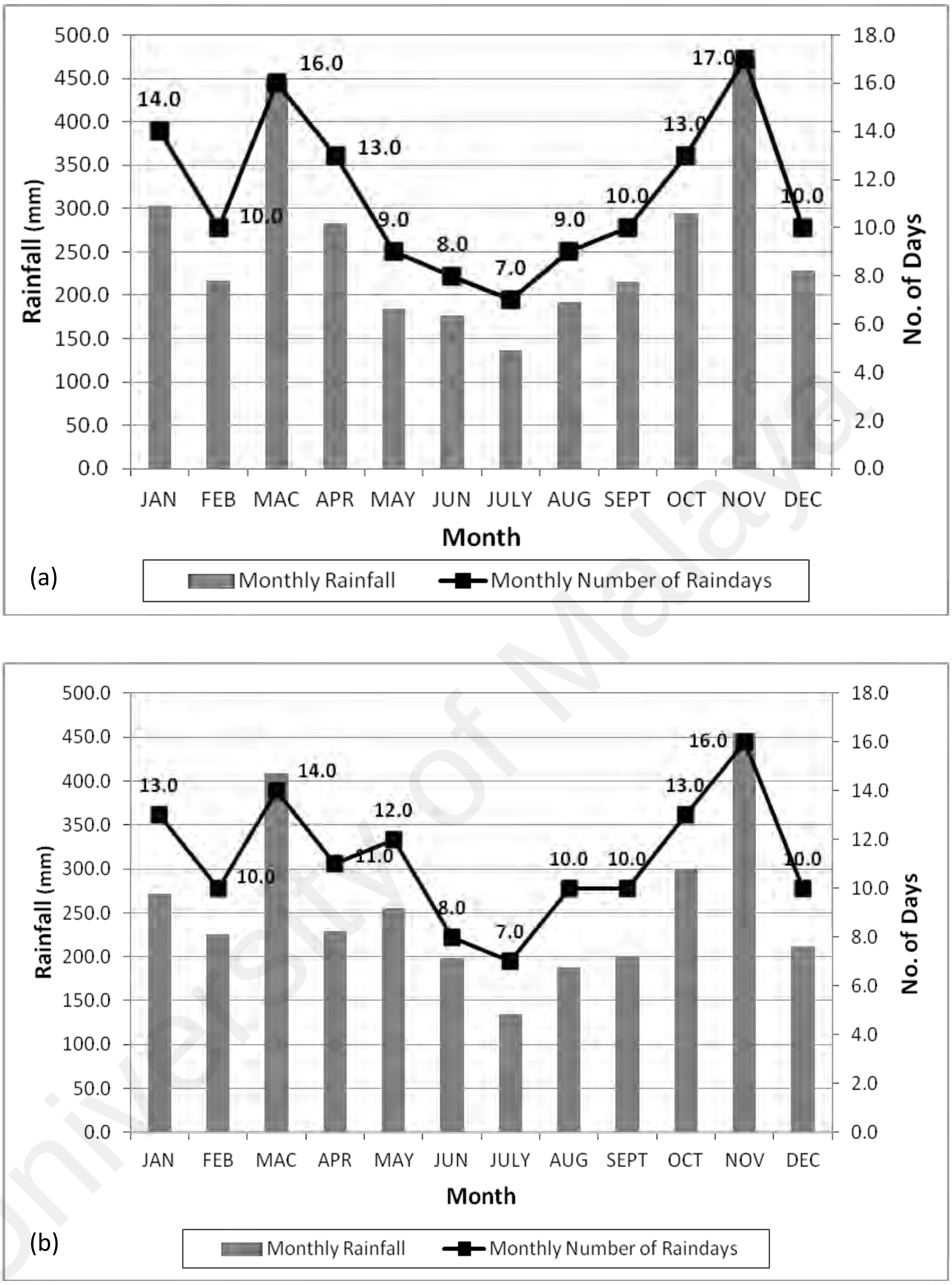


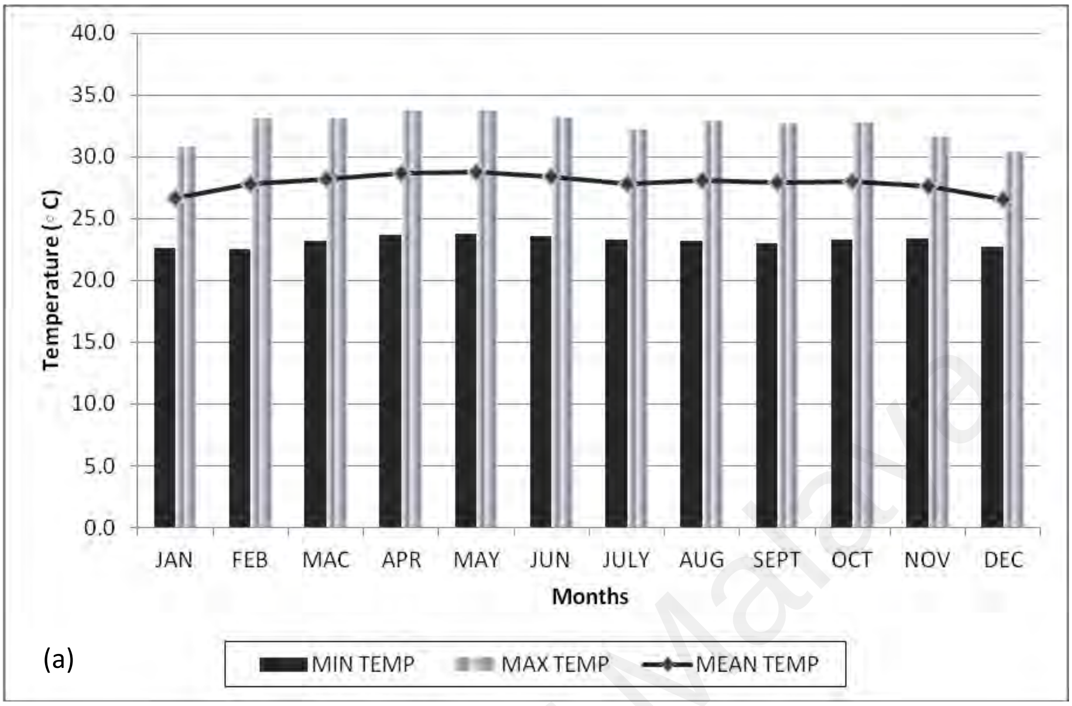
Figure 3.1 : Mean monthly rainfall at FRIM nursery for the year (a) 2009 and (b) 2010

3.2.2.2 Air temperature

The monthly profile of a 24-hour (24-h) mean temperature for the period between 2009 and 2010, is shown in Figure 3.2. The 24-h mean annual temperature for the FRIM nursery was 27.7^{o} C with a mean daily minimum and maximum of 22.5^{o}C and 33.8^{o}C, respectively. The lowest and highest temperatures at the nursery were recorded between January-December and April-May, respectively. The mean monthly temperature fluctuated around 27.9^{o}C, with higher temperatures between February to June and lower temperatures between the months of December to January.

3.2.2.3 Relative humidity

As expected of an equatorial region, high relative humidity was recorded. The monthly mean relative humidity observed for 2009 to 2010 is shown in Figure 3.3. The relative humidity increases significantly towards the end of the year, during the rainy season, from November to December (81.0% - 83.4%), and the lowest was observed during the period of January to March (77.7%. - 80.9%) for both years.



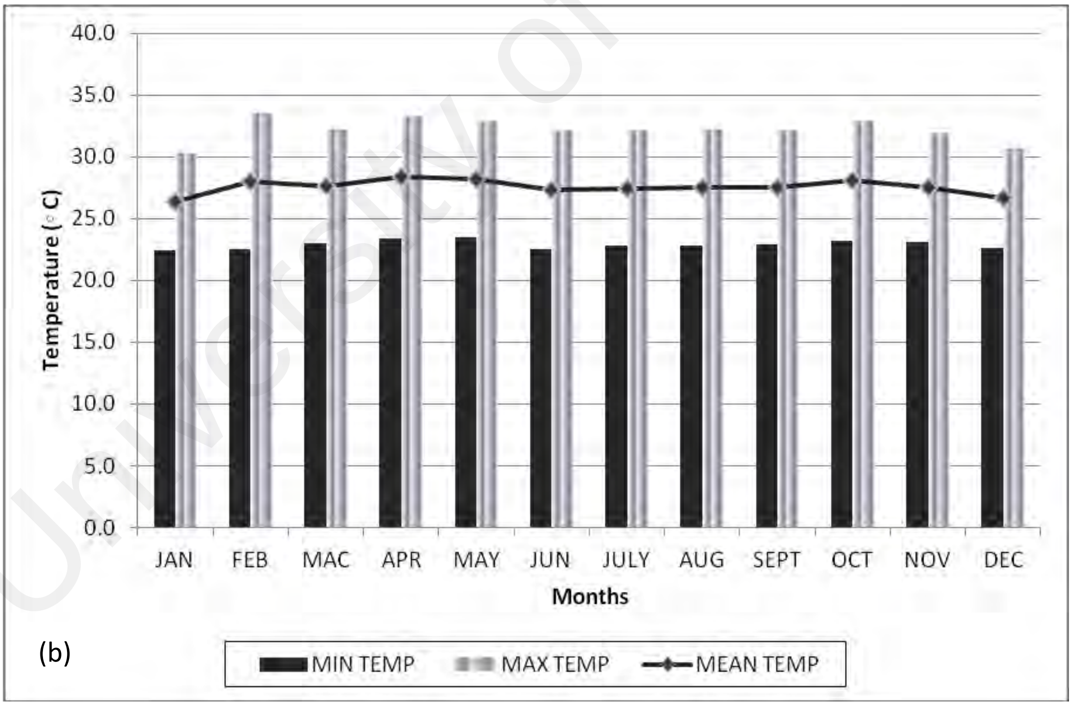


Figure 3.2 : Minimum and maximum air temperatures at FRIM nursery for the year (a) 2009 and (b) 2010

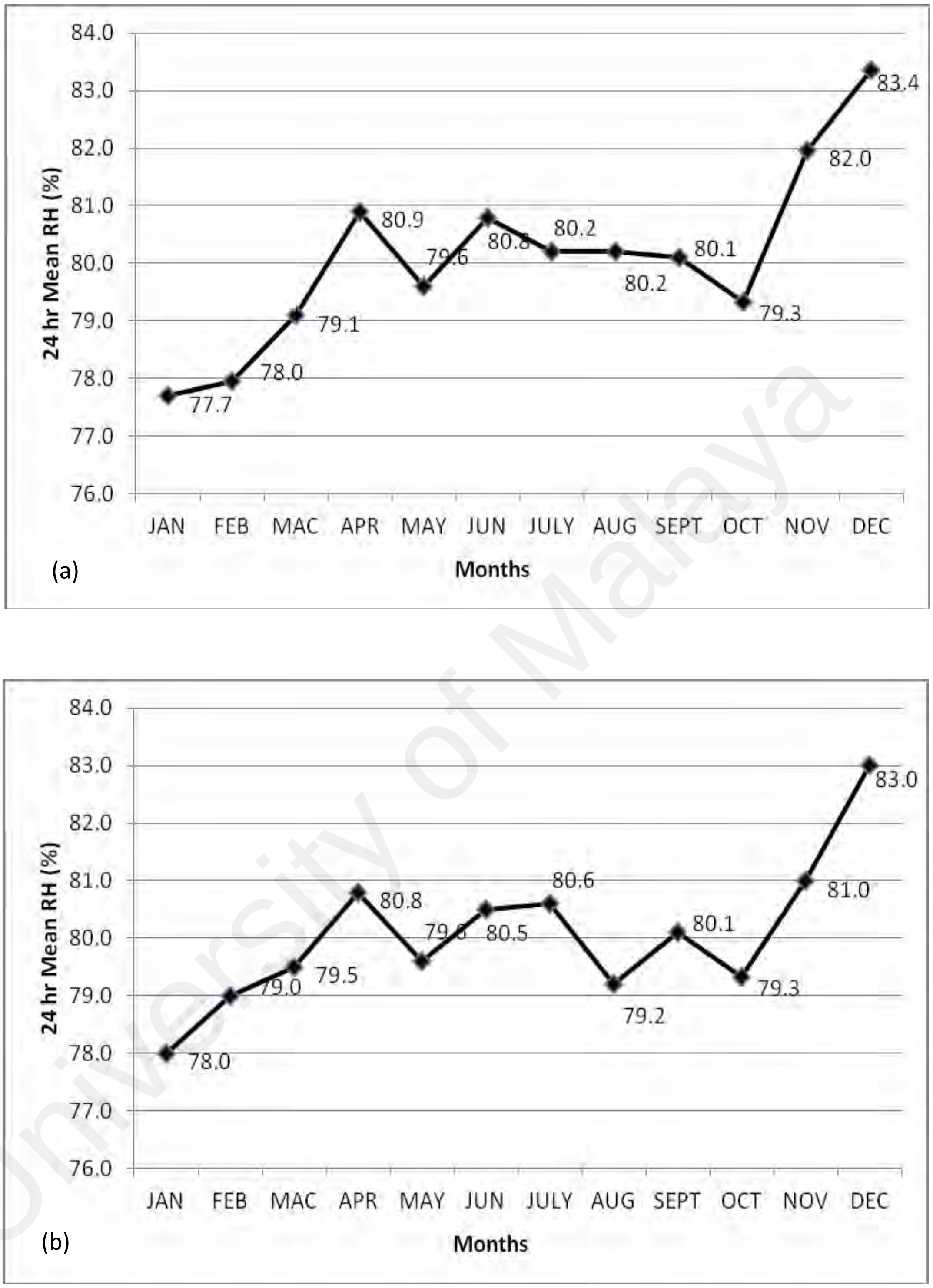


Figure 3.3 : Relative humidity at FRIM nursery for the year (a) 2009 and (b) 2010

3.2.3 Nursery establishment

A total of 720 chengal seedlings from Tembat Forest Reserve, Kenyir, Terengganu, were used to establish the nursery at the Forest Research Institute of Malaysia (FRIM) in year 2009. Chengal seedlings used were at the age of eight months after sowing. Polythene bags of size 10 × 10 inches were used to pot the chengal seedlings. The potting medium used for the regular preparation of planting material was 3:1 (soil:sand) as described in Aminah and Lokmal (2002).

The chemical characteristics and physical properties of the soil used for potting were analyzed in FRIM soil laboratory and are described as in Table 3.1 and Table 3.2. The physical properties of soil used for potting chengal seedling in the nursery which consist of clay, silt, fine sand and coarse sand did not make 100% in total. In Table 3.6, the total of soil physical properties was only 82.48%. The remaining 17.52% was gravels, small stones, rocks and granules. The experimental design is a Randomized Complete Block Design (RCBD) factoring; 3 light intensity × 3 fertilizer × 2 harvest cycle × 40 seedlings. Chengal seedlings were arranged accordingly into 3 blocks or replicates. The three blocks (light treatment) represented the percentage of light intensity, which were 30% (500-600 μmol m^{-2} s^{-1}), 50% (1000-1200 $\mu mol^{-2}s^{-1}$) and 100% (1800-2000 $\mu mol^{-2}s^{-1}$). Each block had three fertilizer treatments and 40 seedlings of chengal. The three fertilizer treatments given were 10g NPK Blue fertilizer (inorganic), 10 g goat dung (organic) and control (no fertilizer applied). The three treatments were arranged randomly in each block. Two harvest cycles were conducted for all the seedlings, at the 6th month and 12th month after chengal potting. The two cycles were mainly for the biomass experiments that will be discussed later in chapter 4.

Table 3.1: Mineral nutrient properties of soil used for potting chengal seedlings in FRIM nursery

Parameter	Value
pH	4.97
Total nitrogen N (%)	0.03
Available phosphorus (P) (ppm)	22.15
Potassium (K) (meg/100g)	0.04
Organic carbon (C) (%)	0.3

Table 3.2: Physical properties of soil used for potting chengal seedlings in FRIM nursery

Parameter	Soil physical and chemical properties
Cation exchange capacity (CEC) ($cmol_c kg^{-1}$)	4.68
Clay (%)	19.58
Silt (%)	8.34
Fine Sand (%)	20.45
Coarse Sand (%)	34.11
Gravels (2-6 mm) (%)	17.52

Each chengal seedlings received 10 g of NPK blue (18:22:16) %, and 10 g of goat dung (11:5:11) % of nitrogen:phosporus:potassium, respectively every month. Watering was done twice daily, in the morning at 9 am and afternoon at 4 pm, to avoid water becoming a limiting factor at the initial growing stage. NPK Blue fertilizer has been the essential fertilizer used in the FRIM nursery for potted seedlings as stated in 'A Manual of Enrichment Planting in Logged-over Forest in Peninsular Malaysia' (FDPM & ITTO, 2006). Thus, this study was focused on comparing these three different fertilizer regimes under three different light intensity in the nursery.

3.2.4 Growth performance measurements

The study in the nursery was done for one year from 2009-2010. The growth measurements of height and diameter were measured at the 1st, 6th, 9th and 12th month. A measuring tape was used to measure height of the saplings from the base of the stem to the highest shoot. A caliper was used to measure the basal diameter at 5 cm from the base.

3.2.5 Field site selection

The Tekai Forest Reserve, located in Jerantut, central in the state of Pahang was the chosen site for the study. The forest reserve is about 235 km from Kuala Lumpur and lies between latitude 4° 10′ - 4° 20′ N and longitude 102° 15′ - 102° 30′ E. The topography is undulating with elevations ranging from 80 to 120 m above sea level, with an area of around 140 hectares. The study plot is located in Plot 4, Compartment 89B, in the Tekai Forest Reserve, Jerantut, Pahang (Figure 3.4). This forest is classified as Permanent Forest Reserve (PRF) and falls under Dipterocarp lowland forest (Forestry Department of Peninsular Malaysia, 2012). It has been logged twice before, the first cycle done 30 years back in the 1970's. The second logging cycle was done in June 2006 using the present technique practised, which is the SMS which involves the use of bulldozers, tractors and lorries. This has resulted in canopy openings along logging roads, decking sites and skid trails. The sites are usually poor in minerals and the soil compaction varies from mid to high due to the loss of top soil.

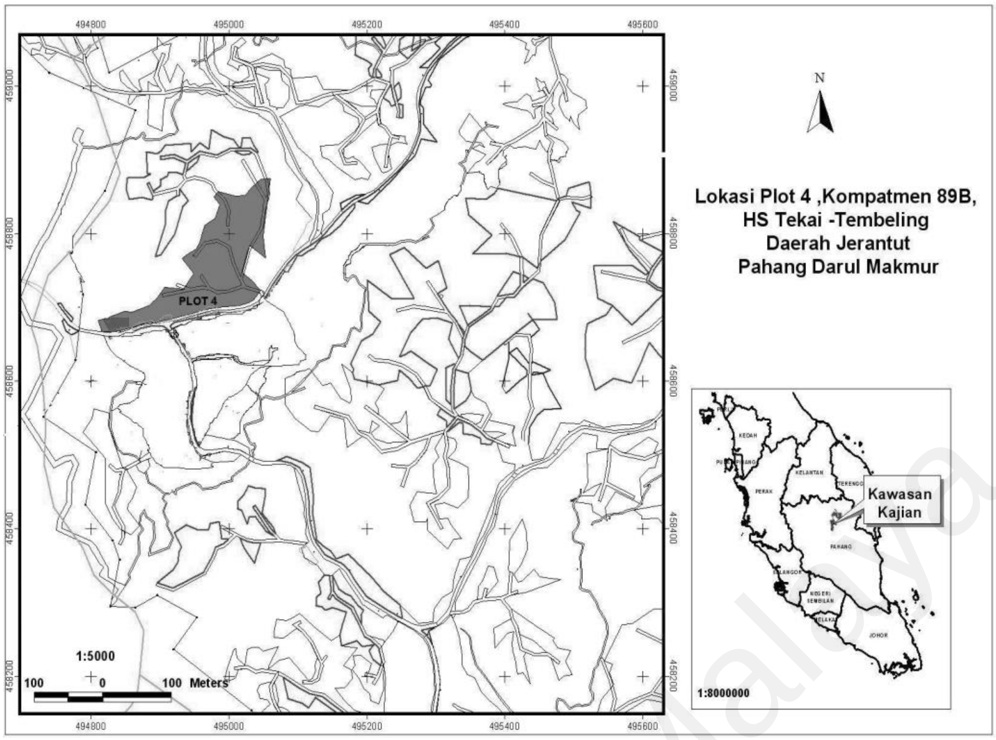


Figure 3.4 : Map of study site located in Plot 4 Compartment 89B, Tekai Forest Reserve (FR), Jerantut, Pahang

3.2.6 Meteorological data

The rainfall, air temperature and relative humidity data from the year 2007 to 2011 were obtained from the Meteorological Department, Petaling Jaya, Selangor. The year 2007 was when the plot was first established and year 2011 was when the physiological parameters were measured and collected.

3.2.6.1 Rainfall

The annual rainfall of the Tekai Forest Reserve, Jerantut, as evident from the rainfall data from 2007 to 2011, varied between 2,530 mm and 3,045 mm, with a mean annual rainfall of 2,772 mm. The lowest mean rainfall occured during the month of February whilst the mean rainfall was recorded in March. The average annual number of raindays from 2007 to 2011 was 198 days per year (Figure 3.5).

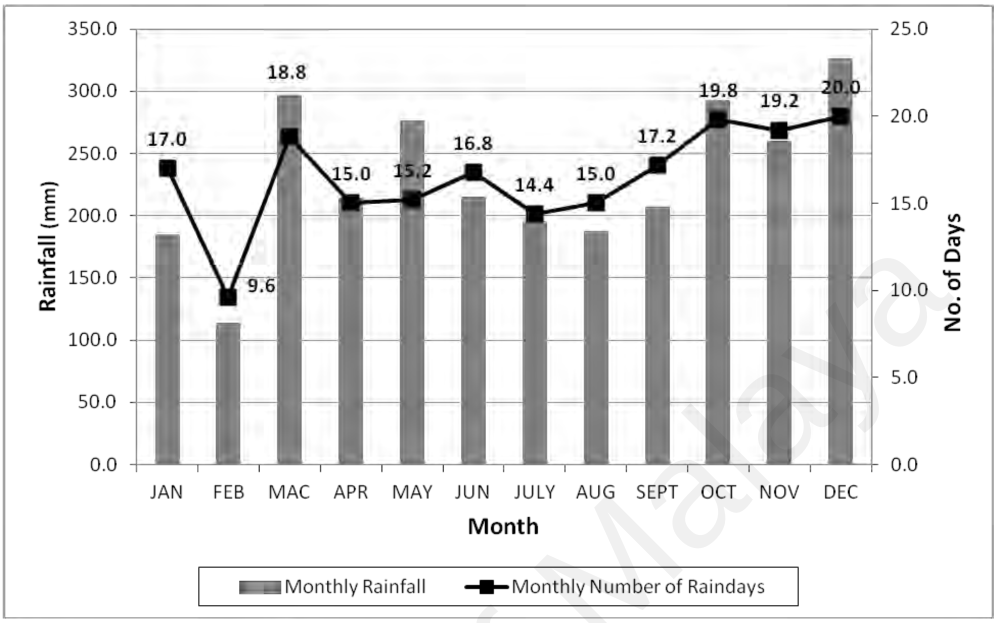


Figure 3.5 : Mean monthly rainfall in Tekai FR from 2007-2011

3.2.6.2 Air temperature

The monthly profile of a 24-h mean temperature for a period from 2007 - 2011, is shown in Figure 3.6. The 24-h mean annual temperature for Tekai Forest Reserve was 27.9^{o} C with a mean daily minimum and maximum of 19.0^{o}C and 37.9^{o}C, respectively. The lowest and highest temperatures recorded in Tekai Forest Reserve was in December and May, respectively. The mean monthly temperature fluctuated around 27.9^{o}C with a distinct high between February to June and a lower temperature period between December to January.

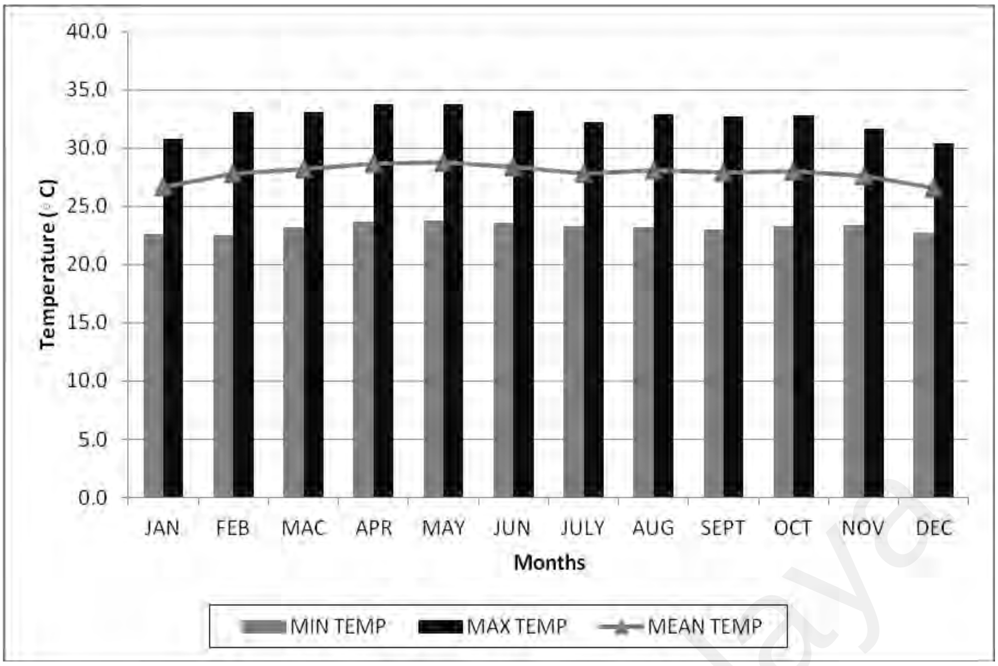


Figure 3.6: Mean temperature for Tekai FR from 2007-2011

3.2.6.3 Relative humidity

As expected of an equatorial tropical rainforest region, the area recorded high humidity. This was evident from the monthly mean relative humidity gathered from 2007 to 2011 (Figure 3.7). The relative humidity was on the high side towards the end of the year from September to December (84.4% - 87.3%), and lowest during the period of February to July (79.9%. - 84.2%).

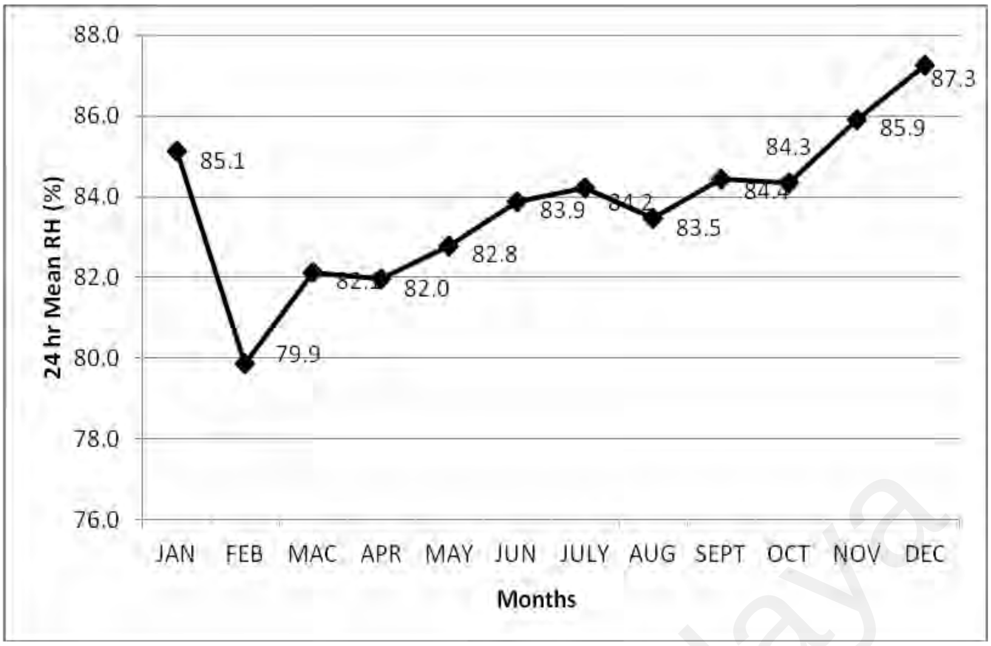


Figure 3.7 : 24 hour Mean Relative Humidity at Tekai FR from 2007-2011.

3.2.7 Preparation of Planting stock

Planting stock size used for plot establishment ranged between 60-100 cm in height and 0.5-1.0 cm in diameter, purchased from a private nursery in the state of Terengganu and raised in the FRIM Research Station Nursery (SPF) in Jengka, Pahang. The planting stock age, of 6 months and 1 year 8 months old were determined based on months after sowing. Therefore, 6 months old stock is 6 months after sowing and 1 year 8 months stock is 1 year 8 months after sowing. All planting stocks were rasied at the same time in the nursery. In order to boost growth rate, the seedlings were re-potted into larger polythene bags measuring 10 × 17.5 cm. The polythene bags were removed when planting in the field to ensure higher field survival and quicker growth. The development of a healthy and fibrous root system needs a medium with good physical properties, that would help the virile growth of roots and for the better quality of the seedlings.

3.2.7.1 Potting medium

The potting medium is important as it physically supports the growing seedling and supplies nutrient, water and air to the root system. A good medium, will ensure the development of a healthy fibrous root system and in consequence better quality seedlings. The potting medium used for chengal seedlings had a ratio of top soil:sand of 3:1. In preparing the mixtures, the soil was first sieved through a wire netting to make it uniform and remove rubbish, stones and large debris. Alternately a soil shredder was used.

3.2.7.2 Watering and fertilizer application

Watering using sprinkler was carried out in the nursery twice daily, in the morning at 9 am and late afternoon at 4 pm, except on rainy days. In the nursery, chengal seedlings were fertilized with NPK fertilizers, NPK Blue ($12N:12P_2O_5:17K_2O:2MgO$ + trace elements) at the rate of 5.0 g/month/plant and increased to the amount of 10 g according to the increment of age and size of the seedlings. The fertilizers were applied carefully to ensure the fertilizers is not in contact with the root collar to avoid burning of the root collar.

3.2.7.3 Slow hardening

At an early stage, all the seedlings were placed under a black net with 70% light intensity to avoid direct sunlight and photoinhibition of the young plants. As the planting was done in an open area, the seedlings needed to go through a slow hardening process whereby seedlings were gradually exposed to 9 hours direct sunlight for a duration of 2 months followed by an exposure to natural direct sunlight for a month (Farah & Raja Barizan, 2007).

3.3.7.4 Planting stock grading and transportation

Only healthy and fit chengal seedlings, that were free from pests and diseases were selected to be transplanted in the field. Watering was carried out just prior to transportation. Seedlings were held in their polythene bags while being transported so that the media and roots are kept intact. A lorry pick-up covered with canvas was used for transporting the seedlings to the field to reduce water loss from evaporation and transpiration. Transportation was also made in the morning to avoid high evaporation during noon that can cause wilting. The stocks were then brought to the nearest suitable transit site prior to field planting.

3.2.8 Establishment of chengal plot

The 1.73 ha plot of chengal stands was established in September 2007, approximately 1 year after logging was completed, using improved planting technique developed by Raja Barizan and Shamsudin (2001, 2008). The planting techniques have been discussed thoroughly in sub-chapter 3.2.8.1.

3.2.8.1 Site preparation using improved planting techniques

The chosen plot was first cleared using a 'back-hoe' tractor. The main purpose of clearing was to provide sufficient space and canopy gaps for planting. However, the big trees were excluded from clearing to conserve the species (Figure 3.8).

Figure 3.8 : Clearing of planting area

3.2.8.2 Planting chengal

Planting was done under gap (open) condition, as close planting spacing was recommended. The planting spacing used was 3 m × 3 m. The close spacing will enhance growth and impede the production of lower branches. Due to the improvement in the method for preparing the planting hole and the usage of larger planting stocks, a semi-mechanized planting approach was applied. The semi-mechanized planting method uses the vehicle of track tires, skid steer loader model 753 or 773 (Bob-Cat) attached with a hydraulic auger size 36 inches (90 cm) diameter. The vehicle was found suitable for preparing big holes and it is able to travel along difficult terrain and soft grounds at the planting site. The size of planting hole prepared was ± 90 cm width and ± 90 cm depth, to provide ample space for root growth. Due to soil compaction which ranged from (0.89 – 1.06) gcm^{-3} within the gaps, the hydraulic auger loosens the compaction within the planting hole. All planting holes were prepared on the same day. The standard practice in enrichment planting requires a series of post tendings which is an important silviculture treatment. However, the improved planting techniques used in this study was designed for providing conducive growth conditions at an early stage and thereafter minimal intervention tending (post tending) was required.

The RCBD experimental design took into account the following: 2 age × 3 fertilizer × 3 block × 30 seedlings. The plots were replicated into 3 blocks (replication) which consisted of two different age groups of chengal seedlings, which were 6-months and 1 year 8 months old. Three types of fertilizer treatments were used for planting, which included, 400 g slow release fertilizer (SRF), 500 g goat dung and lastly a combination of slow release fertilizer (200 g) + goat dung (200 g). The use of SRF fertilizer was recommended by Raja Barizan and Shamsudin (2001, 2008) and is considered essential to be used as the main fertilizer whenever a planting is taking place in a logged over forest, which is known to have poor soil mineral and nutrient content. The chengal plot established is shown in Figure 3.9. A total of 540 chengal seedlings were planted. The inorganic slow release fertilizer brand Multi-cote contains 19:10:13 % of nitrogen:phosphorus:potassium. The organic fertilizer used (goat dung) contains 11:5:11 % of nitrogen:phosporus:potassium. Information on soil chemical characteristics and physical properties of the plot area before planting was obtained from the Soil Management Division of FRIM and are shown in Table 3.3 and Table 3.4, respectively. The physical properties of soil at study area which consists of clay, silt, fine sand and coarse sand did not make 100% in total. In Table 3.4, the total of soil physical properties was only 86.66%. The remaining 13.34% was gravels, small stones, rocks and granules.

Figure 3.9 : Established chengal stands at time of planting

Table 3.3: Chemical characteristics of soil at study area

Element	Content
Total N (%)	0.12
Available P (ppm)	4.48
Magnesium (Mg) (meg/100g)	0.30
Calcium (Ca) (meg/100g)	0.18
Potassium (K) (meg/100g)	0.14
Organic C (%)	1.34

(source: FRIM Soil Management Department)

Table 3.4: Physical properties of soil at study area

Parameter	Soil physical and chemical properties
pH	4.56
CEC ($cmol_c kg^{-1}$)	14.40
Clay (%)	24.14
Silt (%)	10.05
Fine Sand (%)	22.36
Coarse Sand (%)	30.11
Gravels (2-6 mm) (%)	13.34

(source: FRIM Soil Management Department)

3.2.9 Growth performance measurements

The study in the field was done for 44 months from 2007-2011. The growth measurements of height and diameter of chengal saplings were measured at the 1st, 5th, 8th, 12th, 15th, 22nd, 33rd and 44th month after planting in the field. Zero (0) month data of chengal stocks during transplanting were not included because the height and diameter were at average size. Initial height and diameter measurement of chengal potted seedlings before planting were not done because the height and diameter would be affected due to planting depth and the way the soil was covered during planting. Therefore, the initial reading for growth were fixed to 1 month after planting. A height pole was used to measure height of the saplings from the base of the stem to the highest shoot. A caliper was used to measure the basal diameter at 10 cm from the base.

3.2.10 Statistical analysis and interpretation for nursery and field

The statistical analysis used for the analysis of both data in the nursery and field was Statistical Package for the Social Sciences (SPSS). RCBD was used as the experimental design for both nursery and field establishment. Post hoc multiple comparisons were run to analyse all possible tests of factors. Therefore, to determine the significant interaction effect between the treatments given, two-way analysis of variance (ANOVA) and Generalized linear model (GLM) was opted for both nursery and field data analysis. A two-way ANOVA is an appropriate analysis method for this study with a quantitative outcome and two (or more) categorical explanatory variables. All data collected were tested for normality. The value of Skewness and Kurtosis determined were divided with the standard error. The data value which falls within ± 2 is considered to be normally distributed. In nursery, the growth performance of height and Generalized linear model (GLM) to test the significant difference of light and and diameter were analysed by month using two-way analysis of variance (ANOVA) fertilizer treatments on the growth parameters. As for the light and fertilizer effect on growth parameters, the Least significant difference (LSD) and Waller-Duncan's Multiple Range Test (DMRT) under GLM were used.

In the field, the Least Significant Difference (LSD) and Waller-Duncan's Multiple Range Test (DMRT) under GLM were used for the fertilizer effect on growth parameters. Meanwhile for age treatment, post hoc comparison test could not be performed since there are only two independent variables. Therefore, only the mean values were compared and the significant levels can be made based on ANOVA.

3.3 Results

3.3.1 Nursery experiments

3.3.1.1 Survival rate

Assessment of the survival rate included all the seedlings in the nursery. The survival rate of the chengal seedlings were 100% throughout the first 12 months of growth (Table 3.5). Since the seedlings were well maintained in the nursery, the survival rate was as expected. The maintenance of the seedlings included proper watering twice daily and organized fertilizing.

Table 3.5: The survival rate of chengal seedlings in the nursery

Month	Survival rate (%)
1	100
6	100
9	100
12	100

3.3.1.2 Growth performance of chengal seedlings

The analyses of variance on potted chengal seedlings in the nursery shows that light and fertilizer treatments had a significant effect on height and diameter (Table 3.6). Interactions between both light and fertilizer treatment also recorded significant effect on height and diameter increment at $p<0.05$. Mean height and diameter regardless of light and fertilizer treatment recorded an increment from the 1st to the 12th month. Growth was exponential with height and diameter trend showing $y= 15.24e^{0.3027x}$ (R^2= 0.94) and $y=3.3727e^{0.1537x}$ (R^2=0.97), respectively (Figures 3.10 and 3.11).

Table 3.6 : Analysis of variance for growth performance of chengal seedlings under light and fertilizer treatment

Month	Source of variance	df	F-value[1]	
			Height (cm)	Diameter (mm)
1 month	LIGHT	2	9073.02*	6072.86*
	FERTILIZER	1	8340.07*	6041.18*
	LIGHT*FERTILIZER	2	336.31*	127.52*
6 month	LIGHT	2	12824.62*	16417.84*
	FERTILIZER	1	21713.24*	20195.11*
	LIGHT*FERTILIZER	2	1704.12*	749.44*
9 month	LIGHT	2	5396.32*	4457.85*
	FERTILIZER	1	33418.02*	24167.38*
	LIGHT*FERTILIZER	2	615.03*	346.99*
12 month	LIGHT	2	15401.85*	3058.87*
	FERTILIZER	1	93224.98*	33100.02*
	LIGHT*FERTILIZER	2	514.34*	125.25*

** significant at p < 0.05*

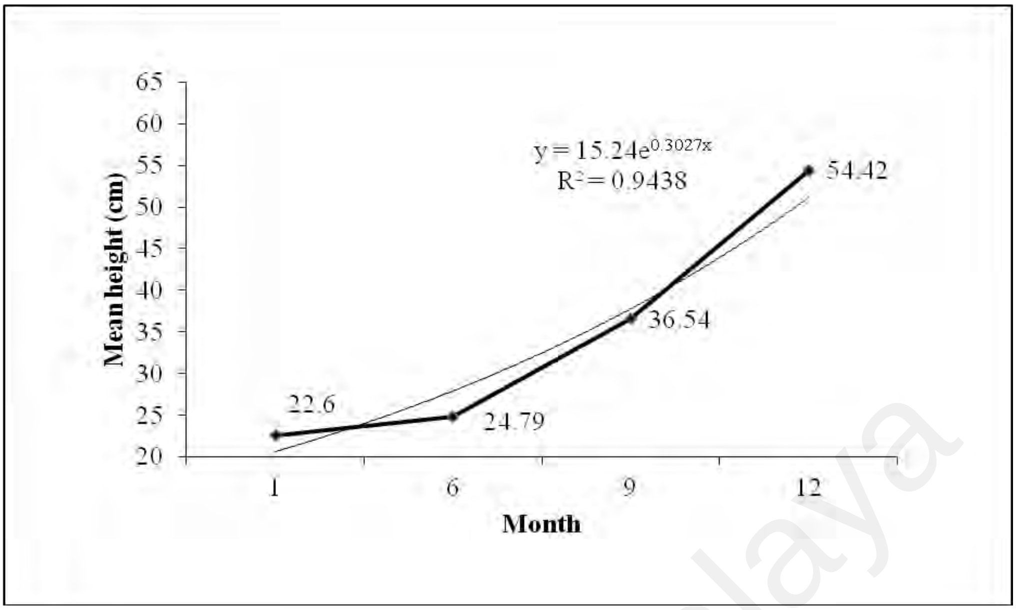


Figure 3.10: Mean height of chengal potted seedlings regardless of light and fertilizer treatment in nursery (n = 720 for each month)

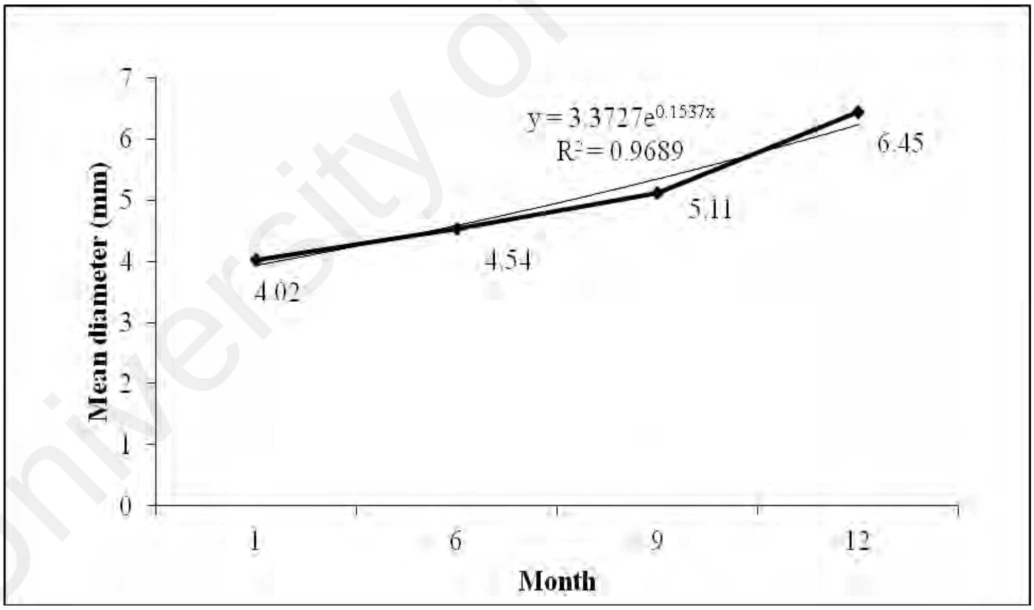


Figure 3.11: Mean diameter of chengal potted seedlings regardless of light and fertilizer treatment in nursery (n = 720 for each month)

3.3.1.3 Growth performance under different light and fertilizer treatment

Chengal seedlings grown under different light treatments recorded a significant increment in height and diameter (Table 3.7). Seedlings exposed to 50% light intensity (LI) showed the highest height and diameter after 12 months in the nursery. Seedlings grown under 30% and 100% light intensities similarly recorded increments, but the mean value of growth was much lower compared to seedlings under 50% light intensity treatment, with growth under 100% light intensity registering the lowest of growth performance in terms of height and diameter. The increment in height from the 1st to the 12th months were 58.2, 57.6 and 60.0 % and in diameter 59.7, 37.3 and 38.4 % under 30, 50 and 100 % LI, respectively. After 12 months, seedlings under 50% LI recorded greater height by 12.2 and 25.3 % and diameter by 6.0 and 12.7 % compared to seedlings under 30 and 100 % LI, respectively.

Height and diameter of chengal seedlings treated with different fertilizer treatments recorded significant increments compared to the control (Table 3.8). NPK Blue fertilizer recorded the highest mean throughout the first 12 months compared to organic fertilizer, followed by control. The increment in both height and diameter of the seedlings were 61.8, 62.9 and 42.6 % and 42.5, 42.4 and 23.3 % under NPK Blue, organic fertilizer and control treatment, respectively. At 12 months, the height of the potted seedlings given NPK Blue was 4.5 and 52.3 % higher and diameter of 3.9 and 35.3 % greater, compared to organic fertilizer and control treatments, respectively.

Table 3.7: Height and diameter of chengal seedlings in the nursery under different light treatments

Month	Light treatment	Height (cm)	Diameter (mm)
1 month	30%	22.82 ± 2.54 **b**	4.05 ± 0.20 **b**
	50%	26.37 ± 4.28 **a**	4.31 ± 0.32 **a**
	100%	18.54 ± 2.67 **c**	3.70 ± 0.24 **c**
	Mean	22.58 ± 4.57	4.02 ± 0.36
6 month	30%	24.44 ± 4.70 **b**	4.55 ± 0.43 **b**
	50%	29.49 ± 7.23 **a**	5.03 ± 0.59 **a**
	100%	20.46 ± 2.71 **c**	4.05 ± 0.33 **c**
	Mean	24.79 ± 6.39	4.54 ± 0.61
9 month	30%	36.47 ± 9.64 **b**	5.12 ± 0.65 **b**
	50%	41.20 ± 11.56 **a**	5.45 ± 0.80 **a**
	100%	31.94 ± 7.24 **c**	4.76 ± 0.54 **c**
	Mean	36.54 ± 10.34	5.11 ± 0.73
12 month	30%	54.65 ± 16.15 **b**	6.47 ± 1.19 **b**
	50%	62.20 ± 17.9 **a**	6.88 ± 1.30 **a**
	100%	46.47 ± 13.82 **c**	6.01 ± 1.06 c
	Mean	54.42 ± 17.25	6.45 ± 1.23

Mean values ± SD, * means in each column not sharing same letter is significant at $p < 0.05$ with $n = 720$ for each month

Table 3.8: Height and diameter of chengal seedlings in the nursery under different fertilizer treatments

Month	Fertilizer	Height (cm)	Diameter (mm)
1 month	NPK Blue	25.61 ± 3.70 **a**	4.27 ± 0.27 **a**
	Organic	23.76 ± 3.83 **b**	4.11 ± 0.29 **b**
	Control	18.19 ± 2.45 **c**	3.68 ± 0.22 **c**
	Mean	22.58 ± 4.57	4.02 ± 0.36
6 month	NPK Blue	29.48 ± 5.29 **a**	4.99 ± 0.49 **a**
	Organic	26.73 ± 4.90 **b**	4.70 ± 0.48 **b**
	Control	18.37 ± 1.06 **c**	3.94 ± 0.23 **c**
	Mean	24.80 ± 6.39	4.54 ± 0.61
9 month	NPK Blue	44.67 ± 5.03 **a**	5.68 ± 0.35 **a**
	Organic	41.59 ± 5.25 **b**	5.47 ± 0.38 **b**
	Control	23.35 ± 1.30 **c**	4.19 ± 0.14 **c**
	Mean	36.54 ± 10.33	5.11 ± 0.73
12 month	NPK Blue	67.09 ± 7.93 **a**	7.42 ± 0.41 **a**
	Organic	64.08 ± 7.48 **b**	7.13 ± 0.46 **b**
	Control	32.00 ± 4.15 **c**	4.80 ± 0.24 **c**
	Mean	54.42 ± 17.25	6.45 ± 1.23

Mean values ± SD, * means in each column not sharing same letter is significant at $p < 0.05$ with $n = 720$ for each month

3.3.2 Field experiment

3.3.2.1 Survival rate under different age group and fertilizer regimes

It was observed that age of planting stock and fertilizer application affected the survival rate throughout the planting period (Tables 3.9 and 3.10). The survival rate of chengal stands also varied according to age and fertilizer treatments (Table 3.11). After 44 months of planting in the field, the survival rate decreased gradually by 10.8 %. It was observed that the survival rate of the bigger sized chengal stands, aged 1y 8 m, was higher compared to the smaller and younger chengal stands of 6 m, from the 5^{th} to the 44^{th} month with decrement percentage of 7.9 and 14.3 % respectively. After 44 months, the 1 y 8 m chengal stands survival rate was 8.0 % higher compared to the 6 m old chengal stands. The results indicated that the mortality rates of the larger seedling were lower compared to the smaller ones.

Chengal stands fertilized with the combination of SRF + organic fertilizer recorded a higher survival rate compared to chengal seedlings applied with SRF only while the lowest was observed in seedlings given only organic fertilizer. The survival decrement of chengal stands decreased throughout the planting were 11.3, 14.4 and 9.5 % under SRF, organic and the combination of SRF and organic fertilizer treatments respectively. Seedlings fertilized with the combination fertilizer recorded 2.0 and 6.6 % greater survival rates compared to those given organic and SRF singly after 44 months in the field.

Table 3.9: Mean survival (%) by age treatment

Month	Age of planting stock	
	1y8m	6m
5	100.0	99.0
8	99.1	94.3
12	98.3	91.0
15	98.2	90.3
22	96.7	90.1
33	94.2	86.9
44	92.1	84.8

Table 3.10: Mean survival (%) by fertilizer treatment

Month	Fertilizer treatment		
	SRF	Organic	SRF + Organic
5	100.0	98.7	100.0
8	96.8	95.0	98.2
12	94.9	92.1	97.0
15	94.3	91.9	96.5
22	92.7	91.1	90.9
33	90.9	88.0	92.0
44	88.7	84.5	90.5

Table 3.11: Mean survival (%) under the interaction between age and fertilizer

Month	Survival (%)
5	99.5
8	96.7
12	94.7
15	94.3
22	93.5
33	90.5
44	88.8

3.3.2.2 Effect of age and fertilizer treatment on the growth performance of chengal seedlings

The analyses of variance on growth performance of chengal stands based on height and diameter were significantly affected by age and fertilizer treatment. Interactions between both age and fertilizer also indicated a significant difference at $p < 0.05$ in height and diameter increment (Table 3.12). The increments for growth parameters were significant for all the months recorded. Mean height and diameter regardless of age and fertilizer treatment recorded an increment of 67.2 and 66.0 % throughout the 44 months of planting in the field (Figures 3.12 and 3.13). The height and diameter growth trend of chengal stands in the field was exponential. (Figures 3.14 and 3.15).

Table 3.12 : Summary of ANOVA for growth performance of chengal seedlings under different age and fertilizer treatments

Source of variance	df	F-value[1]	
		Height (cm)	Diameter (mm)
BLOCK	2	2.47ns	0.54ns
AGE	1	160756.55*	38030.57*
FERTILIZER	2	95336.43*	21882.76*
BLOCK*AGE*FERTILIZER	4	1.69ns	1.48ns
AGE*FERTILIZER	2	11845.52*	2716.78*

* *significant at $p < 0.05$*

Figure 3.12 : Chengal plot establishment at (a & b): 0 month , (c): 12 months, (d): 22 months, (e): 33 months, and (f): 44 months after planting

Figure 3.13 : Chengal seedlings and sapling at (a): 0 month, (b): 12 months, (c) : 33 months, and (d): 44 months after planting

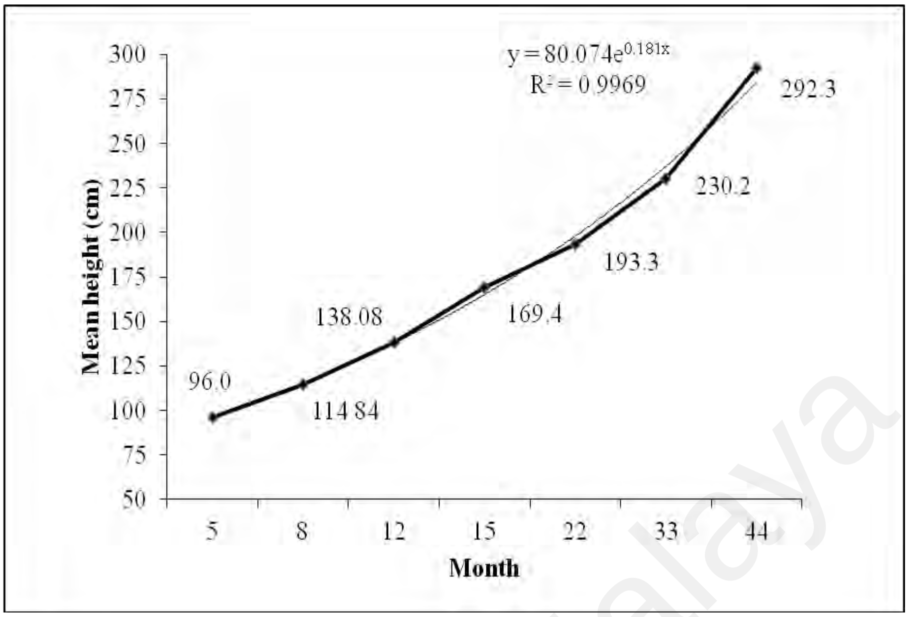


Figure 3.14 : Monthly mean height of chengal planted in Tekai FR

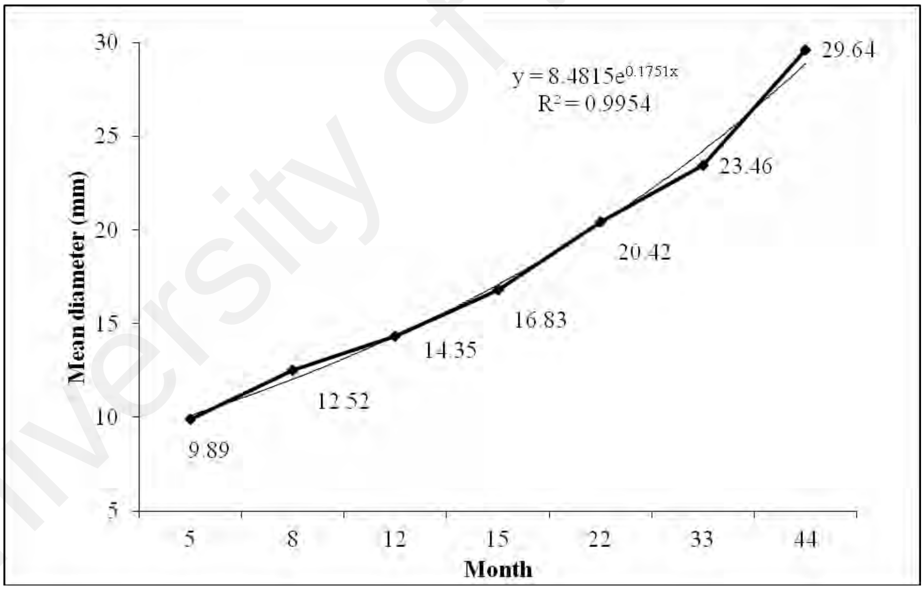


Figure 3.15 : Monthly mean diameter of chengal planted in Tekai FR

Mean height and diameter of chengal stands according to the two different age of planting stocks recorded a significant increment at $p<0.05$ throughout the planting period in the field (Table 3.13). The 1y 8m stands exhibited a higher mean height and diameter compared to the 6m old stands after 44 months of planting. Seedlings height and diameter increased gradually by 67.3 and 68.0 % and 66.1 and 67.0 % after 44 months for both 1 y 8 m and 6 m stands, respectively.

Chengal seedlings treated with different fertilizer treatments recorded a significant increase in mean height and diameter (Table 3.14). Application of SRF + organic fertilizer recorded the highest mean throughout planting followed by SRF while the lowest mean was observed in seedlings applied with only organic fertilizer. Growth in height and diameter from the 5th to the 44th months increased by 67.9, 64.7 and 68.6 % and 67.1, 63.3 and 68.9 % under SRF singly, organic singly and the combination of fertilizer treatments respectively. After 44 months, the height and diameter of chengal stands given the combination of fertilizer (SRF and organic fertilizer) were higher by 3.9 and 14.6 % for height and 6.1 and 17.9 % for diameter compared to stands applied with SRF singly and organic fertilizer singly. The stands given the combination fertilizer also recorded 4% and 14.6% greater height compared to those treated with SRF and organic fertilizer respectively, after 44 months. With regard to diameter, stands treated with the combination of fertilizers recorded 6% and 18% higher compared to SRF and organic fertilizer treated stands.

Table 3.13: Mean height and diameter of chengal seedlings in the field according to different age groups

Month	Age	Height (cm)	Diameter (mm)
5 month			
	1y 8m	99.77±1.28	10.39±0.14
	6 m	92.17±2.85	9.39±0.19
	Mean	95.97±4.39	9.89±0.52
8 month			
	1y 8m	118.34±4.97	12.97±0.46
	6 m	111.41±4.74	12.08±0.42
	Mean	114.84±5.91	12.52±0.62
12 month			
	1y 8m	143.20±3.86	15.06±0.53
	6 m	132.88±3.51	13.64±0.30
	Mean	138.08±6.30	14.35±0.83
15 month			
	1y 8m	175.45±11.84	17.25±0.98
	6 m	163.47±2.27	16.43±0.36
	Mean	169.40±10.27	16.83±0.84
22 month	1y 8m	191.93±9.02	21.20±1.16
	6 m	174.38±3.83	19.55±0.65
	Mean	193.32±11.18	20.42±1.25
33 month	1y 8m	239.40±20.61	24.77±1.70
	6 m	219.82±7.82	22.01±1.05
	Mean	230.16±18.55	23.46±1.98
44 month	1y 8m	305.18±25.27	30.68±2.88
	6m	287.09±13.20	28.49±2.09
	Mean	292.26±24.60	29.64±2.77

Mean values ± SD with n = 720 for each month

Table 3.14 : Mean height and diameter of chengal seedlings in the field according to different fertilizer treatments

Month	Fertilizer	Height (cm)	Diameter (mm)
5 month			
	SRF	96.18 ±2.78 **b**	9.96 ±0.49 **b**
	Organic	93.94 ±5.27 **c**	9.70 ±0.53 **c**
	SRF + Organic	97.89 ±3.77 **a**	10.02 ±0.48 **a**
	Mean	95.97±4.39	9.89±0.52
8 month			
	SRF	116.22 ±1.67 **b**	12.37 ±0.60 **b**
	Organic	108.85 ±3.92 **c**	12.19 ±0.41 **c**
	SRF + Organic	119.89 ±4.98 **a**	13.05 ±0.49 **a**
	Mean	114.84±5.91	12.52±0.62
12 month			
	SRF	138.62 ±4.03 **b**	14.20 ±0.71 **b**
	Organic	133.82 ±5.52 **c**	14.09 ±0.64 **c**
	SRF + Organic	141.95 ±6.38 **a**	14.79 ±0.95 **a**
	Mean	138.08±6.31	14.35±0.83
15 month			
	SRF	172.71 ±9.98 **b**	16.48 ±0.28 **b**
	Organic	160.19 ±1.89 **c**	16.28 ±0.18 **c**
	SRF + Organic	175.29 ±90.12 **a**	17.76 ±0.87 **a**
	Mean	169.40±10.27	16.83 ±0.84
22 month			
	SRF	184.87 ±12.58 **b**	20.13 ±0.42 **b**
	Organic	175.18 ±4.49 **c**	19.55 ±0.82 **c**
	SRF + Organic	189.22 ±9.57 **a**	21.49 ±1.36 **a**
	Mean	183.32±11.18	20.42±1.25
33 month			
	SRF	234.00 ±13.27 **b**	23.46 ±0.83 **b**
	Organic	210.57 ±1.84 **c**	21.84 ±1.25 **c**
	SRF + Organic	244.65 ±15.51 **a**	24.95 ±2.15 **a**
	Mean	230.16±18.55	23.46±1.99
44 month			
	SRF	299.42 ±13.38 **b**	30.25 ±0.48 **b**
	Organic	265.99 ±6.22 **c**	26.45 ±0.85 **c**
	SRF + Organic	311.48 ±21.39 **a**	32.23 ±2.09 **a**
	Mean	292.26±24.58	29.64±2.77

*Mean values ± SD, * means in each column not sharing same letter is significant at p < 0.05 with n = 720 for each month*

3.4 Discussion

3.4.1 Effect of different light and fertilizer treatments on the growth of chengal seedlings in the nursery

This study has shown that the survival rate of chengal seedlings in the nursery was exceptionally high, achieving 100% survival. This indicated that all the chengal seedlings were well raised in the nursery (Table 3.5). Furthermore, the different light and fertilizer treatments had no negative impact on the survival of the seedlings in the nursery. However, the results of the growth performance suggest clearly that the height and diameter of the pot grown chengal species differed significantly under the different light and fertilizer treatments. The mean height and diameter of the potted seedlings at 12 months after sowing was 54.2 cm and 6.45 mm, respectively (Figure 3.10 and 3.11). These values are considered high for chengal seedlings which are known to have a relatively slow growth rate compared to other medium and fast growing dipterocarps, namely the *Shorea* and *Hopea* species. A joint research carried out by Malaysia and the International Tropical Timber Organisation (ITT0) in 2006, found that the standard average height and diameter recommended for the planting of *Shorea leprosula* and *Shorea macroptera* in the field were 30-45 cm and 6.8-7.4 mm and 31.-48 cm and 0.54 - 0.78 mm, respectively. Amongst others, Turjaman et al. (2006) reported *Shorea seminis* recorded an average mean height of 26.26 cm after 7 months of potting regardless of any fertilizer application and light treatment. This indicated that the height and diameter of the chengal seedlings in this study were above the acceptable standard.

Sunlight exposure of 50% increased the mean height and diameter of the seedlings compared to 30% and 100% LI at all months. After 12 months of sowing, the highest mean height and diameter under 50% sunlight was higher by 12% compared to

30% sunlight and higher by 25.3% compared to 100% sunlight (Table 3.7). This showed that the species was shade tolerant and optimized its growth under partial shade during the early stages of growth. Potted chengal seedlings are usually raised in the nursery for about one to two years before it is planted in the field. Therefore, it can be concluded that 50% sunlight is the best light exposure that is optimum for chengal growth in the nursery. Similar findings were reported by Paine et al. (2012) and Chaudhry (2001), who observed that shading is a common cultural practice in nurseries that can influence seedling quality. Given the prevalent semi-arid to arid environmental conditions, some shading is essential, particularly during the initial stages of seedling development. Their studies showed that the survival rate of dipterocarp seedlings increased with a decrease in shade intensity of 50%. Shade intensities and species, varied significantly with respect to percent survival after the 20^{th} week of study. They observed that no shade and 50% shade treatments were significantly better than full shade (100% shade) with regard to survival, height and diameter growth. All the species exhibited maximum height and diameter under half shade (50% light intensity) treatment followed by no shade treatment. These results showed that seedlings of dipterocarps require moderate shade for their best growth. A study by Chanhsamone et al. (2012), also observed that the mean diameter for *Hopea odorata* was significantly higher under moderate light conditions (50-70% light). Height was significantly affected by the different light intensity treatment used for the species tested. This means that 50-70% light intensity is the optimum amount needed by the plant species to survive and to obtain good performance in the nursery or field. The presence of optimum light can have a direct bearing on the plant's rate of growth. A plant's most natural habitat provides the intensity of light needed for optimal growth.

This result is also supported by reports from Kenzo et al. (2011), who observed that chengal seedlings showed greater growth under relatively shaded conditions. The heights of the seedlings were greater under partial light conditions compared to seedlings under large or closed canopy conditions. The best and favourable growth conditions for chengal under partial light can be related to its leaf eco-physiological traits such as maximum photosynthetic rate (A_{max}) and ratio of variable maximum fluorescence (Fv/Fm). In this study, chengal showed higher A_{max} under relatively shaded conditions (35 - 50) % LI. The Fv/Fm values recorded also showed a significant decrease with increasing canopy openness. The lower maximum fluorescence values of the chengal leaves indicate that this species may suffer from chronic photoinhibition, due to strong sunlight under high canopy openness (Kitao et al., 2006). These responses showed that chengal could be categorized as low producers of photosynthesis and is less tolerant to photoinhibition under strong light conditions, even for new leaves that have expanded in the nursery or after planting.

The use of NPK Blue fertilizer resulted in a significant increment in height and diameter of the seedlings compared to the use of organic fertilizer and control at the first, sixth, ninth and 12th month of growth. After 12 months, the mean height and diameter of chengal seedlings applied with NPK Blue fertilizer increased by about 4.5% compared to seedlings under organic fertilizer treatment and increased by 52.3% compared to seedlings without any fertilizer treatment (control), (Table 3.8). This indicated that, NPK Blue fertilizer had a better impact on the growth performance of chengal potted seedlings compared to organic fertilizer and control. These results could be due to the fact that NPK Blue has a higher percentage and content of nitrogen by nearly 42% and phosphorus 50% compared to organic fertilizer. Therefore, it could be concluded that nutrient uptake in seedlings fertilized with higher concentrations of nutrients was greater compared to those fertilized with lower nutrient fertilizers, provided that there was no leaching of soil during potting or raining. It has been reported previously that phosphorus applied to potted seedlings had a significant positive effect on seedling performance following out-planting, in two dipterocarp species in Peninsular Malaysia (Turner et al., 2001; Raja Barizan et al., 2000; Nussbaum et al., 1995). A healthy seedling, however, must be well supplied with all the macro and micro-nutrients in proper proportions (Afa et al., 2011). If a given nutrient is deficient, seedlings may compensate to some extent by increasing their capacity to take up the deficient ion (Afa et al., 2011).

Similar results were reported on the growth performance of timber seedlings by Feng et al. (2008) and Bungard et al. (2000). The results of this study also concur with the findings of Aminah et al. (2013), where the dipterocarp seedlings fertilized with NPK blue fertilizer showed significantly better height and diameter increments than those not fertilized. Her study indicated that application of nutrients is important for healthy growth of stock plants. However, the required optimal amount of fertilizer of stock plants should be determined for producing fit and best quality of planting stocks. Application of too much fertilizer would affect the survival of stock plants as indicated in experiments with *Dyera costulata* where their survival percentage was significantly reduced (Aminah & Lokmal, 2002). Differences in response to fertilizers, by the different dipterocarp species, cannot be simply attributed to the amount or type of fertilizer added, but is also probably a result of the different levels of light intensities required by the different species.

Islam et al. (2014) amongst others, reported that improving the fertility of nursery soils is essential to guarantee the production of high quality planting stocks.

Most tropical soils and forest soils are deficient in nitrogen and phosphorus and uptake of these nutrients in limited quantities by plant roots from forest litter is difficult (Sayer et al., 2011; Lawrence et al., 1999). Therefore, inadequate management of nursery soil can result in depletion of site fertility and reduction in seedling growth (Sayer et al., 2012; Hoque et al., 2004; Ang & Maruyama, 1993).

3.4.2 Growth performance by fertilizer and age treatment in the field

3.4.2.1 Survival

The survival rate of chengal seedlings planted in the field was high with an 88% survival percentage. This percentage is considered acceptable and higher compared to other reported planted dipterocarp species in logged over forest (Table 3.9). The survival percentage of chengal planted using improved planting techniques proved that the survival of dipterocarp seedlings can be increased and improved compared to those planted using the conventional method. A study by Widiyatno et al. (2014) on early performance of 23 dipterocarp species planted in logged over forest using conventional method recorded only a 70% survival rate after 6.5 years of planting. The species planted included namely *Hopea, Shorea* and other *Dipterocarpus* species. The lower survival rates of dipterocarp seedlings were mainly due to dehydration in the location caused and also those species had not grown enough to tolerate direct sunlight by land clearing preparation on the site. Land clearing preparation in tropical rainforest will also increase water stress on planting seedling and relative light intensity (Kamo et al., 2009).

A small scale plantation of different ages of chengal planted named 'Multi-storied Forest Management in Chikus site, Perak recorded survival percentage of only 44%, 10 years after planting regardless of any treatment application (ITTO, 2002). Chengal in above mentioned plantation did not perform well mainly because the species could not compete with other fast-growing species namely *Shorea roxburghii, Artocarpus rigidus, Dryobalanops oblongifolia* and *Neolamarckia cadamba.* All other species spread well in the monsoon forest where it has a distinctive dry season. Hence, they have high drought tolerance and therefore showed high survival rates and good growth performance throughout trial sites.

Improved planting techniques can be seen as a boost for the survival of dipterocarps, especially for the chengal species, which is under the threat of extinction, as the species has a very slow growth and is shade tolerant. The techniques which takes into account the use of mechanized machine in creating larger planting holes has provided ample space for root growth, therefore, the plant could grow at an ideal rate provided that there were no drought stress or soil mineral deficiency. However, there are a few earlier studies involving enrichment planting of logged over forest which reported varied results. Affendi et al. (2009) reported that *Shorea leprosula* had a poor survival rate of 20.7% after 4 years of planting in a logged forest. The low survival rate could be due to the low adaptability of the species with site conditions such as water stress and soil poor nutrient. In degraded forests and in open areas, a combination of increased run-off and higher light levels may lead to increased water stress on planted seedlings (Farrick & Branfireun, 2013; Malmer, 1992). Environmental factors such as weather condition, pest attack and animal distribution, planting technique, weed competition and poor soil condition which may lead to variation in survival rate and growth performance (Affendi et al., 2009).

In this study, the slow hardening process, which the seedlings went through for 3 months in the nursery, could be one of the reasons for the higher survival rate recorded for chengal stands planted in the field. During the hardening period, the seedlings were protected from the shock of sudden exposure to full sunlight and enabled the seedlings to acclimatise better to the new environment in the forest.

The effect of age on the survival rate of the planted chengal (Table 3.10) showed that the average mean of survival percentage was 92.0% and 84.8% for 1 y 8 m and 6 m old seedlings, respectively, after 44 months of planting. The older stands of 1y 8m showed a higher survival percentage compared to 6 m old stands. This is probably due to the fact that the 6 m chengal, which has an initial height smaller than the older 1y 8m old seedlings, had not grown enough to be able to tolerate direct sunlight. The smaller stands were also susceptible to damage by fallen branches from the canopy over them, which can break trample and kill them.

The average mean survival percentage for chengal under different fertilizer treatment were 88.7%, 84.5% and 90.5% for SRF, organic fertilizer and the combination of SRF + organic fertilizer, respectively at the 44th month (Table 3.11). Previous studies have shown that the application of nutrients showed a higher survival rate compared to non-fertilized seedlings (Juliana et al., 2009). Species vary in nutrient requirements and the demand for a particular element or nutrient depends upon the growth requirements of the species. Nutrient requirements for species also differ with environmental conditions (Pinkard et al., 2007; Groves & Keraitis, 1976). It has been suggested that in cases where a particular nutrient is limited in a forest, seedlings may forage with their root to some extent to compensate for the deficiency or pick up the element from the atmosphere through leaf pores or stomata (Afa et al., 2011; Hoque et al., 2004; Islam et al., 2004).

3.4.2.2 Growth performance

The growth performance of chengal stands based on height and diameter were significantly affected by age and fertilizer. The mean value for both height and diameter increased gradually for all months. Improved planting techniques which put a high emphasis on selecting only quality and fit saplings with the application of slow release fertilizer have contributed to the significant increment of growth performance of planted chengal stands. The MAI of chengal with regard to height and diameter recorded an average mean of 60.4 cm year $^{-1}$ and 6.07 mm year $^{-1}$ (Figures 3.14 and 3.15). These mean values are considered moderate and acceptable for a heavy hardwood and slow growing species, since other dipterocarp species which are mainly fast growing species, such as *Hopea* and *Shorea* species, record values comparable to the values observed in the chengal stands in this study (Okuda et al., 2013).

A study carried out by Safa et al. (2004) on enrichment planting, showed better growth rate, with greater height and diameter increments in dipterocarp seedlings, in selected plots that were all more than 24 years old. The areas under study were planted with indigenous species such as meranti rambai daun (*Shorea accuminata*), meranti tembaga (*Shorea leprosula*), meranti sarang punai (*Shorea parvifolia*), chengal (*Neobalanocarpus heimii*), kapur (*Dryobalanops aromatica*) and keladan (*Dryobalanops oblongifolia*) with the help of the Forestry Department. The growth of the trees was better, although some trees failed to survive due to natural courses. These findings were also supported by Hamzah et al. (2009) on a degraded forest in Pasoh

Forest Reserve. After six years of planting using conventional methods in open area, the MAI recorded for height and diameter for *Neobalanocarpus heimii* was 57.0 cm year^{-1} and 6.1 mm year^{-1}, while for *Dryobalanops aromatica,* it measured 43.0 cm year^{-1} and 4.1 mm year^{-1} respectively. The lower rates of these two species by 14.0 cm year^{-1} and 2.0 mm year^{-1} compared to chengal planted in our study, were because their seedlings were planted conventionally (small planting holes of 25 cm of depth and width and with only rock phospate fertilizer).

3.4.2.3 Age

This study has shown that the older chengal 1y 8 m seedlings performed significantly better than the 6 m old chengal in terms of height and of diameter increment (Table 3.13). However, a general recommendation on the age of planting stock most suitable for field planting is not possible, considering the great variation in the early development of the different species especially chengal. In order to minimize early tendings following planting, larger seedlings are generally preferable. Since improved planting techniques does not require frequent, repeated returns to the forests for silvicultural treatments, bigger and older chengal are best suited to be planted and this can be seen in the highest mean increment in height and diameter displayed by the older seedlings. The older seedlings could withstand intensive weed growth compared to the 6 m old stands. To reduce the amount of weeding, it is preferable to plant seedlings which are large enough to overcome weed competition at an early stage.

To date, not many studies have been done on the effect of age and size on the growth rate. Nevertheless, a few studies have been reported by Philipson (2009), Yamada et al. (2014), Shaharuddin (2011), Skarpe & Hester (2008), Raja Barizan

(1998) and Hogson & Eggers (1937). Some of them concurred with the use of bigger seedlings for planting in the field (Philipson, 2009; Yamada et al., 2014; Shaharuddin, 2011; Raja Barizan, 1998) while others recommended smaller seedlings to be planted in the field (Skarpe & Hester, 2008; Hogson, 1937). Earlier studies in the 1930's, has shown that one year old stock (big and old) of many species, for example, *Dryobalanops aromatica, Shorea leprosula, Shorea pauciflora, Heritiera* spp. and *Pentace* spp. performed poorly, while those of *Gmelina arborea, Koompassia malaccensis and Dipterocarpus baudii* exhibited good survival rate (Hogson, 1937). The overall indications then (before 90s') were that younger seedlings, three to eight months old, survive better than older seedlings. On the other hand, Shaharudin (2011) proposed the use of bigger 1.5-2.0 m tall planting stocks for economic and handling purposes. His study was also supported by the work of Raja Barizan (1998) in Berkelah Forest Reserve, where larger *Hopea ordorata* seedlings showed higher significant increments and a better survival rate over smaller seedlings. In her study, seedlings were planted under few different categories of large gap with less compacted soil, large gap with compacted soil, partially shaded area (30-40%) LI, and closed canopy with other natural dipterocarp saplings. The results led to a greater increment of growth for larger seedlings due to those larger seedlings received adequate light under all categories mentioned above. Small seedlings received extremely low light and were shadowed by other bigger saplings in the forest.

3.4.2.4 Fertilizer

Fertilizing chengal seedlings significantly increased growth in both height and diameter regardless of age (Table 3.14). The mean value of these growth parameters varied significantly for all months. The results also showed that the application of the combination of SRF and organic fertilizers contributed to a higher mean value compared to the application of only SRF and organic fertilizer separately. The combined nutrient content of SRF, which consisted of higher ratio of nitrogen:phosphorus:potassium (19:10:13) % and goat dung contains 11:5:11% which were much higher compared to the fertilizers applied singly and this contributed to the highest increment for height and diameter observed in seedlings treated with the combination of fertilizers. Therefore, an addition of extra nutrients could improve the growth performance of chengal stands in logged-over forest. The application of only SRF and only organic fertilizer resulted in lower mean increment for both height and diameter. It has been well documented in the literature that nitrogen plays an important role as a major constitutent of chlorophyll, amino acids and nucleic acids, amongst many other cellular components and the same goes for phosphorous which is an important constituent of the enrgy currency of the cell, ATP and nucleic acids too. In photosynthesis, potassium regulates the opening and closing of stomata, and therefore regulates CO_2 uptake. Potassium also triggers activation of enzymes and is essential for production of ATP.

Afa et al. (2011) reported similar observations in their study with *Khaya ivorensis* seedlings, which recorded the highest growth increments when the fertilizers were combined than when fertilizers were applied singly. Feng et al. (2008) and Bungard et al. (2000) suggested that the extra nutrients (N and P) could increase the growth rates of seedlings in a tropical rainforest given optimum light exposure (canopy gap). N and P stimulated growth have been shown to result in greater foliar N and P concentration (Feng, 2008; Bungard et al., 2000). Furthermore they observed that, the high N and P were also accompanied by a stimulation in the light saturation rate of photosynthesis. Therefore, it was proposed that the seedlings were more responsive to growth when higher N and P were available in the leaves.

The right and optimum amount of fertilizer application is also crucial in enhancing the growth of dipterocarp seedlings as the application of large doses of certain nutrients, especially phosphorus, can cause toxicity to the seedlings. since absorption of this element can affect regular metabolic processes, such as the uptake of other important minerals from the soil, and cell differentiation and multiplication (Lee & Jose, 2003). In this study, the best growth increment in the presence of the combination of fertilizers of SRF (200 g) and organic fertilizer (200 g) has shown that the amount of fertilizer applied for the chengal stands were optimum and ideal for improving the growth performance in a logged over forest, which has very low soil fertility, are heavily compacted and are log-landing sites with no topsoil.

3.5 Conclusion

Raising chengal seedlings in the nursery under different light and fertilizer treatments and later planting chengal stands of different age group and fertilizer application in logged-over forest gave significant results on its survival and growth performance. In the nursery, chengal seedlings fertilized with 10g of NPK Blue fertilizer monthly treated under 50% light intensity exhibited highest growth in terms of survival, height and diameter after 12 months. Comparatively, 1y 8m stands applied with combination fertilizer of 200g slow release fertilizer and 200g of organic fertilizer showed greater survival as well as growth of height and diameter throughout 44 months after planting. The techniques used in planting which has been improved especially on the usage of semi-mechanized machine for creating bigger planting holes and slow release fertilizer application as well as planting bigger planting stocks have proved that a slow growth and shade tolerant chengal species can be successfully established in logged-over forest. Other than that, studying the chengal species could be essential and more knowledge can be gained if this study is widen to relate the growth to its biomass and soil at the planting site. The relationship between biomass and growth and soil nutrient characterization under optimum light, fertilizer treatment and age of seedlings from nursery to field can be used as a basis for a successful establishment of chengal species in a logged degraded forest. Thus, the effect of fertilizer, light and age of chengal seedlings on the plant biomass and soil properties, from nursery to outplanting in the field, were investigated in the following chapter.

CHAPTER 4 : BIOMASS QUANTIFICATION AND SOIL CHARACTERIZATION OF CHENGAL SEEDLINGS FROM NURSERY TO FIELD UNDER DIFFERENT AGE, LIGHT AND FERTILIZER TREATMENTS

4.1 Introduction

Biomass of forests is defined as the total amount of aboveground living organic matter in trees expressed as oven-dry tons per unit area (hectare, region, or country). Forest biomass can be classified into aboveground biomass and belowground biomass. Aboveground biomass is the living biomass above the soil and includes stem, stump, branches, bark, seeds, and foliage. Belowground biomass is all the living biomass of roots. Whilst carbon stock is the carbon content expressed in per cent (%) in dry oven mass of certain component of forests (stem, branches, foliage and root).

Trees and woody biomass play an important role in the global carbon cycle. Forest biomass accounts for over 45% of terrestrial carbon stocks, with approximately 70% and 30% contained within the above and belowground biomass, respectively (Ngo et al., 2013; Mokany et al., 2006). An overview of recent forest carbon stocks in tropical regions is given elsewhere, where it is reported a total aboveground carbon (TAGC) estimate of 164–196 Mg ha^{-1} for Malaysia (Saner et al., 2012). As far as Malaysia is concerned, the majority of the carbon in the forest is stored in aboveground biomass and soil. Meanwhile, understorey trees namely trees with diameter of breast height (DBH) more than 1.0 cm and lower than 10 cm, contributes to (1.0- 3.0 %) of the total forest biomass (Ngo et al., 2013; Pinard & Putz, 1996), which also includes saplings from dipteorcarpaceae family. Dipterocarpaceae, the dominant tree family, contributed a large proportion of above ground biomass (AGB) in the primary forest. Little knowledge is known on understorey trees contribution towards forest biomass of seedlings especially of dipterocarp species. Planted trees in a logged over forest could increase the value of forest especially through the value of timber industry as well as the carbon stock value of the forest. Given 30-40 years, the timber trees that are planted, such as chengal could grow up to 40-50 cm DBH and this could definitely contribute to biomass and carbon stock of the forest. Ngo et al. (2013) reported in his study of the Bukit Timah Reserve, Singapore, that the top 10 species with above 30 cm DBH are made up of 46.3% total aboveground biomass in the primary forest and these are markedly *Shorea* and other dipterocarp species.

The proper application of commercial and organic fertilizers to forest nursery soils is considered important since it may profoundly influence the value of seedlings produced, optimize seedlings growth and indirectly increases the biomass production of those seedlings. The primary purpose of forest nurseries is to produce and supply quality seedlings to form new forests and re-forest overexploited forest stands (Afa et al., 2011). Improving the fertility of nursery soils is essential to guarantee the production of high quality seedlings for nursery establishment (Rahman et al., 2013; Islam et al., 2004).

Furthermore it has been documented that, nutrient deficiency and soil compaction have led to poor seedling establishment on degraded rainforest soils, in most places in Peninsular Malaysia as well as in Sabah and Sarawak (Feng et al., 2008; Bungard et al., 2000; Nussbaum et al., 1995). In lowland tropical dipterocarp forest, inadequate light and low availability of soil nutrients and moisture are the major constraints affecting seedling recruitment (Kettle, 2010). To successfully re-plant chengal into degraded environments, it is important to understand the site requirement for its regeneration and growth in a natural habitat. It is necessary to determine the best and optimum soil used for potting seedlings since production of good quality planting stocks are from the best condition of both light, soil and fertilizer application in the nursery.

Moreover, knowledge on the biomass production and the optimum soil nutrient requirements of chengal, which is known to have a slow growth, and is considered a heavy hardwood with a density of 0.76 gcm^{-3}, would be essential for this study. The relationship between biomass and growth and soil nutrient characterization under optimum light, fertilizer treatment and age of seedlings from nursery to field can then be used as a basis for a successful establishment of chengal species in a logged degraded forest. Along these lines, the study in this chapter has the following objectives; 1) to determine and quantify biomass using the destructive biomass method for chengal potted seedlings in the nursery under different light and fertilizer treatments, 2) to quantify biomass using an existing developed equation and the carbon stock of chengal seedlings planted in a logged over forest and 3) to determine soil mineral content and the physical characteristics of chengal seedlings in the nursery and field under different light, age and fertilizer treatments.

4.2 Methodology

4.2.1 Nursery establishment

The Forest Research Institute Malaysia (FRIM) nursery was chosen as the location for the nursery experiments (Chapter 3.1.3). A total of 720 chengal seedlings from Tembat Forest Reserve, Kenyir were used to establish the nursery at the Forest

Research Institute of Malaysia (FRIM). The experimental design is a Randomized Complete Block Design (RCBD) factoring; 3 light Intensity × 3 fertilizer × 2 harvest cycle × 40 seedlings (Chapter 3.2.3). Two biomass harvest cycles were conducted for all the seedlings, at the 6^{th} month and 12^{th} month after chengal potting.

4.2.2 Destructive biomass method

Biomass was determined using the destructive sampling method and all the chengal seedlings were harvested (100%). Data was collected at 6 months interval, at the 6th (harvest 1) and 12th month (harvest 2). The total leaf number were also counted at both harvest periods. Stems of seedlings were cut horizontally at the base to determine seedling height. Foliage was peeled from the wood fraction (stem and branches) and placed in labelled paper bags. A weighing machine was used to determine the fresh weight of the samples. The samples were then oven dried at 80ºC for 72 hours. The dry weight were then weighed and recorded. Before measuring the dry weight, samples were placed in a descicator containing silica gel for 1 hour to prevent gain in weight from humidity.

4.2.3 Determination of soil mineral content and soil physical properties in the nursery

The mineral content and physical properties of the soil, of potted chengal seedlings were determined at the Department of Laboratory of Soil Science, FRIM. For the nursery experiments, for each treatment, three soil samples of the chengal potted seedlings were sampled in plastic bags for mineral content and physical properties analysis. The soils were collected following the biomass harvesting cycles, at 6^{th} and 12^{th} month of establishment in the nursery. The soils from three polythene bags from each treatment were packed in plastic bags and sent to the soil laboratory for analysis. Analysis was carried out to determine the soil pH, the total nitrogen (N), organic carbon (C), the available Phosporus (P) and exchangeable K. Other nutrients such as Mg and Ca were not measured as these nutrients are considered secondary and while they are essential for tree development, their uptake is usually lower than that for the primary nutrients N, P, and K.

4.2.4 Determination of plant mineral and nutrient content in nursery

Mineral and nutrient analysis of chengal seedlings were carried out for all the seedlings in accordance to the biomass harvesting procedure. The seedlings were 100% harvested and separated into three parts consisting of roots, stem and leaves. All the separated parts were packed in an envelope and labeled according to treatment given and sent to the laboratory for mineral and nutrient analysis for total N, C, P and K.

4.2.5 Data analysis in nursery

The data collected were subjected to two-way analysis of variance (ANOVA) and Generalized linear model (GLM) to test the significant difference of light and fertilizer treatments on the biomass quantification, plant mineral and nutrient content and also on the soil mineral content and physical characteristics. As for the light and fertilizer effect on the parameters mentioned above, Least significant difference (LSD) and Waller-Duncan's Multiple Range Test (DMRT) under GLM were used. Pearson correlation analyses were used to explore the relationship between the growth parameters (data from Chapter 4), total dry weight, plant mineral content, soil mineral content and soil physical properties among and within the light and fertilizer treatments.

4.2.6 Field establishment

The Tekai Forest Reserve, located in Jerantut, central in the state of Pahang was the chosen site for the study. The study plot was located in Plot 4, Compartment 89B, in the Tekai Forest Reserve, Jerantut, Pahang (Figure 3.4), in (Chapters 3.3.4). The RCBD experimental design took into account the following**:** 2 age × 3 fertilizer treatment × 3 block × 30 seedlings**.** Details are in Chapter 3.2.8.2. Information on soil chemical characteristics and physical properties of the plot area before planting was done and obtained with the help of the Soil Management of FRIM (Table 3.3 and Table 3.4).

4.2.7 Determination of top soil nutrients in the field

A soil sampling technique, whereby five random points for each treatment in each block was carried out for top-soil nutrient analysis. This was to ensure adequate representation of the entire field. Sampling was taken at two depths, namely, 0-20 cm and 20-40 cm at the 22nd and 44th month of planting, as it has been documented that 80 to 90% of the nutrients taken up by the plant come from this tillage depth even though plants also obtain nutrients from lower depths. A soil auger was used to take the soil samples. Plant residues were scraped away before sampling started. The top soil of five random points at each block were then filled into a clean plastic bag and labelled. Plastic bags were used to avoid any contamination from trace metals. All three blocks representing all the treatments in the whole study plot were sampled. Soil samples were then sent to the FRIM soil laboratory for nutrient and physical properties analysis. Analysis was done to determine the soil pH, the total total N, C, P and K. Soil texture clay, sand and silt), cation exchange capacity (CEC) and pH value analyses were also done to determine the physical properties of the soil sample.

4.2.8 Determination of foliar nutrients in the field

Determination of foliar nutrients of chengal seedlings in the field were done by selecting ten mature leaves from the middle branch of the seedlings at the 22^{nd} and 44^{th} month of planting. Three plants from each treatments from each blocks were selected. All the leaves were weighed for fresh weights, packed in a clean plastic bag and labelled. Foliar samples were sent to the FRIM laboratory for oven drying and nutrient analysis. Analysis was then done to determine the total total N, C, P and K.

4.2.9 Data analysis for field experiments

The growth parameters data from the field (results from Chapter 3) were used for the purpose of biomass quantification in the field. The allometric equation model developed by Kirby & Potvin (2007) was used for converting saplings measures to above ground biomass in the forest. This model was developed for forest type for saplings above 1 cm and below 5 cm of basal diameter (BD).

Above ground biomass = exp [3.965 + 2.383 ln (BD)]

BD = basal diameter (cm)

The total root biomass was indirectly estimated as 24% of the above-ground biomass of trees above 1 cm BD (Niiyama et al., 2010; Kenzo et al., 2008; Jobbagy &

Jackson, 2000). As for carbon stock determination, the method in the guidelines established by the Intergovernmental Panel of Climate Change (IPCC) in 2006 was used. Carbon stock was calculated and estimated as 47% of the above ground biomass of individual trees. The total dry weight of individual seedlings recorded were then multipled with 0.47 to give the carbon stocks.

The paramaters for biomass, soil mineral nutrient and soil physical characteristics were analysed using two ANOVA and GLM to test the significant difference of light and age treatments on the growth parameters. As for the fertilizer effect on the above parameters, the LSD and DMRT under GLM were used. While for age treatments, post hoc comparison test could not be performed since there were only two independent variables. Therefore, only the mean values were compared and the significant levels determined based on ANOVA. Correlation coefficient's Pearson was also carried out to measure the degree of association between growth parameters, biomass, soil mineral nutrient and soil physical characteristics among and within the age and fertilizer treatments.

4.3 Results

4.3.1 Nursery

4.3.1.1 Effect of light and fertilizer treatment on biomass

The analyses of variance on biomass fractions of chengal seedlings in the nursery revealed significant differences under different light and fertilizer treatments. Biomass fraction of leaves, stem and root for both fresh and dry weight showed a significant variation after the 6th and 12th month. Interactions between both light and fertilizer treatments had a significant effect on biomass quantification at $p<0.05$ by month. Biomass of chengal was found to be increasing from the 6th to the 12th month in the nursery. This indicated that both light and fertilizer treatments influenced the increment of biomass fractions of chengal seedlings in the nursery within the first year of its growth (Tables 4.1 and 4.2).

Chengal seedlings treated with different light regimes showed that, exposure to 50% light intensity contributed to the highest allocation of biomass portion in leaves, stems and roots at the 6th and 12th month of growth. The other light intensities tested (30% and 100%) gave a similar significant increment, but the mean value of the biomass fractions were much lower compared to treatment with 50% light intensity. The use of 100% light intensity registered the lowest biomass for fresh and dry weights for leaves, stems and roots at both 6 and 12 months. Number of leaves under different light intensities was also significantly different, whereby 50% light intensity recorded the highest number of leaves, compared to 30% and 100% light treatments, with 100% light recording the lowest value for number of leaves (Table 4.3).

On the other hand, chengal seedlings treated under different fertilizer regimes recorded a significant increment in the number of leaves and biomass of leaves, stems and roots for both fresh and dry weights at the 6th and 12th months of growth (Table 4.4). NPK Blue fertilizer impacted the increment of biomass fractions and number of leaves giving the highest value compared to goat dung and control (no fertilizer applied) for both months. Only the number of leaves at the 12th month recorded a similar value for both NPK Blue and goat dung fertilizers. NPK Blue treatment recorded the highest increment and mean value of all the biomass fractions and number of leaves followed by goat dung fertilizer at the 6th and 12th month for both fresh and dry weights. Control recorded the lowest values. The average ratio of fresh/dry weights for biomass fractions (for leaf, stem and root) increased from the 6th to the 12th month within the range of 0.39–0.47 and 0.34-0.39, respectively.

Total dry weight of chengal seedlings at 6 and 12 months are as shown in Figures 4.1 and 4.2. The total dry weight under 50% light intensity and NPK blue fertilizer recorded the highest value compared to 30% and 100% light intensities treatment, as well as under goat dung fertilizer and control. At 12th month, although 50% light intensity exhibited the highest mean value for total dry weight, it was found to be not significant compared to seedlings treated under 30% light intensity (Figure 4.1). It was also observed that, the percentage increment from 6 to 12 months between treatments of 30%, 50% and 100% light intensities were 55.2, 49.7 and 50.6% respectively. Whilst increment percentage of chengal seedlings treated under NPK Blue, goat dung fertilizer and control from 6 to 12 months were in a range of 50.5, 51.8 and 52.1% respectively (Figure 4.2). The total dry weight of biomass fractions of leaves, stems and roots regardless of light and fertilizer treatments varied from the 6th to the 12th month (Figures 4.3 a & b). At 6 months, the the increment in leaves, stems and roots were 35, 39 and 26% whilst at 12 months, it was 33, 37 and 30% respectively. The mean percentage for both leaf and stem decreased by about 2% from the 6th to the 12th month but increased for roots by about 4%.

Table 4.1: Summary of analysis of variance (ANOVA) of biomass fraction fresh weights (g) for chengal potted

Source of Variance	df	F-value[1]					
		Fresh weight (g) of					
		No of leaves	Leaves	Stem	Total shoot	Root	Total weight
6 month							
LIGHT	2	776.88*	11389.33*	7071.41*	11701.41*	9947.04*	16045.16*
FERTILIZER	2	764.03*	13117.95*	8144.35*	13476.78*	12520.49*	18950.38*
LIGHT*FERTILIZER	4	57.28*	1056.34*	648.17*	1078.87*	814.71*	1389.09*
12month							
LIGHT	2	144.18*	762.75*	597.28*	924.40*	425.99*	1066.33*
FERTILIZER	2	500.65*	1474.46*	1386.08*	1950.54*	1101.69*	2384.63*
LIGHT*FERTILIZER	4	25.42*	7.10*	10.17*	9.09*	49.30*	25.81*

* significant at $p < 0.05$

Table 4.2: Summary of ANOVA of biomass fraction dry weights (g) for chengal potted seedlings

Source of Variance	df	F-value[1] Dry weight (g) Leaves	Stem	Total shoot	Root	Total weight
6 month						
LIGHT	2	2753.29*	1267.60*	2448.95*	290.02*	2280.87*
FERTILIZER	2	2503.65*	1133.29*	2209.96*	266.16*	2062.70*
LIGHT*FERTILIZER	4	150.89*	118.22*	170.27*	12.95*	150.13*
12month						
LIGHT	2	529.00*	355.11*	589.50*	84.49*	26.98*
FERTILIZER	2	551.57*	393.42*	666.62*	125.64*	267.45*
LIGHT*FERTILIZER	4	12.72*	42.33*	30.06*	114.92*	103.92*

* significant at p < 0.05

Table 4.3: Effect of light intensity treatments on biomass fraction of fresh and dry weights for chengal potted seedlings

	Weight (unit mg g^{-1})					
	6 month			12 month		
Light intensity	30%	50%	100%	30%	50%	100%
Number of leaves	61 ± 10 **b**	72 ± 15**a**	48 ± 11 **c**	89 ± 12 **b**	97 ± 15 **c**	83 ± 11 **a**
<u>Fresh weight</u>						
Leaves	20.31 ± 5.78 **b**	25.74± 5.26 **a**	13.11 ± 7.02 **c**	39.40 ± 7.00 **b**	46.15 ± 7.35 **a**	34.36 ± 7.12 **c**
Stem	22.18 ± 5.80 **b**	27.64 ± 5.30 **a**	15.02 ± 7.05 **c**	42.56 ± 6.49 **b**	49.02 ± 7.17 **a**	39.33 ± 6.05 **c**
Total shoot	42.49 ± 11.5 **b**	53.38 ± 10.5 **a**	28.13 ± 14.03 **c**	81.97 ± 13.35 **b**	95.17 ± 14.41**a**	73.69 ± 12.76 **c**
Root	16.14 ± 4.31 **b**	20.51 ± 5.20 **a**	10.68 ± 5.04 **c**	31.29 ± 5.06 **b**	36.56 ± 7.79 **a**	28.47 ± 4.84 **c**
<u>Dry weight</u>						
Leaves	7.84 ± 1.00 **b**	9.03 ± 1.57 **a**	6.16 ± 1.15 **b**	14.35 ± 1.68 **b**	16.22 ± 2.08 **a**	12.48 ± 1.68 **c**
Stem	8.61 ± 0.90 **b**	9.70 ± 1.57 **a**	7.22 ± 0.97 **c**	15.53 ± 1.42 **b**	17.24 ± 1.98 **a**	14.37 ± 1.33 **c**
Total shoot	16.45 ± 1.84 **b**	18.73 ± 3.13 **a**	13.38 ± 2.00 **c**	29.88 ± 3.01 **b**	33.45 ± 4.02 **a**	26.95 ± 2.73 **c**
Root	5.89 ± 0.40 **b**	6.20 ± 0.49 **a**	5.41 ± 0.56 **c**	10.69 ± 0.78 **b**	16.74 ± 11.80 **a**	10.17 ± 0.89 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 40 seedlings

Table 4.4: Effect of fertilizer treatment on biomass fraction of fresh and dry weights for chengal potted seedlings

Fertilizer	Weight (unit mg g^{-1})					
	6 month			12 month		
	NPK Blue	Goat dung	Control	NPK Blue	Goat dung	Control
Number of leaves	71 ± 13 **c**	62 ± 16 **a**	48 ± 8 **c**	98 ± 7 **b**	97 ± 12 **a**	74 ± 8 **c**
<u>Fresh weight</u>						
Leaves	26.08 ± 3.48 **a**	20.53 ± 7.85 **b**	12.56 ± 4.93 **c**	46.48 ± 5.27 **a**	42.70 ± 5.82 **b**	30.73 ± 5.14 **c**
Stem	27.98 ± 3.56 **a**	22.40 ± 7.88 **b**	14.46 ± 4.98 **c**	49.31 ± 5.18 **a**	46.49 ± 4.63 **b**	35.12 ± 4.10 **c**
Total shoot	54.06 ± 6.96 **a**	42.93 ± 15.68 **b**	27.02 ± 9.85 **c**	95.79 ± 10.31 **a**	89.19 ± 10.11 **b**	65.85 ± 8.79 **c**
Root	20.85 ± 3.40 **a**	16.59 ± 6.10 **b**	9.89 ± 3.10 **c**	37.03 ± 5.34 **a**	34.69 ± 4.39 **b**	24.61 ± 2.83 **c**
<u>Dry weight</u>						
Leaves	8.89 ± 1.24 **a**	7.96 ± 1.66 **b**	6.18 ± 0.95 **c**	15.85 ± 1.92 **a**	14.99 ± 1.90 **b**	12.20 ± 1.55 **c**
Stem	9.54 ± 1.27 **a**	8.77 ± 1.50 **b**	7.23 ± 0.84 **c**	16.81 ± 1.91 **a**	16.34 ± 1.52 **b**	13.97 ± 1.16 **c**
Total shoot	18.43 ± 2.48 **a**	16.73 ± 3.12 **b**	13.41 ± 1.66 **c**	32.76 ± 3.65 **a**	31.34 ± 3.28 **b**	26.18 ± 2 .42 **c**
Root	6.19 ± 0.40 **a**	5.89 ± 0.55 **b**	5.43 ± 0.53 **c**	17.44 ± 11.36 **a**	10.92 ± 0.71 **b**	9.97 ± 1.17 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 40 seedlings

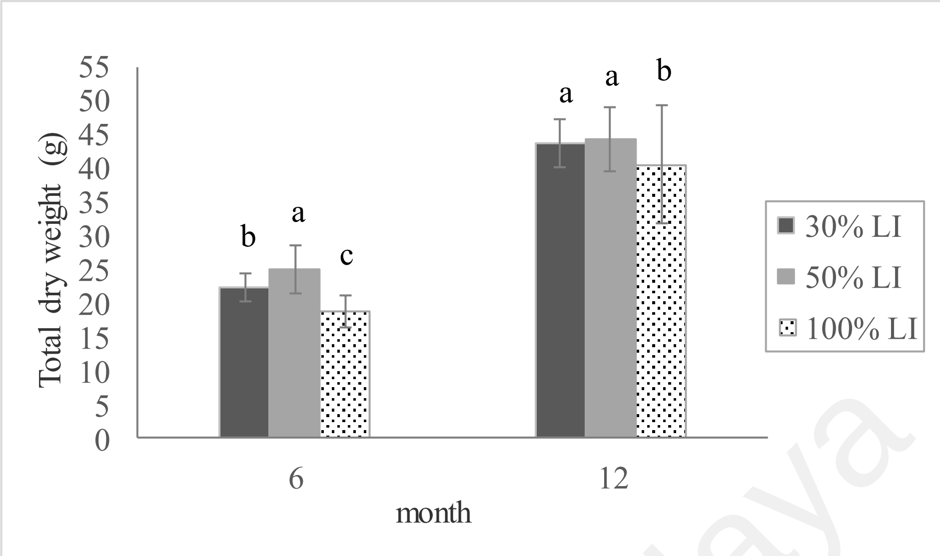


Figure 4.1: Total dry weights (g) of chengal potted seedlings under different light intensity treatments. Means with different letter are significantly different at $p < 0.05$ with $n = 40$ seedlings

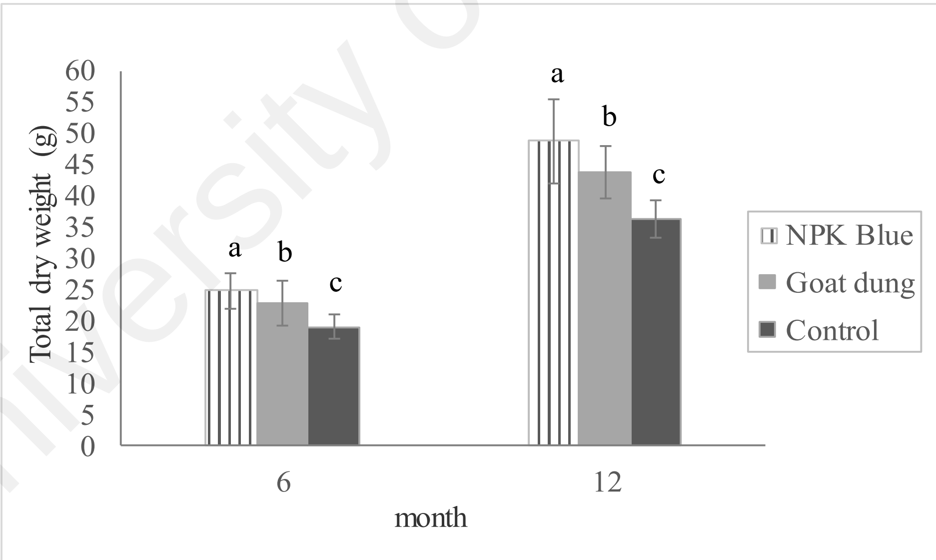


Figure 4.2: Total dry weights (g) of chengal potted seedlings under different fertilizer treatments. Means with different letter are significantly different at $p < 0.05$ with $n = 40$ seedlings

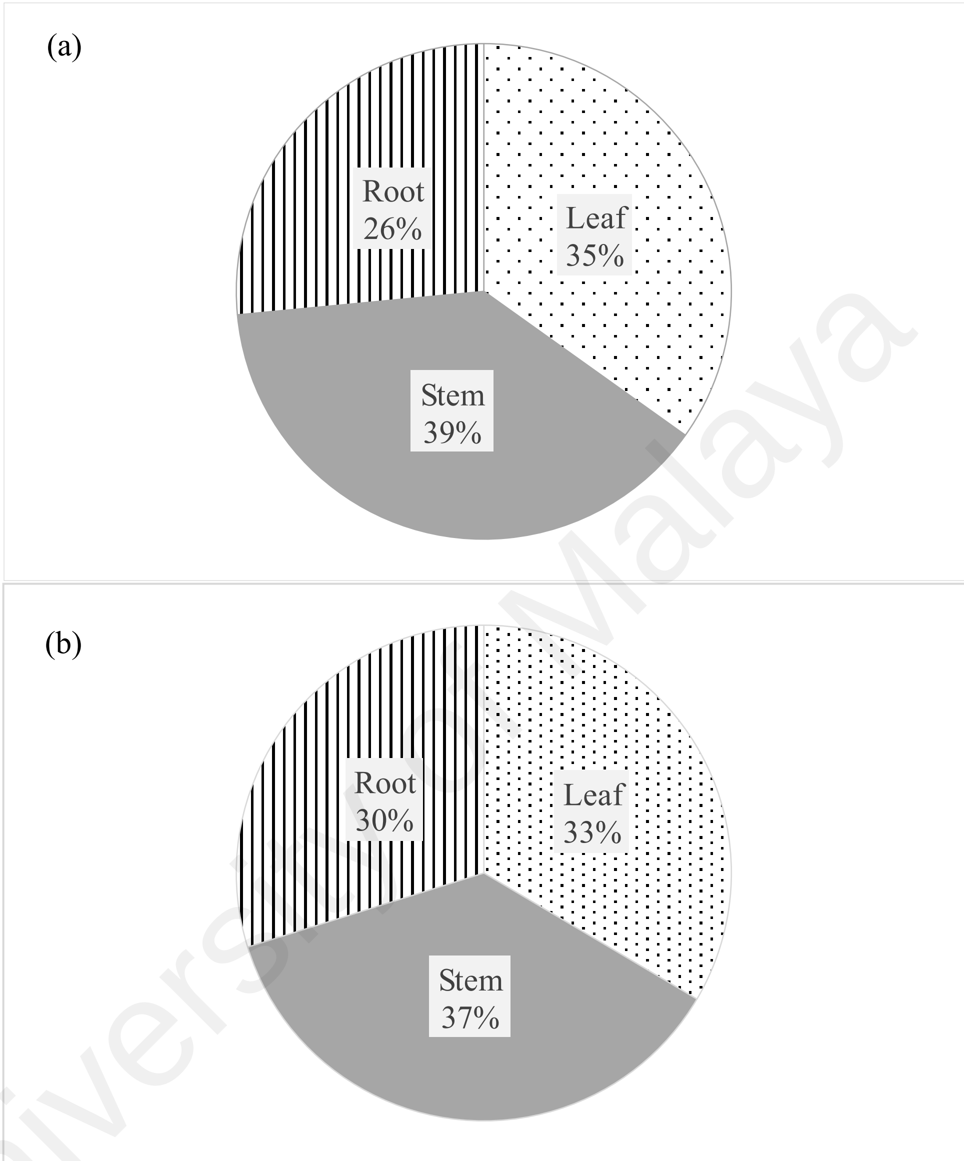


Figure 4.3: Dry weights proportion of leaves, stem and root of chengal potted seedlings under different light and fertilizer treatment. (a) 6 months after potting in the nursery. (b) 12 months after potting in the nursery

4.3.1.2 Effect of light and fertilizer treatment on plant mineral content

A significant difference was found for plant mineral content in stems at the 6th and 12th month and for roots at 6th month of growth treated under different light and fertilizer treatments. However, there were no significant differences recorded for mineral content in leaves at 6 and 12 months, as well as for root mineral content after 12 months. Similar results for biomass fractions were recorded for plant mineral content, where 50% light intensity recorded the highest value for plant mineral content compared to 30% and 100% LI, with the lowest observed under 100% LI (Table 4.5). Fertilizer treatment also recorded a significant impact on the plant mineral content of chengal seedlings. As was expected, NPK Blue recorded the highest increment compared to goat dung and control. Control, with no fertilizer, applied recorded the lowest plant mineral content readings. It was also observed that the plant mineral content increased from the 6th to the 12th after potting in the nursery.

The leaves, stems and roots under 50% LI and NPK Blue fertilizer showed the highest value of N, P and K. After 12 months, regardless of the fertilizer applied and light intensity treatment, the mineral content of the biomass fractions was at the highest percentage for N and lowest for P (Tables 4.6 and 4.7). The total (N:P:K) % estimated for light was at a ratio of (57.8:8.7:33.5)% of the total content of mineral nutrients (Figure 4.5). For fertilizer treatment, the total (N:P:K)% was (52.8:9.5:37.7)% (Figure 4.6). However, the leaves:stem:root ratio percentage recorded a range of ratios for N, P and K content for both light and fertilizer treatments. The leaves:stem:root mineral ratio percentage for all light and fertilizer treatments were (53.0:26.9:20.1)% for N, (46.7:21.2:15.1)% for P and (63.7:35.1:18.2)% for K respectively, indicating in general, that leaves had double the N, P and K content compared to stems and roots.

Table 4.5: Summary of ANOVA of plant mineral content for chengal potted seedlings

Source of variance	df	F-value-1											
		Mineral content											
		N				P				K			
		Leaves	Stem	Root	Total	Leaves	Stem	Root	Total	Leaves	Stem	Root	Total
<u>6 month</u>													
LIGHT	2	1644.8*	4181.7*	854.8*	2068.8*	25.2*	168.2*	21.2*	44.6*	1478.7*	347.0*	32.4*	526.2*
FERTILIZER	2	30531.6*	6019.2*	3596.2*	1187.2*	190.8*	542.52*	117.7*	236.6*	11239.6*	1905.2*	79.1*	3087.9*
LIGHT*FERTILIZER	4	88.30*	466.0*	131.5*	202.8*	2.18ns	44.6*	4.8*	6.8*	155.2*	17.9*	5.7ns	46.8*
<u>12 month</u>													
LIGHT	2	763.6*	292.6*	163.9*	1605.5*	67.4*	60.3*	9.8*	108.1*	1147.2*	105.4*	37.3*	2077.8*
FERTILIZER	2	4532.3*	421.9*	515.5*	5430.0*	212.1*	154.0*	46.2*	512.2*	4350.1*	344.7*	106.8*	9457.3*
LIGHT*FERTILIZER	4	113.62*	42.4*	30.3*	245.7*	3.7ns	12.0*	2.2ns	17.0*	185.3*	12.7*	9.3*	329.2*

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

Table 4.6: Effect of light intensity treatments on plant mineral content of chengal potted seedlings

	Mineral content					
	6 month			12 month		
Light intensity	30%	50%	100%	30%	50%	100%
N (%)						
Leaves	11.96 ± 3.61 **b**	12.95 ± 3.62 **a**	11.06 ± 3.10 **c**	21.86 ± 8.46 **b**	25.64 ± 10.39 **a**	17.72 ± 6.39 **c**
Stem	6.26 ± 1.66 **b**	7.29 ± 1.91 **a**	4.56 ± 0.64 **c**	11.39 ± 4.01 **b**	14.41 ± 5.64 **a**	7.27 ± 1.73 **c**
Shoot	18.22 ± 5.27 **b**	20.25 ± 5.52 **a**	15.63 ± 3.74 **c**	33.25 ± 12.47 **b**	40.05 ± 16.00 **a**	24.99 ± 8.10 **c**
Root	4.79 ± 1.37 **b**	4.99 ± 1.44 **a**	3.72 ± 0.74 **c**	8.73 ± 3.25 **b**	9.86 ± 4.17 **a**	6.03 ± 1.75 **c**
P (ppm)						
leaves	2.48 ± 0.54 **b**	2.88 ± 0.65 **a**	2.47 ± 0.50 **b**	4.62 ± 1.41 **b**	5.89 ± 1.86 **a**	4.04 ± 1.19 **c**
Stem	0.72 ± 0.36 **b**	1.13 ± 0.49 **a**	0.76 ± 0.22 **b**	1.34 ± 0.78 **b**	2.31 ± 1.26 **a**	1.23 ± 0.51 **b**
Shoot	3.21 ± 0.87 **c**	4.0 ± 1.14 **a**	3.30 ± 0.71 **b**	5.96 ± 2.16 **b**	7.54 ± 2.72 **a**	5.26 ± 1.68 **c**
Root	0.56 ± 0.23 **b**	0.76 ± 0.34 **a**	0.52 ± 0.27 **b**	1.08 ± 0.54 **b**	1.52 ± 0.93 **a**	0.89 ± 0.51 **c**
K (meg $100g^{-1}$)						
leaves	7.29 ± 1.72 **b**	8.63 ± 2.32 **a**	7.17 ± 1.62 **c**	13.17 ± 4.38 **b**	17.04 ± 6.75 **a**	11.38 ± 3.59 **c**
Stem	5.60 ± 0.93 **b**	6.40 ± 1.28 **a**	5.36 ± 1.03 **c**	10.18 ± 2.70 **b**	12.53 ± 4.27 **a**	8.59 ± 2.50 **c**
Shoot	12.92 ± 2.64 **b**	15.03 ± 3.59 **a**	12.53 ± 2.64 **c**	23.36 ± 7.07 **b**	27.84 ± 9.40 **a**	20.00 ± 6.12 **c**
Root	2.92 ± 0.35 **b**	3.29 ± 0.55 **a**	2.79 ± 0.27 **c**	5.27 ± 1.23 **b**	6.37 ± 2.17 **a**	4.54 ± 0.81 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 40 seedlings

Table 4.7: Effect of fertilizer treatments on plant mineral content of chengal potted seedlings

	Mineral content					
	6 month			12 month		
	NPK Blue	Goat dung	Control	NPK Blue	Goat dung	Control
N (%)						
Leaves	14.53 ± 0.09 **a**	14.33 ± 0.09 **b**	7.29 ± 0.10 **c**	28.83 ± 4.78 **a**	25.63 ± 4.70 **b**	10.75 ± 1.09 **c**
Stem	7.06 ± 1.54 **a**	6.93 ± 1.56 **b**	4.13 ± 0.44 **c**	14.16 ± 4.39 **a**	12.79 ± 4.27 **b**	6.12 ± 0.81 **c**
Shoot	21.62 ± 2.58 **a**	21.06 ± 2.42 **b**	11.43 ± 0.99 **c**	42.99 ± 9.12 **a**	38.43 ± 8.96 **b**	16.87 ± 1.90 **c**
Root	5.36 ± 0.77 **a**	5.25 ± 0.84 **b**	2.89 ± 0.15 **c**	10.68 ± 2.46 **a**	9.72 ± 2.48 **b**	4.22 ± 0.41 **c**
P(ppm)						
leaves	3.17 ± 0.32 **a**	2.75 ± 0.28 **b**	1.92 ± 0.19 **c**	6.38 ± 1.18 **a**	5.12 ± 0.91 **b**	3.05 ± 0.52 **c**
Stem	1.26 ± 0.27 **a**	0.88 ± 0.31 **b**	0.46 ± 0.08 **c**	2.55 ± 0.83 **a**	1.67 ± 0.71 **b**	0.66 ± 0.12 **c**
Shoot	4.42 ± 0.57 **a**	3.64 ± 0.58 **b**	2.37 ± 0.25 **c**	8.43 ± 1.20 **a**	6.77 ± 1.59 **b**	3.55 ± 0.38 **c**
Root	0.89 ± 0.14 **a**	0.66 ± 0.22 **b**	0.29 ± 0.11 **c**	1.79 ± 0.54 **a**	1.29 ± 0.50 **b**	0.41 ± 0.08 **c**
K(meg $100g^{-1}$)						
leaves	9.14 ± 0.91 **a**	8.83 ± 0.91 **b**	5.13 ± 0.26 **c**	18.11 ± 3.62 **a**	16.01 ± 3.41 **b**	7.47 ± 0.58 **c**
Stem	6.77 ± 0.57 **a**	6.26 ± 0.55 **b**	4.35 ± 0.31 **c**	13.41 ± 2.45 **a**	11.44 ± 2.30 **b**	6.45 ± 0.66 **c**
Shoot	15.9 ± 1.47 **a**	15.09 ± 1.45 **b**	9.49 ± 0.53 **c**	29.83 ± 3.34 **a**	27.45 ± 5.71 **b**	13.93 ± 1.22 **c**
Root	3.36 ± 0.39 **a**	3.08 ± 0.31 **b**	2.55 ± 0.17 **c**	6.72 ± 1.45 **a**	5.78 ± 1.09 **b**	3.67 ± 0.22 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 40 seedlings

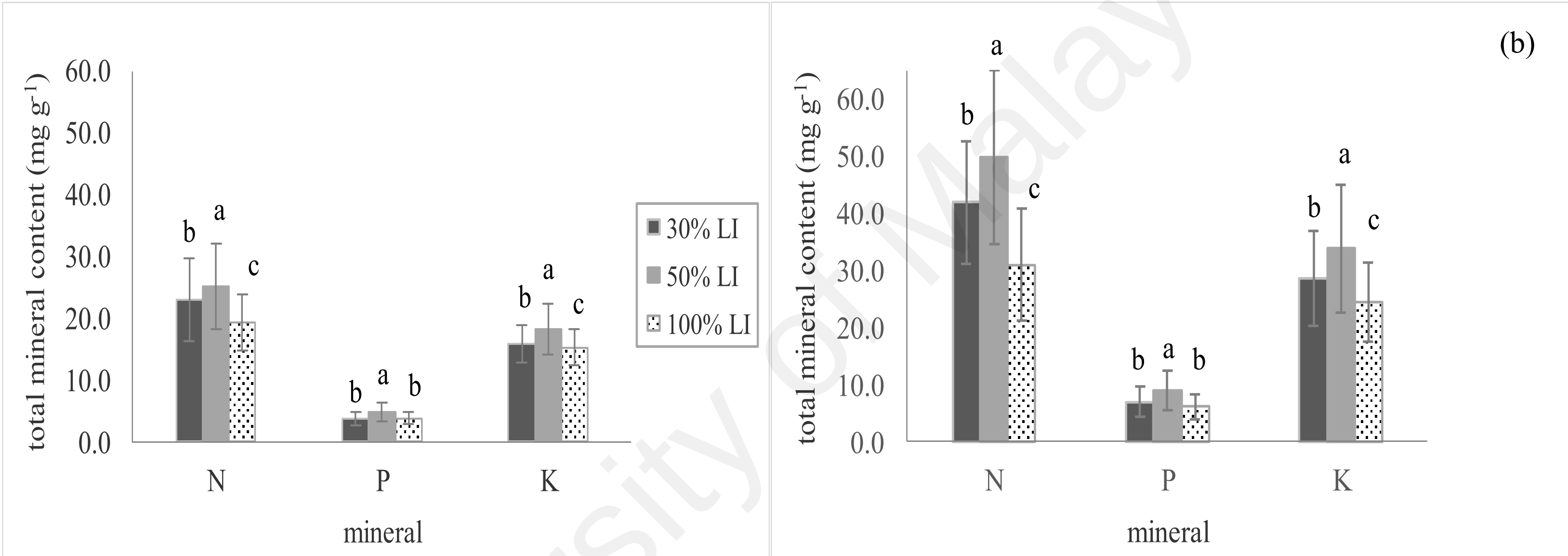


Figure 4.5: Effect of light intensity treatments on plant mineral content of chengal potted seedlings. (a) 6 months after potting in the nursery. (b) 12 months after potting in the nursery. Means with different letter are significantly different at $p < 0.05$ with $n = 40$ seedlings

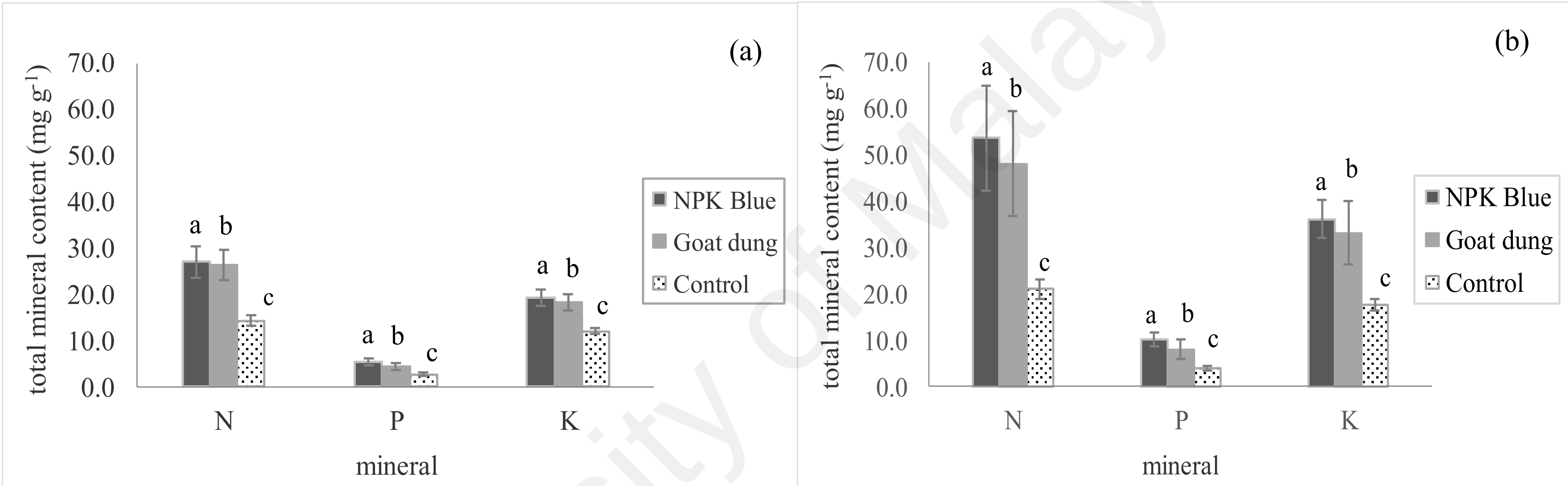


Figure 4.6: Effect of fertilizer treatments on plant mineral content of chengal potted seedlings. (a) 6 months after potting in the nursery. (b) 12 months after potting in the nursery. Means with different letter are significantly different at $p < 0.05$ with $n = 40$ seedlings

4.3.1.3 Effect of light and fertilizer treatment on soil physical characteristics

Table 4.8 presents the analysis of variance for physical characteristics of soil on which the chengal potted seedlings were grown in. There were no significant differences found for soil physical characteristics under the different light intensity and fertilizer treatments, 6 and 12 months after potting. The interactions between light and fertilizer treatments also did not affect the soil characteristics at 6 and 12 months. However, at 6 months, light treatment only affected CEC while fertilizer treatment affected CEC and pH values. After 12 months, light treatment affected CEC while fertilizer treatment affected CEC, silt and pH values significantly. It was also found that the soil physical elements increased from zero month (before application of fertilizer) (Table 3.2) to the 12th month after potting in the nursery in all the treatments (Tables 4.9 and 4.10). The soil physical properties of chengal potted seedling in the nursery which consist of clay, silt, fine sand and coarse sand accounted more than 100% in total with an average of 100 – 128 % under all light and fertilizer treatments. The values obtained might be due to soil sample contaminations by fertilizers. Chengal potted seedlings in the nursery were fertilized monthly using 10g NPK Blue fertilizers. The mixture of those inorganic fertilizers may have contaminated the samples and indirectly disrupted the data obtained.

The variations between soil physical characteristics were low at the 6th and 12th month under all the light and fertilizer treatments. At 6 months, it was observed that 50% LI contributed to the highest value for all soil physical characteristics values namely CEC, clay, silt, fine and coarse sand, followed by 100% and 30% LI. But at the 12th month, 30% LI recorded the highest value compared to 50% LI whilst the lowest was seen under 100% LI treatment (Table 4.9). Even though there was no significant interaction within fertilizer treatments, NPK Blue still produced the highest values and had the most effect on all soil physical characteristics compared to goat dung and control (Table 4.10). Soil physical characteristics under control showed the lowest value at both 6 and 12 months. On the contrary, soil pH value was lowest for soil under 50% LI, followed by 100% and then 30% at 6^{th} and 12 months. A similar pattern was observed for fertilizer treatment, where the pH values were lowest under NPK Blue, followed by goat dung and the highest was seen in control treatment. At 6^{th} and 12^{th} month, different light intensities and fertilizer treatments influenced soil mineral content at of N,P,K content and organic C for chengal seedlings. The interaction between both light and fertilizer treatment were found to be significant for N,P,K and organic carbon except for N and K at 6 months as well as for K at 12 months (Table 4.11). Soil under 50% LI recorded the highest mineral content, whilst the lowest was observed under 100% LI (Table 4.12). In addition, NPK Blue was found to increase the soil mineral content more than treatment with goat dung and control (Table 4.13). As was expected, control recorded the lowest value for all soil mineral content (Table 4.13). It was also observed that, the percentage of total P was higher by 99%, compared to N, K and organic C for soil treated under the different light (Figure 4.7) and fertilizer treatments (Figure 4.8) at 6 and 12 months. The percentage N:P:K:organic C ratio recorded was (99:0.08:0.1:0.7)% for all the soil samples at all the different light intensity and fertilizer treatments.

4.3.1.4 Correlation between growth, total dry weight and plant mineral content

Tables 4.14 and 4.15 present the correlation between growth parameters (height and diameter), total dry weight and plant mineral content for potted chengal seedlings

Table 4.8: Summary of ANOVA of soil physical characteristcs for chengal potted seedlings

	Source of variance	df	F-value[1]					
			Soil physical characteristics					
			CEC	Clay	Silt	Fine sand	Coarse sand	pH
<u>6 month</u>								
	LIGHT	2	0.424 *	0.032 ns	0.163 ns	0.135 ns	0.227 ns	0.765 ns
	FERTILIZER	2	2.342 *	5.009 ns	0.258 ns	0.937 ns	0.702 ns	5.210 *
	LIGHT*FERTILIZER	4	1.041 ns	0.828 ns	0.265 ns	1.722 ns	1.857 ns	0.977 ns
<u>12 month</u>								
	LIGHT	2	3.443 *	0.031 ns	0.670 ns	0.341 ns	0.301 ns	0.804 ns
	FERTILIZER	2	3.757 *	0.698 ns	3.889 *	0.435 ns	0.412 ns	5.125 *
	LIGHT*FERTILIZER	4	0.534 ns	0.191 ns	0.296 ns	0.534 ns	0.512 ns	1.317 ns

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

Table 4.9: Effect of light intensity treatments on soil physical characteristics of chengal potted seedlings

Light intensity	Soil physical characteristics					
	6 month			12 month		
	30%	50%	100%	30%	50%	100%
CEC ($cmol_c kg^{-1}$)	6.44 ± 0.88 **a**	6.22 ± 0.69 **b**	6.20 ± 0.82 **b**	7.81 ± 0.85 **a**	7.31 ± 0.63 **b**	7.25 ± 0.50 **b**
Clay (%)	26.28 ± 1.69 **a**	26.42 ± 1.22 **a**	26.35 ± 1.93 **a**	32.81 ± 1.84 **a**	32.68 ± 1.99 **b**	32.65 ± 1.58 **b**
Silt (%)	14.12 ± 1.38 **b**	14.42 ± 1.56 **a**	14.33 ± 1.14 **a**	17.82 ± 0.76 **b**	17.56 ± 1.19 **b**	17.95 ± 0.91 **a**
Fine sand (%)	27.46 ± 1.00 **a**	27.67 ± 1.41 **a**	27.60 ± 1.08 **a**	32.39 ± 1.14 **a**	32.33 ± 1.37 **a**	31.99 ± 1.57 **b**
Coarse sand (%)	39.54 ± 1.10 **b**	39.81 ± 1.41 **a**	39.74 ± 1.08 **a**	45.66 ± 1.14 **a**	45.60 ± 1.37 **a**	45.26 ± 1.57 **b**
pH	4.80 ± 0.18 **a**	4.75 ± 0.23 **a**	4.77 ± 0.21 **a**	4.74 ± 0.18 **a**	4.70 ± 0.15 **a**	4.72 ± 0.20 **a**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 3

Table 4.10: Effect of fertilizer treatments on soil physical characteristics of chengal potted seedlings

Fertilizer	Soil physical characteristics					
	6 month			12 month		
	NPK Blue	Goat dung	Control	NPK Blue	Goat dung	Control
CEC ($cmol_c kg^{-1}$)	6.61 ± 0.77 **a**	6.25 ± 0.94 **a**	6.00 ± 0.53 **a**	7.83 ± 0.78 a	7.28 ± 0.67 **ab**	7.25 ± 0.54 **b**
Clay (%)	25.42 ± 0.92 **b**	27.16 ± 1.77 **a**	26.45 ± 1.57 **ab**	33.15 ± 1.93 **a**	32.65 ± 1.77 **a**	32.33 ± 1.64 **a**
Silt (%)	14.29 ± 1.65 **ab**	14.47 ± 1.11 **a**	14.10 ± 1.28 **b**	18.29 ± 1.08 **a**	17.69 ± 0.82 **b**	17.35 ± 0.77 **c**
Fine sand (%)	27.87 ± 1.39 **a**	27.56 ± 0.83 **b**	27.30 ± 1.17 **b**	32.45 ± 1.30 **a**	32.28 ± 1.39 **ab**	31.98 ± 1.42 **b**
Coarse sand (%)	39.95 ± 1.48 a	39.44 ± 1.17 **ab**	39.66 ± 0.83 **b**	45.72 ± 1.30 **a**	45.55 ± 1.39 **b**	45.25 ± 1.42 **c**
pH	4.86 ± 0.15 **a**	4.65 ± 0.17 **c**	4.77 ± 0.14 **b**	4.78 ± 0.13 **a**	4.58 ± 0.20 **c**	4.71 ± 0.17 **b**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 3

Table 4.11: Summary of ANOVA of soil mineral content for chengal potted seedlings

Source of variance	df	F-value[1]			
		Soil mineral content			
		N	P	K	Organic C
6 month					
LIGHT	2	100.27*	327.43*	66.87*	831.20*
FERTILIZER	2	100.28*	115.25*	60.87*	508.46*
LIGHT*FERTILIZER	4	8.81ns	21.97*	6.54ns	161.19*
12 month					
LIGHT	2	38.13*	356.69*	87.88*	133.91*
FERTILIZER	2	45.68*	273.94*	113.92*	137.63*
LIGHT*FERTILIZER	4	3.69*	31.94*	7.43ns	22.53*

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

Table 4.12: Effect of light intensity treatments on soil mineral of chengal potted seedlings

	Soil mineral content					
	6 month			12 month		
Light intensity	30%	50%	100%	30%	50%	100%
N (%)	0.13 ± 0.02 **b**	0.18 ± 0.03 **a**	0.04 ± 0.03 **c**	0.18 ± 0.06 **b**	0.28 ± 0.08 **a**	0.07 ± 0.04 **c**
P (ppm)	122.88 ± 8.37 **b**	152.22 ± 23.70 **a**	97.55 ± 15.36 **c**	220.43 ± 38.20 **b**	296.78 ± 85.46 **a**	157.01 ± 44.16 **c**
K (meg $100g^{-1}$)	0.15 ± 0.04 **b**	0.18 ± 0.03 **a**	0.10 ± 0.04 **c**	0.29 ± 0.10 **b**	0.36 ± 0.11 **a**	0.17 ± 0.08 **c**
Organic C (%)	0.99 ± 0.06 **b**	0.98 ± 0.29 **a**	0.57 ± 0.19 **c**	1.78 ± 0.20 **b**	1.94 ± 0.84 **a**	0.95 ± 0.39 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 3

Table 4.13: Effect of fertilizer treatments on soil mineral of chengal potted seedlings

	Soil mineral content					
	6 month			12 month		
	NPK Blue	Goat dung	Control	NPK Blue	Goat dung	Control
N (%)	0.09 ± 0.02 **a**	0.07 ± 0.03 **b**	0.04 ± 0.02 **c**	0.18 ± 0.06 **a**	0.13 ± 0.07 **b**	0.06 ± 0.02 **c**
P (ppm)	139.55 ± 24.30 **a**	125.89 ± 31.87 **b**	107.22 ± 17.35 **c**	278.87 ± 72.44 **a**	237.22 ± 83.63 **b**	158.13 ± 32.07 **c**
K (meg $100g^{-1}$)	0.18 ± 0.03 **a**	0.15 ± 0.06 **b**	0.10 ± 0.03 **c**	0.36 ± 0.08 **a**	0.29 ± 0.13 **b**	0.15 ± 0.05 **c**
Organic C (%)	1.01 ± 0.25 **a**	0.90 ± 0.16 **b**	0.64 ± 0.30 **c**	2.02 ± 0.68 **a**	1.69 ± 0.44 **b**	0.97 ± 0.48 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD with n = 3

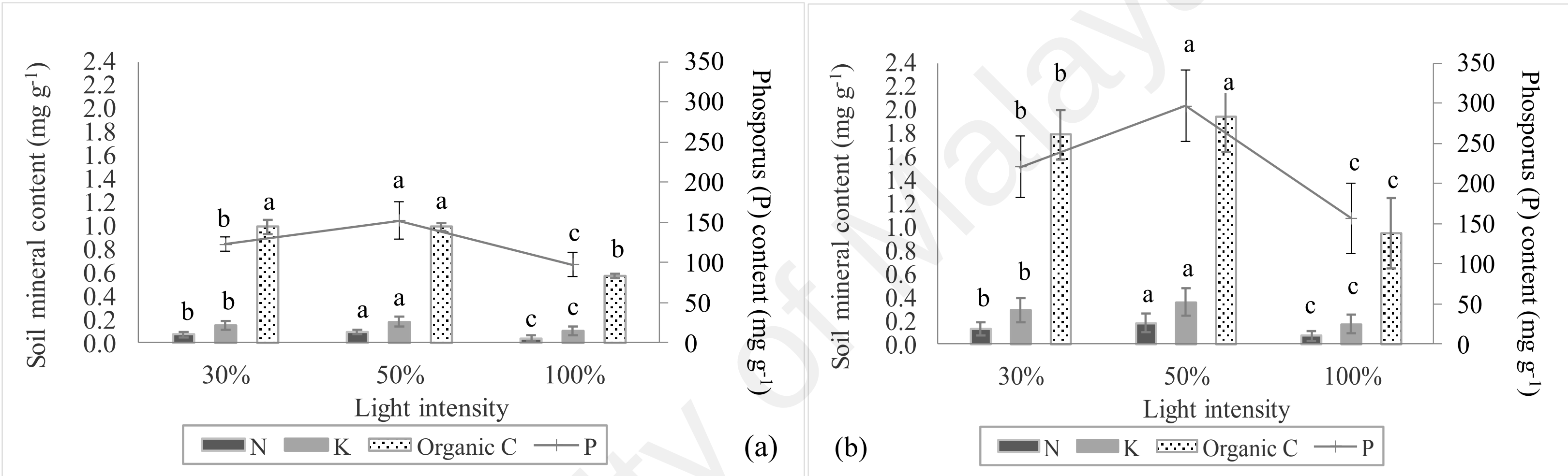


Figure 4.7: Total soil mineral content under different light intensity of chengal potted seedlings. (a) 6 months after potting in the nursery. (b) 12 months after potting in the nursery. Means with different letter are significantly different at $p < 0.05$ with $n = 3$

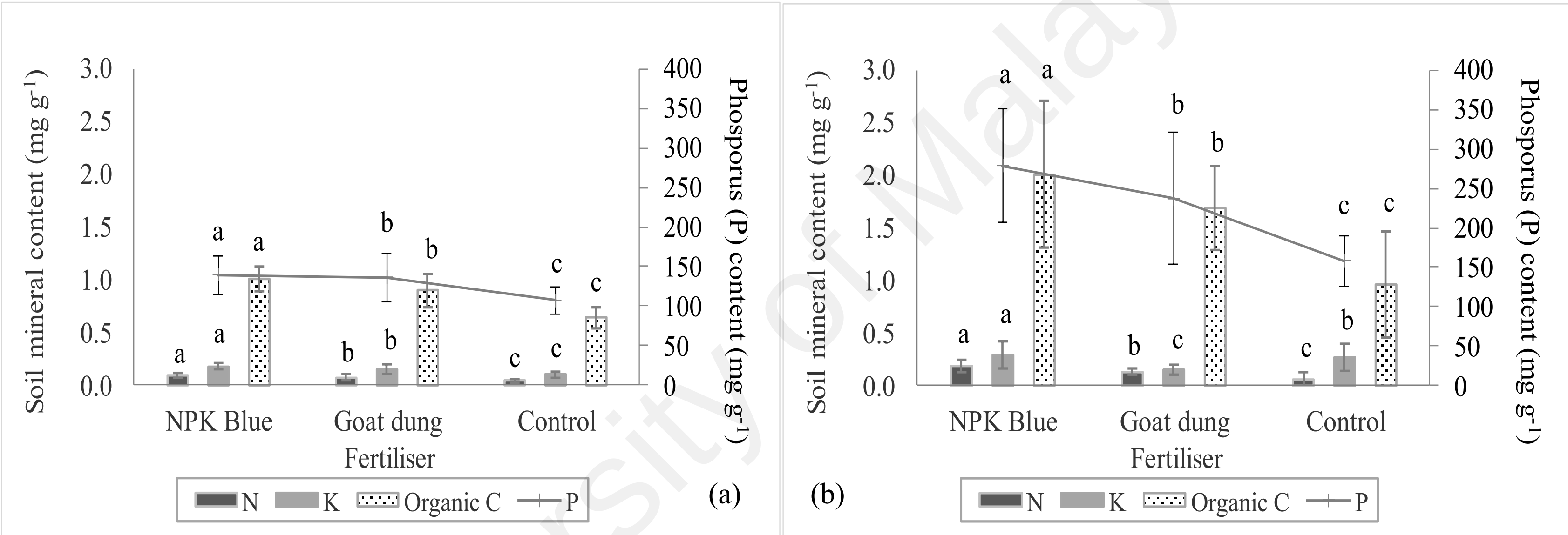


Figure 4.8: Total soil mineral content under different fertilizer treatments of chengal potted seedlings. (a) 6 months after potting in the nursery. (b) 12 months after potting in the nursery. Means with different letter are significantly different at $p < 0.05$ with $n = 3$

under different light and fertilizer treatments in the nursery. There was a highly significant correlation observed between the growth parameters, total dry weight and plant mineral content at $p<0.01$ (height and diameter) and $p<0.05$ for total dry weight and plant minerals. The total dry weight of the seedlings and the different plant mineral concentrations showed some specific associations which varied with the different elements. Growth parameters and total dry weight were positively correlated, showing there is a strong and significant relationship between the two under all the different light intensity and fertilizer treatments. However, they negatively correlated with N, P and K content. Nevertheless a positive correlation was observed within and among the minerals. It was also observed that the correlation of total dry weight and N, P and K were higher under 50% LI compared to 30% and 100% LI treatments. Furthermore, it was also observed that the correlation under the different fertilizer treatments was greater for NPK Blue compared to goat dung and control.

4.3.1.5 Correlation between growth, total dry weight and soil physical characteristics

The correlation between growth parameters (height and diameter), total dry weight and soil physical characteristics for potted chengal seedlings under different fertilizer treatments are shown in Table 4.16. A highly significant relationship between growth parameters and total dry weight towards soil physical characteristics at $p<0.05$ were recorded for all fertilizer treatments. However, growth and total dry weight were not significantly correlated towards silt, fine and coarse sand. It was also observed that CEC and clay were significantly and negatively correlated to fine and coarse sand respectively. Nevertheless, all other elements of CEC, clay, silt, fine and coarse sand, growth and TDW positively correlated towards each other. In addition the SRF fertilizer treatments gave the highest correlation compared to goat dung fertilizer and control.

Table 4.14: Correlation between growth parameters, total dry weight (TDW) and plant mineral content of chengal potted seedlings

(a) 30% Light intensity

	Height	Diameter	TDW	N	P	K
Height	1					
Diameter	0.989**	1				
TDW	0.721*	0.693*	1			
N	-0.421*	-0.678*	-0.486*	1		
P	-0.535*	-0.462*	-0.365*	0.336*	1	
K	-0.591*	-0.636*	-0.394*	0.436*	0.435*	1

(b) 50% Light intensity

	Height	Diameter	TDW	N	P	K
Height	1					
Diameter	0.987**	1				
TDW	0.741*	0.793*	1			
N	-0.411*	-0.673*	-0.426*	1		
P	-0.503*	-0.302*	-0.319*	0.304*	1	
K	-0.391*	-0.496*	-0.328*	0.412*	0.331*	1

(c) 100% Light intensity

	Height	Diameter	TDW	N	P	K
Height	1					
Diameter	0.972**	1				
TDW	0.701*	0.684*	1			
N	-0.755*	-0.678*	-0.456*	1		
P	-0.508*	-0.362*	-0.415*	0.333*	1	
K	-0.491*	-0.516*	-0.344*	0.386*	0.415*	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter and TDW n = 40; plant mineral content n = 30

Table 4.15: Correlation between growth parameters, TDW and plant mineral content of chengal potted seedlings under different fertilizer treatments after 12 months of potting

(a) NPK Blue fertilizer

	Height	Diameter	TDW	N	P	K
Height	1					
Diameter	0.991**	1				
TDW	0.712*	0.609*	1			
N	-0.411*	-0.613*	-0.437*	1		
P	-0.448*	-0.452*	-0.315*	0.330*	1	
K	-0.381*	-0.430*	-0.308*	0.446*	0.422*	1

(b) Goat dung fertilizer

	Height	Diameter	TDW	N	P	K
Height	1					
Diameter	0.977**	1				
TDW	0.741*	0.763*	1			
N	-0.441*	-0.612*	-0.446*	1		
P	-0.513*	-0.411*	-0.329*	0.354*	1	
K	-0.472*	-0.547*	-0.311*	0.449*	0.393*	1

(c) Control

	Height	Diameter	TDW	N	P	K
Height	1					
Diameter	0.982**	1				
TDW	0.543*	0.793*	1			
N	-0.465*	-0.632*	-0.478*	1		
P	-0.524*	-0.665*	-0.425*	0.447*	1	
K	-0.438*	-0.516*	-0.366*	0.556*	0.515*	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter and TDW n = 40; plant mineral content n = 30

4.3.1.6 Correlation between growth, total dry weight and soil mineral content

The correlation between growth parameters (height and diameter), total dry weight and soil mineral content for chengal seedlings under different fertilizer treatments are shown in Tables 4.17. A similar trend was found for the correlation between growth, total dry weight and soil mineral concentration as recorded for plant mineral content. There was a strong significant relationship recorded between growth parameters, total dry weight and soil mineral concentration at $p < 0.01$ (height and diameter) and $p < 0.05$ for others. The total dry weight of the seedlings and the different soil mineral concentrations also contributed to a varied specific association with the different elements. Growth parameters and total dry weight were found to correlate negatively towards soil mineral content in terms of N,P and K. Nevertheless, a positive correlation was recorded within the minerals. It was also observed that the correlations under the different fertilizer treatments were closer for NPK Blue compared to goat dung and control.

4.3.2 Field

4.3.2.1 Effect of age and fertilizer treatments on biomass of chengal seedlings

Quantification of above ground (AGB) and root biomass, as well as carbon stock of chengal seedlings in the field showed a significant difference under different age group and fertilizer treatments. Interactions between both age and fertilizer treatments also recorded a significant effect on AGB, root biomass and carbon stock at $p < 0.05$ (Tables 4.18). Figure 4.9 shows the percentage ratio of total AGB and root biomass of chengal seedlings at 12 and 44 months after planting in the field under different age group and fertilizer treatments. It was observed that there was an increment ratio of 2%

Table 4.16: Correlation between growth parameters, TDW and soil physical characteristics of chengal potted seedlings under different fertilizer treatments after 12 months of potting

(a) NPK Blue fertilizer

	Height	Diameter	TDW	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1							
Diameter	0.991**	1						
TDW	0.766*	0.759*	1					
CEC	0.883*	0.799*	0.716*	1				
Clay	0.715*	0.637*	0.513*	0.451*	1			
Silt	0.848	0.903	0.872	0.782	0.547	1		
Fine sand	0.739	0.781	0.746	-0.554	-0.627	0.774	1	
Coarse sand	0.707	0.753	0.788	-0.541	-0.374	0.726	0.983	1

(b) Goat dung fertilizer

	Height	Diameter	TDW	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1							
Diameter	0.977**	1						
TDW	0.765*	0.752*	1					
CEC	0.804*	0.781*	0.671*	1				
Clay	0.639*	0.572*	0.437*	0.423*	1			
Silt	0.812	0.873	0.855	0.733	0.505	1		
Fine sand	0.725	0.774	0.717	-0.428	-0.414	0.714	1	
Coarse sand	0.665	0.714	0.672	-0.418	-0.204	0.700	0.952	1

(c) Control

	Height	Diameter	TDW	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1							
Diameter	0.982**	1						
TDW	0.771*	0.812*	1					
CEC	0.776*	0.654*	0.663*	1				
Clay	0.590*	0.517*	0.406*	0.401*	1			
Silt	0.776	0.879	0.806	0.711	0.447	1		
Fine sand	0.715	0.666	0.629	-0.302	-0.297	0.628	1	
Coarse sand	0.593	0.618	0.645	-0.343	-0.200	0.602	0.944	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter and TDW n = 40; soil physical characteristic n = 3

Table 4.17: Correlation between growth parameters, TDW and soil mineral content of chengal potted seedlings under different fertilizer treatments after 12 months of potting

(a) <u>NPK Blue</u>

	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.971**	1					
TDW	0.766*	0.759*	1				
N	-0.487*	-0.533*	-0.479*	1			
P	-0.631*	-0.537*	-0.486*	0.354*	1		
K	-0.536*	-0.489*	-0.477*	0.488*	0.519*	1	
Organic C	-0.608*	-0.477*	-0.403*	0.627*	0.511*	0.692*	1

(b) <u>Goat dung</u>

	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.992**	1					
TDW	0.765*	0.752*	1				
N	-0.480*	-0.613*	-0.389*	1			
P	-0.677*	-0.541*	-0.489*	0.377*	1		
K	-0.538*	-0.480*	-0.466*	0.474*	0.555*	1	
Organic C	-0.601*	-0.473*	-0.428*	0.611*	0.537*	0.698*	1

(c) <u>Control</u>

	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.980**	1					
TDW	0.771*	0.812*	1				
N	-0.390*	-0.673*	-0.380*	1			
P	-0.676*	-0.591*	-0.477*	0.487*	1		
K	-0.545*	-0.537*	-0.471*	0.517*	0.495*	1	
Organic C	-0.651*	-0.443*	-0.439*	0.653*	0.560*	0.558*	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter and TDW n = 40; soil mineral content n = 3 for root biomass from the 12th to the 44th month but a decrease of 2% for total AGB, indicating that the root accumulated more dry weight with time compared to AGB. Furthermore, it was recorded that 1 year 8 months old chengal seedlings contributed the highest allocation of biomass quantification and carbon stock throughout, compared to the 6 months old seedlings (Table 4.19). The biomass and carbon stock quantification ratio was higher by 11.3 - 33.9% in the 1 year 8 months old seedlings, compared to that in the 6 months old seedlings from the 5th to the 44th month. The combination of SRF and organic fertilizer contributed to the highest mean for AGB, root biomass, above ground carbon stock and root carbon stock compared to SRF and organic separately (alone) (Table 4.20). Organic fertilizer recorded the lowest mean for all biomass and carbon quantifications. Significant increments were recorded but varied within fertilizer treatments for all the months. The combination of SRF + organic was higher by 2% and 14% compared to SRF and Organic respectively at the 5th month. It then increased by 15% and 38% at the 44th month. This indicated that with time, chengal seedlings given combination treatments of SRF + organic at the time of planting, showed higher increments for all biomass quantifications compared to SRF and organic fertilizer applied separately. The average increment for total AGB and carbon stock as well as root biomass and root carbon, increased within the range of 28.0 - 42.8% from the 5th to the 44th month under the different age and fertilizer treatments.

Table 4.18: Summary of ANOVA for biomass quantification and carbon stock of chengal seedlings according to age and fertilizer treatment

Source of Variance	df	F– value^{-1}			
		AGB	Root biomass	Carbon stock above ground	Root carbon stock
BLOCK	2	0.44 ns	0.43 ns	0.44 ns	0.43 ns
AGE	1	35232.2*	35232.3*	35232.2*	35232.3*
FERTILIZER	2	28488.5*	28488.4*	28488.5*	28488.4*
BLOCK*AGE*FERTILIZER	4	0.30 ns	0.30 ns	0.30 ns	0.30 ns
AGE*FERTILIZER	2	4916.6*	4916.7*	4916.6*	4916.7*

* significant at $p < 0.05$

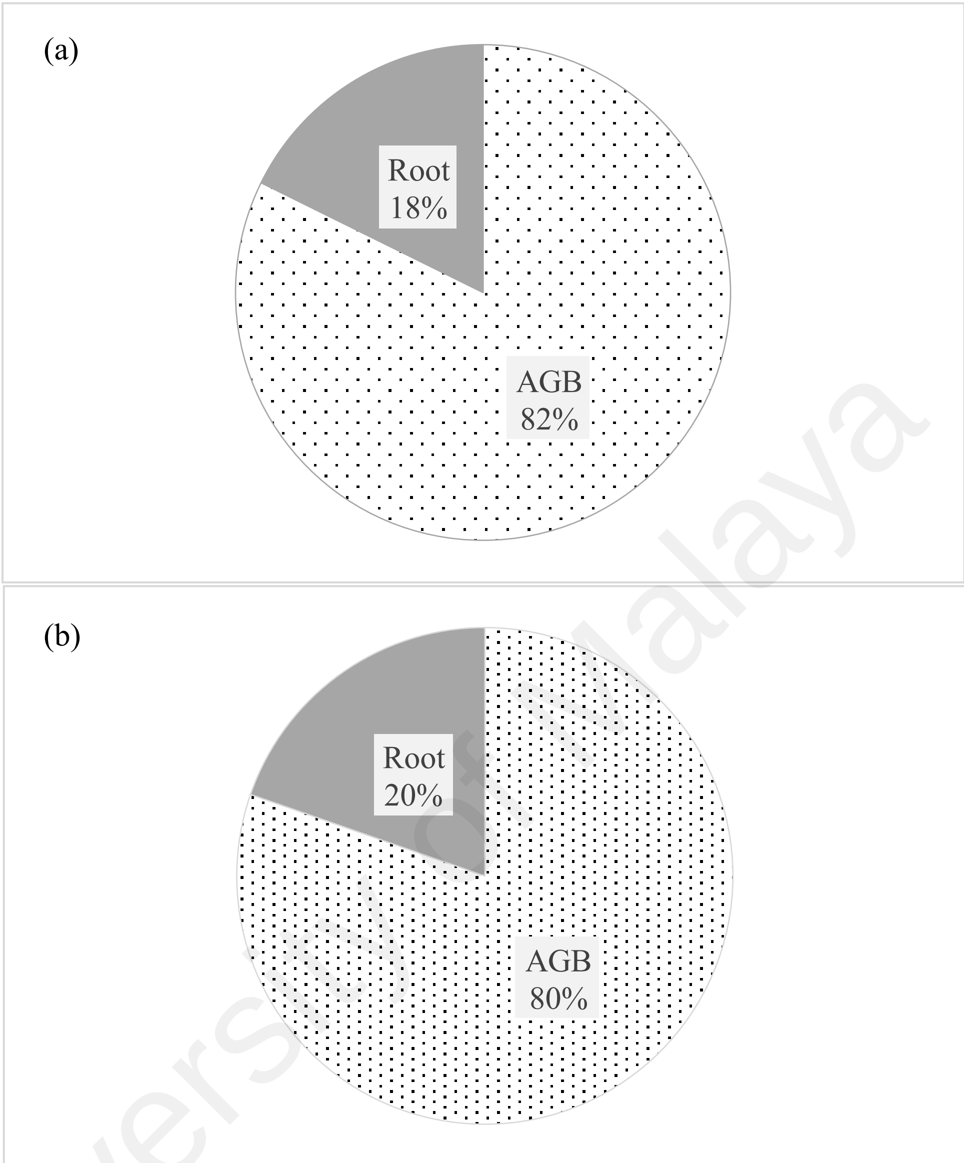


Figure 4.9: Percentage of total AGB and root of chengal seedlings under different age and fertilizer treatment. (a) 12 months after planting. (b) 44 months after planting

Table 4.19 : Mean biomass quantification and carbon stock of chengal seedlings under different age; (units are in Mg ha^{-1})

Age	AGB	Root biomass	Above ground carbon stock	Root carbon stock
5 month				
1y 8m	8.10 ± 0.26	1.95 ± 0.62	3.81 ± 0.12	0.91 ± 0.23
6 m	6.38 ± 0.31	1.53 ± 0.72	2.99 ± 0.14	0.72 ± 0.04
Mean	7.25 ± 0.91	1.74 ± 0.22	3.40 ± 0.43	0.82 ± 0.10
8 month				
1y 8m	13.78 ± 1.19	3.31 ± 0.29	6.48 ± 0.56	1.55 ± 0.13
6 m	11.63 ± 0.97	2.79 ± 0.23	5.47 ± 0.46	1.31 ± 0.11
Mean	12.69 ± 1.53	3.05 ± 0.37	5.96 ± 0.72	1.43 ± 0.17
12 month				
1y 8m	19.65 ± 1.67	4.73 ± 0.40	9.25 ± 0.79	2.22 ± 0.19
6 m	15.51 ± 0.80	7.72 ± 0.19	7.29 ± 0.38	1.75 ± 0.09
Mean	17.61 ± 2.46	4.23 ± 0.59	8.28 ± 1.15	1.99 ± 0.28
15 month				
1y 8m	27.28 ± 3.79	6.55 ± 0.91	12.82 ± 1.75	3.08 ± 0.43
6 m	24.19 ± 1.26	5.81 ± 0.30	11.37 ± 0.59	2.73 ± 0.14
Mean	25.69 ± 3.20	6.17 ± 0.77	12.08 ± 1.50	2.89 ± 0.36
22 month				
1y 8m	44.76 ± 5.92	10.69 ± 1.42	21.04 ± 2.78	5.05 ± 0.67
6 m	36.80 ± 2.89	8.79 ± 0.69	17.29 ± 1.36	4.15 ± 0.33
Mean	40.81 ± 6.13	9.79 ± 1.47	19.18 ± 2.88	4.60 ± 0.69
33 month				
1y 8m	65.14 ± 10.73	15.63 ± 2.57	30.62 ± 5.04	7.35 ± 1.21
6 m	48.65 ± 5.42	11.72 ± 1.30	22.96 ± 2.55	5.51 ± 0.61
Mean	57.14 ± 11.80	13.71 ± 2.83	26.85 ± 5.55	6.45 ± 1.33
44 month				
1y 8m	108.95 ± 24.08	26.15 ± 5.78	51.21 ± 11.32	12.29 ± 2.72
6 m	90.28 ± 15.16	21.60 ± 3.64	42.43 ± 7.12	10.18 ± 1.71
Mean	100.05 ± 22.34	24.01 ± 5.36	47.02 ± 10.5	11.29 ± 2.52

Mean values ± SD with n = 30 seedlings

Table 4.20: Mean for biomass quantification and carbon stock of chengal seedlings under different fertilizer treatments; (units are in Mg ha^{-1})

Fertilizer	AGB	Root biomass	Above ground carbon stock	Root carbon stock
<u>5 month</u>				
SRF	7.36 ± 0.87 **b**	1.77 ± 0.21 **b**	3.46 ± 0.41 **b**	0.83 ± 0.09 **b**
Organic	6.93 ± 0.90 **c**	1.66 ± 0.22 **c**	3.26 ± 0.42 **c**	0.78 ± 0.10 **c**
SRF + Organic	7.47 ± 0.85 **a**	1.79 ± 0.20 **a**	3.51 ± 0.40 **a**	0.84 ± 0.09 **a**
Mean	7.25 ± 0.91	1.74 ± 0.22	3.41 ± 0.43	0.82 ± 0.10
<u>8 month</u>				
SRF	12.33 ± 1.46 **b**	2.96 ± 0.35 **b**	5.79 ± 0.68 **b**	1.39 ± 0.16 **b**
Organic	11.87 ± 0.95 **c**	2.84 ± 0.23 **c**	5.58 ± 0.45 **c**	1.33 ± 0.11 **c**
SRF + Organic	13.99 ± 1.26 **a**	3.36 ± 0.30 **a**	6.58 ± 0.59 **a**	1.58 ± 0.14 **a**
Mean	12.69 ± 1.53	3.05 ± 0.37	5.97 ± 0.72	1.43 ± 0.17
<u>12 month</u>				
SRF	17.14 ± 2.07 **b**	4.16 ± 0.44 **b**	8.06 ± 0.97 **b**	1.93 ± 0.23 **b**
Organic	16.80 ± 1.79 **c**	4.03 ± 0.43 **c**	7.89 ± 0.84 **c**	1.89 ± 0.21 **c**
SRF + Organic	18.90 ± 2.87 **a**	4.55 ± 0.69 **a**	8.90 ± 1.35 **a**	2.14 ± 0.32 **a**
Mean	17.60 ± 2.46	4.23 ± 0.59	8.28 ± 1.15	1.99 ± 0.28
<u>15 month</u>				
SRF	24.35 ± 1.00 **b**	5.84 ± 0.24 **b**	11.45 ± 0.47 **b**	2.75 ± 0.11 **b**
Organic	23.66 ± 0.61 **c**	5.67 ± 0.15 **c**	11.11 ± 0.28 **c**	2.66 ± 0.07 **c**
SRF + Organic	29.19 ± 3.42 **a**	7.00 ± 0.82 **a**	13.72 ± 9.60 **a**	3.29 ± 0.39 **a**
Mean	25.69 ± 3.20	6.17 ± 0.77	12.08 ± 1.50	2.89 ± 0.36
<u>22 month</u>				
SRF	39.26 ± 1.94 **b**	9.42 ± 0.46 **b**	18.45 ± 0.91 **b**	4.42 ± 0.22 **b**
Organic	36.68 ± 3.65 **c**	8.80 ± 0.87 **c**	17.24 ± 1.71 **c**	4.13 ± 0.41 **c**
SRF + Organic	46.09 ± 6.87 **a**	11.06 ± 1.65 **a**	21.66 ± 3.23 **a**	5.19 ± 0.77 **a**
Mean	40.81 ± 6.13	9.79 ± 1.47	19.18 ± 2.88	4.60 ± 0.69
<u>33 month</u>				
SRF	56.59 ± 4.77 **b**	13.58 ± 1.14 **b**	26.60 ± 2.24 **b**	6.38 ± 0.54 **b**
Organic	47.88 ± 6.46 **a**	11.49 ± 1.55 **a**	22.50 ± 3.03 **a**	5.40 ± 0.73 **a**
SRF + Organic	66.22 ± 13.38 **c**	15.89 ± 3.21 **c**	31.12 ± 6.28 **c**	7.47 ± 1.50 **c**
Mean	57.14 ± 11.8	13.71 ± 2.83	26.85 ± 5.54	6.44 ± 1.33 b
<u>44 month</u>				
SRF	103.50 ± 3.87 **b**	24.84 ± 0.93 **b**	48.65 ± 1.82 **b**	11.67 ± 0.43 **b**
Organic	75.29 ± 5.71 **c**	18.06 ± 1.37 **c**	35.38 ± 2.68 **c**	8.49 ± 0.64 **c**
SRF + Organic	121.16 ± 18.51 **a**	29.07 ± 4.42 **a**	56.94 ± 8.70 **a**	13.67 ± 2.09 **a**
Mean	100.05 ± 22.34	24.01 ± 5.36	47.02 ± 10.51	11.29 ± 2.52

Means in each column with different letter is significant at $p < 0.05$; mean values ± SD with n = 30 seedlings

4.3.2.2 Effect of age and fertilizer treatments on leaf mineral content of chengal seedlings

Analysis of variance of leaf mineral content in chengal seedlings showed a significant difference under different age and fertilizer treatments in the field (Table 4.21). Seedling age and fertilizer treatment contributed to a significant variance among all the major foliar minerals (N, P, K) and organic C determined. Interactions of both age and fertilizer treatments also significantly affected foliar mineral content for all months. It was also noted that the leaf mineral content decreased from the 22nd to the 44th month under different fertilizer treatments and the two chengal age groups. Chengal seedlings aged 1y 8m recorded a lower N, P, K and organic C leaf content compared to 6m old seedlings at both 22 and 44 months after planting (Table 4.22). After 44 months of planting, N, P, K and organic C in the younger chengal leaves were higher by an average of 14, 25, 20 and 13 % respectively compared to older seedlings. However there was a decrease in percentage from the 22nd to the 44th months in N, P, K and organic C by 15.3, 16.7, 12.8 and 11.7% respectively between the different age groups. The use in combination of SRF + goat dung contributed to the highest leaf mineral content compared to application of only SRF and goat dung separately (Table 4.23). The two fertilizers used in combination resulted in an increment percentage of 7 and 19 % for N, 8 and 22% for P, 5 and 19% for K and lastly 4 and 11% for organic C, when compared to the use of only SRF and goat dung. Mineral N, P, K and organic C were also found to decrease from the 22nd to the 44th month by 11, 12, 11 and 9 % respectively under the different fertilizer treatments. The ratio between N, P, K and organic C content under different age and fertilizer treatments averaged 33, 2, 15 and 50%, respectively.

Table 4.21: Summary of ANOVA for foliar mineral content of chengal seedlings under different age and fertilizer treatment

Source of variance	df	F-value[1] Foliar mineral content N	P	K	Organic C
BLOCK	2	0.004ns	0.07ns	0.134ns	0.024ns
AGE	1	28.45*	8.11*	10.47*	40.74*
FERTILIZER	2	77.55*	8.45*	21.55*	67.34*
BLOCK*AGE*FERTILIZER	4	0.072ns	0.019ns	0.087ns	0.047ns
AGE*FERTILIZER	2	10.33*	6.78*	7.55*	6.55*

* significant at $p < 0.05$

Table 4.22: Mean foliar mineral content of two chengal seedlings age groups

	Foliar mineral nutrient			
	22 month		44 month	
Age	1y 8m	6m	1y 8m	6m
N	21.11 ± 2.55	23.56 ± 4.11	17.53 ± 4.21	20.33 ± 3.25
P	1.01 ±0.35	1.38 ±0.47	0.85 ± 0.21	1.14 ± 0.54
K	8.65 ±2.17	11.05 ±2.46	7.63 ±1.33	9.54 ±2.16
Organic carbon	29.88 ±9.54	34.27 ±10.27	26.32 ±5.69	30.35 ±7.69

Mean values ± SD with n = 30

Table 4.23: Mean foliar mineral content of chengal seedlings under different fertilizer treatments

Fertilizer	Foliar mineral nutrient					
	22 month			44 month		
	SRF	Organic	SRF + Organic	SRF	Organic	SRF + Organic
N	23.43 ± 4.63 **b**	22.24 ± 5.27 **c**	25.41 ± 4.47 **a**	21.45 ± 3.87 **b**	18.66 ± 4.44 **a**	23.12 ± 4.86 **a**
P	1.40 ± 0.36 **b**	1.21 ± 0.22 **c**	1.55 ± 0.47 **a**	1.26 ± 0.61 **b**	1.07 ± 0.19 **c**	1.37 ± 0.36 **a**
K	10.74 ± 3.77 **b**	9.43 ± 3.61 **c**	12.13 ± 4.77 **a**	9.87 ± 5.11 **b**	8.41 ± 3.46 a **c**	10.43 ± 4.22 **a**
Organic C	33.65 ± 5.66 **b**	32.22 ± 7.66 **c**	35.11 ± 8.54 **a**	30.88 ± 5.48 **b**	28.68 ± 4.96 **c**	32.17 ± 4.73 **a**

Means in each column with different letter is significant at $p < 0.05$; mean values ± SD with n = 30

4.3.2.3 Effect of age and fertilizer treatments on soil mineral content

Analysis of variance on soil mineral content of chengal seedlings resulted in a significant difference under different age and fertilizer treatments for two depths, namely, 0-20 cm and 20-40 cm (Table 4.24). Seedling age affected soil mineral content, with the exception of P at both depths and mineral K at 0-20 cm depth. However, fertilizer treatment showed a significant variance in the all soil mineral content at both depths. Interaction between age and fertilizer treatment were found not to be significant for soil mineral content excepting for N at 20-40 cm depth. The soil N,P,K and organic carbon content showed an increment in content from before planting (Table 3.2) up to the 22nd month after planting. However the mean content decreased from the 22nd month to the 44th month after planting (Tables 4.25 and 4.26). This proved that application of fertilizer contributed to a higher level of soil mineral content in the soil at the planting site at the time of planting, but over time the uptake of mineral by the chengal seedlings contributed to the decrease in soil mineral content at the planting site. Even though age was found to be not significant for most of the soil mineral content, with the exception of N, 6m old chengal seedlings had higher mineral content compared to 1 y 8 m old seedlings. The difference was insignificant and was higher by only 15, 4, 8, and 13 % for N, P, K and organic C respectively, compared to 1y 8m old chengal seedlings for both depths at the 44th month. The combination fertilizer recorded the highest value for soil mineral content compared to SRF alone, while the least was observed under organic fertilizer treatment at both depths. The increment within fertilizer treatments was also significantly different. This showed that the use of fertilizers in combination, which would contain to more N, P and K mineral content than only SRF and organic fertilizer on its own, has enriched the soil more and was better for uptake by the chengal seedlings. It was also observed that the soil mineral content decreased from the 22nd

Table 4.24: Summary of ANOVA for soil mineral content according to age and fertilizer treatment under two depths of (0-20) cm and (20-40) cm

Source of variance	df	F-value[1]							
		Soil mineral content							
		N (0-20)	P (0-20)	K (0-20)	Organic C (0-20)	N (20-40)	P (20-40)	K (20-40)	Organic C (20-40)
BLOCK	2	0.022ns	0.024ns	0.011ns	0.005ns	0.009ns	0.05ns	0.115ns	0.014ns
AGE	1	8.02*	1.13ns	3.29ns	2.74 ns	25.78*	0.72ns	0.15 ns	028ns
FERTILIZER	2	26.61*	9.29*	18.60*	38.98*	62.35*	4.88*	19.64*	58.00*
BLOCK*AGE*FERTILIZER	4	0.06ns	0.025ns	0.063ns	0.002ns	0.062ns	0.036ns	0.073ns	0.017ns
AGE*FERTILIZER	2	0.92ns	0.37ns	0.32ns	1.79ns	3.92*	0.04ns	0.18ns	1.92ns

* significant at $p < 0.05$

Table 4.25: Mean for soil mineral content according to different age groups

		Soil mineral content			
		22 month		44 month	
		1y 8m	6m	1y 8m	6m
(0-20) cm					
	N	0.22 ± 0.06	0.23 ± 0.06	0.17 ± 0.05	0.20 ± 0.06
	P	11.84 ± 1.89	12.05 ± 0.75	7.86 ± 1.47	8.15 ± 1.79
	K	0.37 ± 0.06	0.39 ± 0.03	0.22 ± 0.06	0.24 ± 0.06
	Organic carbon	2.38 ± 0.50	2.53 ± 0.30	1.33 ± 0.34	1.53 ± 0.32
(20-40) cm					
	N	0.19 ± 0.05	0.21 ± 0.06	0.14 ± 0.02	0.17 ± 0.04
	P	8.77 ± 1.62	8.79 ± 0.42	5.75 ± 0.82	6.02 ± 0.90
	K	0.35 ± 0.07	0.37 ± 0.03	0.20 ± 0.05	0.22 ± 0.05
	Organic carbon	1.81 ± 0.37	2.06 ± 0.42	1.13 ± 0.28	1.32 ± 0.29

Mean values ± SD with n = 5

Table 4.26: Mean soil mineral content under different fertilizer treatments

	Fertilizer	Soil mineral content					
		22 month			44 month		
		SRF	Organic	SRF + Organic	SRF	Organic	SRF + Organic
(0-20) cm							
	N	0.23 ± 0.05 **b**	0.19 ± 0.05 **b**	0.26 ± 0.05 **a**	0.19 ± 0.05 **b**	0.16 ± 0.05 **c**	0.22 ± 0.05 **a**
	P	11.91 ± 0.05 **b**	11.70 ± 1.47 **b**	12.21 ± 1.3 **a**	8.14 ± 1.67 **b**	6.96 ± 1.31 **c**	8.91 ± 1.33 **a**
	K	0.37 ± 0.05 **b**	0.36 ± 0.05 **b**	0.41 ± 0.03 **a**	0.23 ± 0.05 **a**	0.19 ± 0.05 **b**	0.26 ± 0.05 **a**
	Organic carbon	2.51 ± 0.34 **b**	2.16 ± 0.39 **c**	2.69 ± 0.39 **a**	1.38 ± 0.26 **b**	1.17 ± 0.27 **c**	1.72 ± 0.25 **a**
(20-40) cm							
	N	0.19 ± 0.05 **b**	0.15 ± 0.03 **c**	0.25 ± 0.04 **a**	0.16 ± 0.03 **b**	0.14 ± 0.03 **c**	0.18 ± 0.03 **a**
	P	8.66 ± 1.40 **ab**	8.57 ± 1.07 **b**	9.10 ± 0.97 **a**	5.89 ± 0.90 **b**	5.53 ± 0.80 **c**	6.23 ± 0.83 **a**
	K	0.37 ± 0.05 **a**	0.33 ± 0.06 **b**	0.38 ± 0.05 **a**	0.20 ± 0.04 **b**	0.18 ± 0.04 **b**	0.25 ± 0.04 **a**
	Organic carbon	1.89 ± 0.40 **b**	1.64 ± 0.30 **c**	2.25 ± 0.30 **a**	1.23 ± 0.19 **b**	0.97 ± 0.22 **c**	1.47 ± 0.26 **a**

Means in each column with different letter is significant at $p < 0.05$; mean values ± SD with $n = 5$

month to the 44th month. After 44 months of planting, the mineral content was higher in SRF + organic compared to only SRF and organic by 14 and 27 % for N, 9 and 22 % for P, 12 and 26 % for K and 20 and 32 % for organic C respectively at the depth of 0-20 cm. At the depth of 20-40 cm, the SRF + organic combination treatment was higher compared to only SRF and organic by 11 and 22 % for N, 5 and 11 % for P, 20 and 28 % for K and 16 and 34 % for organic C respectively. It was also observed that, the soil mineral content at the depth of 0-20 cm was higher by 16, 27, 9 and 14 % for N, P, K and organic C respectively compared to the depth at 20-40 cm regardless of age and fertilizer treatments.

4.3.2.4 Effect of age and fertilizer treatments on soil physical characteristics

The analysis of variance for soil physical characteristics at the depth of 0-20 and 20-40 cm is shown in Tables 4.27 and 4.28. It was found to be not significant for both age and fertilizer treatments. The interaction between age and fertilizer too was found to be not significant. However, by month, all the elements of soil physical characteristics changed significantly. The soil physical properties in the field which consist of clay, silt, fine sand and coarse sand accounted for below and more than 100% in total with an average of 90 – 130 % under all age and fertilizer treatments. The values attained might be due to disruption of soil physical properties in the study area. The study area was selected as an R&D demo plot for students from higher institutions and field managers. Therefore, the plot was prone to receiving numerous visitors. The soil surface could be leached, removed as well as increased the sediment. This could lead to higher soil compaction and indirectly disrupted the physical texture of the soil in those areas.

Table 4.27: Summary of ANOVA for soil physical characteristics under different age and fertilizer treatment under (0-20) cm depth

Source of variance	df	F-value[1]					
		Soil physical characteristic					
		CEC	Clay	Silt	Fine sand	Coarse sand	pH
BLOCK	2	0.36ns	0.78ns	0.07ns	1.77ns	2.24ns	0.001ns
AGE	1	0.03ns	2.84ns	0.79ns	0.89ns	0.24ns	2.79ns
FERTILIZER	2	0.34ns	1.66ns	1.43ns	1.63ns	1.34ns	22.65*
BLOCK*AGE*FERTILIZER	4	0.14ns	0.29ns	0.12ns	0.23ns	0.27ns	0.03ns
AGE*FERTILIZER	2	2.52ns	0.76ns	0.78ns	0.36ns	0.24ns	0.03ns

* significant at $p < 0.05$

Table 4.28: Summary of ANOVA for soil physical characteristics under different age and fertilizer treatment under (20-40) cm depth

Source of variance	df	F-value[1]					
		Soil physical characteristic					
		CEC	Clay	Silt	Fine sand	Coarse sand	pH
BLOCK	2	0.07ns	0.76ns	0.04ns	2.36ns	2.51ns	0.002ns
AGE	1	0.00ns	3.05ns	0.74ns	1.32ns	0.49ns	7.44ns
FERTILIZER	2	1.40ns	1.77ns	1.43ns	1.38ns	1.16ns	16.99*
BLOCK*AGE*FERTILIZER	4	0.19ns	0.26ns	0.12ns	0.16ns	0.29ns	0.007ns
AGE*FERTILIZER	2	2.15ns	0.80ns	0.81ns	0.56ns	0.28ns	0.78ns

* significant at $p < 0.05$

Other than that, it was also observed that the soil physical characteristics increased for all the elements at the time before planting (Table 3.3) up to the 44^{th} month after planting (Table 4.29). The variations between soil physical characteristics were found to be very low at 22^{nd} and 44^{th} month except for pH which was moderately low in all the age and fertilizer treatments. It was also noted that the soil of the older 1y 8m old chengal seedlings had higher soil physical characteristics values compared to 6m old seedlings at both the 22^{nd} and 44^{th} month for both depths (Table 4.29).

Furthermore, the use of SRF + organic in combination influenced and increased all the soil physical characteristics parameters compared to the application of only SRF and only organic fertilizer for both depths (Table 4.30). However, pH was lowest for soil under 1y 8m old chengal seedlings compared to soil under 6m old seedlings. A similar pattern was observed under fertilizer treatment, where the pH value was lowest under the combination of fertilizer treatment, followed by SRF alone and lastly organic fertilizer treatment. Soil physical elements were also observed to increase from the 22^{nd} to the 44^{th} month after planting for both depths regardless of age and fertilizer treatments. The percentage of coarse sand was higher by an average of 21% compared to fine sand for soil depth of 0-20 cm and 34% for depth at 20-40 cm at both months regardless of age and fertilizer treatments. Silt and clay recorded higher values at both the 22^{th} and 44^{th} months regardless of age and fertilizer treatment. Basically, soil with heavy clay has more positions to hold cations and thus they have higher CEC, as was explained earlier.

Table 4.29: Mean soil physical characteristics of different age groups at (0-20) cm and (20-40) cm depths

		Soil physical characteristic			
		22 month		44 month	
		1y 8m	6m	1y 8m	6m
(0-20) cm					
	CEC	17.63 ± 1.55	17.56 ± 1.56	22.03 ± 1.71	22.01 ± 1.74
	Clay	31.40 ± 4.20	30.28 ± 4.21	35.84 ± 4.63	34.52 ± 5.59
	Silt	18.76 ± 1.28	18.40 ± 1.38	25.44 ± 1.75	25.38 ± 1.47
	Fine sand	29.50 ± 1.87	29.27 ± 2.27	34.50 ± 2.20	34.09 ± 2.35
	Coarse sand	39.19 ± 1.87	39.02 ± 2.25	43.42 ± 2.19	43.41 ± 2.33
	pH	4.79 ± 0.17	4.82 ± 0.32	4.56 ± 0.22	4.64 ± 0.20
(20-40) cm					
	CEC	14.53 ± 1.65	14.46 ± 1.70	19.03 ± 1.71	18.97 ± 1.80
	Clay	27.40 ± 4.33	26.28 ± 5.35	32.91 ± 4.64	31.45 ± 5.60
	Silt	11.26 ± 1.36	10.90 ± 1.48	17.13 ± 1.75	17.08 ± 1.49
	Fine sand	20.50 ± 1.95	20.27 ± 2.38	25.38 ± 2.09	24.84 ± 2.34
	Coarse sand	33.99 ± 1.07	33.82 ± 2.41	38.17 ± 2.09	37.86 ± 2.40
	pH	4.69 ± 0.16	4.76 ± 0.40	4.52 ± 0.16	4.62 ± 0.14

Mean values ± SD with n = 5

Table 4.30: Mean soil physical characteristics under different fertilizer treatments at (0-20) cm and (20-40) cm depths

Fertilizer	Soil physical characteristic					
	22 month			44 month		
	SRF	Organic	SRF + Organic	SRF	Organic	SRF + Organic
(0-20) cm						
CEC	17.54 ± 1.50 **a**	17.50 ± 1.64 **a**	17.74 ± 1.55 **a**	22.13 ± 1.99 **a**	21.79 ± 1.80 **a**	22.16 ± 1.65 **a**
Clay	30.68 ± 4.81 **a**	30.66 ± 3.67 **a**	31.18 ± 4.41 **a**	36.03 ± 6.22 **a**	33.47 ± 5.00 **a**	36.11 ± 3.62 **a**
Silt	18.66 ± 1.59 **a**	18.35 ± 1.16 **a**	18.73 ± 1.23 **a**	25.39 ± 2.22 **a**	25.12 ± 1.10 **a**	25.72 ± 1.22 **a**
Fine sand	29.32 ± 2.31 **a**	29.31 ± 2.08 **a**	29.52 ± 1.86 **a**	34.05 ± 2.54 **a**	33.82 ± 2.54 **a**	35.02 ± 1.72 **a**
Coarse sand	39.02 ± 2.30 **a**	39.09 ± 2.04 **a**	39.20 ± 1.86 **a**	43.43 ± 2.33 **a**	42.93 ± 2.60 **a**	44.13 ± 1.67 **a**
pH	4.81 ± 0.14 **b**	4.89 ± 0.40 **a**	4.71 ± 0.15 **c**	4.57 ± 0.14 **b**	4.80 ± 0.16 c **a**	4.43 ± 0.17 **b**
(20-40) cm						
CEC	14.44 ± 1.70 **a**	14.40 ± 1.10 **a**	14.64 ± 1.50 **a**	19.00 ± 1.76 **a**	18.81 ± 1.78 **a**	19.17 ± 1.63 **a**
Clay	26.68 ± 3.10 **a**	26.66 ± 3.40 **a**	27.71 ± 4.10 **a**	33.04 ± 3.61 **a**	30.41 ± 5.06 **a**	33.09 ± 6.23 **a**
Silt	11.16 ± 1.30 **a**	10.85 ± 0.90 **a**	11.23 ± 1.06 **a**	17.10 ± 2.25 **a**	16.81 ± 1.15 **a**	17.41 ± 1.14 **a**
Fine sand	20.32 ± 2.40 **a**	20.31 ± 2.40 **a**	20.52 ± 1.90 **a**	24.80 ± 2.05 **a**	24.77 ± 2.34 **a**	25.77 ± 1.70 **a**
Coarse sand	33.89 ± 1.94 **a**	33.82 ± 1.76 **a**	34.00 ± 1.70 **a**	37.91 ± 2.04 **a**	37.53 ± 38.60 **a**	38.60 ± 1.70 **a**
pH	4.74 ± 0.20 **b**	4.78 ± 0.35 **a**	4.65 ± 0.17 **c**	4.53 ± 0.11 **b**	4.74 ± 0.06 **a**	4.45 ± 0.08 **c**

Means in each column with different letter is significant at $p < 0.05$; mean values ± SD with n = 5

4.3.2.5 Correlation between growth, foliar TDW and foliar mineral content

The correlation between growth parameters (height and diameter), total dry weight and foliar mineral content for chengal seedlings under different age and fertilizer treatments are shown in Tables 4.31 and 4.32. A high significant relationship was observed between growth parameters, total dry weight and foliar mineral content at $p < 0.01$ (height and diameter) and $p<0.05$ for total dry weight and plant minerals. Growth (height and diameter) and foliar total dry weight was positively correlated under all age and fertilizer treatments. However, growth and foliar total dry weight were negatively correlated with foliar N,P and K content. Despite that, a positive correlation was found within and among the minerals determined. It was also observed that the correlation between total dry weight and N,P,K was higher in the 6m old chengal seedlings compared to the 1y 8m old seedlings. Furthermore, it was also observed that the correlation under the different fertilizer treatments was highest for the combined fertilizer compared to the applications of SRF and organic separately.

4.3.2.6 Correlation between growth with TAGB, root biomass and soil mineral content

The correlation between growth parameters (height and diameter), TAGB, root biomass and soil nutrient content for 6m and 1 year 8m chengal seedlings are shown in Tables 4.33 and for fertilizer treatments in Tables 4.34. The correlation between height and diameter towards TAGB and root biomass were positively correlated indicating highly signficant relationship between the two, under all age and fertilizer treatments at $p < 0.01$.

Table 4.31: Correlation between growth parameters, TDW and foliar mineral content of 6m and 1 year 8m chengal seedlings

(a) 1 y 8 m

	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.990**	1					
TDW	0.908**	0.913**	1				
N	-0.614*	-0.243*	-0.237*	1			
P	-0.573*	-0.600*	-0.537*	0.411	1		
K	-0.662*	-0.556*	-0.413*	0.401*	0.412*	1	
Organic C	-0.623*	-0.617*	-0.304*	0.573*	0.733*	0.621*	1

(b) 6 m

	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.840**	1					
TDW	0.961**	0.887**	1				
N	-0.303*	-0.216*	-0.140*	1			
P	-0.417*	-0.611*	-0.553*	0.350	1		
K	-0.667*	-0.413*	-0.203*	0.341*	0.342*	1	
Organic C	-0.621*	-0.600*	-0.210*	0.363*	0.711*	0.555*	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter, TAGB and root biomass n = 30; foliar mineral content n = 30

Table 4.32: Correlation between growth parameters, TDW and foliar mineral content of 6m and 1 year 8m seedlings

(a) SRF	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.990**	1					
TDW	0.968**	0.973**	1				
N	-0.624	-0.227	-0.214*	1			
P	-0.513**	-0.604*	-0.531*	0.427	1		
K	-0.505**	-0.303*	-0.357*	0.510*	0.475*	1	
Organic C	-0.534**	-0.511*	-0.276*	0.343*	0.410*	0.630*	1
(b) Organic	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.990**	1					
TDW	0.961**	0.967**	1				
N	-0.713*	-0.342*	-0.290*	1			
P	-0.674*	-0.663*	-0.567*	0.454	1		
K	-0.611*	-0.455*	-0.411*	0.688*	0.652*	1	
Organic C	-0.569*	-0.611*	-0.365*	0.573*	0.646*	0.711*	1
(c) SRF + organic	Height	Diameter	TDW	N	P	K	Organic C
Height	1						
Diameter	0.990**	1					
TDW	0.961**	0.967**	1				
N	-0.303*	-0.214*	-0.190*	1			
P	-0.407*	-0.528*	-0.463*	0.410	1		
K	-0.457*	-0.361*	-0.402*	0.481*	0.502*	1	
Organic C	-0.500*	-0.437*	-0.320*	0.477*	0.626*	0.515*	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter, TAGB and root biomass n = 30; foliar mineral content n = 30

Table 4.33: Correlation between growth parameters, TAGB, root biomass and soil nutrient content of 6m and 1 year 8m seedlings

(a) 1 y 8 m	Height	Diameter	TAGB	Root biomass	N	P	K	Organic C
Height	1							
Diameter	0.990**	1						
TAGB	0.968**	0.973**	1					
Root biomass	0.968**	0.973**	1.00**	1				
N	-0.084	-0.377*	-0.151	-0.151	1			
P	-0.683*	-0.612*	-0.668*	-0.668*	0.521*	1		
K	-0.709*	-0.694*	-0.668*	-0.668*	0.521*	0.932*	1	
Organic C	-0.696*	-0.645*	-0.648*	-0.648*	0.565*	0.821*	0.830*	1

(b) 6 m	Height	Diameter	TAGB	Root biomass	N	P	K	Organic C
Height	1							
Diameter	0.990**	1						
TAGB	0.961**	0.967**	1					
Root biomass	0.961**	0.967**	1.00**	1				
N	-0.293	-0.236	-0.190	-0.190	1			
P	-0.717**	-0.628**	-0.643**	-0.643**	0.450**	1		
K	-0.757**	-0.671**	-0.672**	-0.672**	0.471**	0.762**	1	
Organic C	-0.719**	-0.617**	-0.620**	-0.620**	0.473**	0.776**	0.805**	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter, TAGB and root biomass n = 30; soil nutrient content n = 5

Table 4.34: Correlation between growth parameters, TAGB, root biomass and soil nutrient content in the field under different fertilizer treatments

(a) SRF	Height	Diameter	TAGB	Root biomass	N	P	K	Organic C
Height	1							
Diameter	0.989**	1						
TAGB	0.964**	0.973**	1					
Root biomass	0.964**	0.973**	1.00**	1				
N	-0.197	-0.241	-0.198	-0.198	1			
P	-0.723**	-0.748**	-0.739**	-0.739**	0.501**	1		
K	-0.790**	-0.811**	-0.788**	-0.788**	0.419**	0.888**	1	
Organic C	-0.847**	-0.877**	-0.840**	-0.840**	`0.510**	0.815**	0.791**	1
(b) Organic	Height	Diameter	TAGB	Root biomass	N	P	K	Organic C
Height	1							
Diameter	0.988**	1						
TAGB	0.976**	0.975**	1					
Root biomass	0.976**	0.975**	1.00**	1				
N	-0.321*	-0.302**	-0.106	-0.106	1			
P	-0.859**	-0.854**	-0.778**	-0.778**	0.416**	1		
K	-0.856**	-0.823**	-0.780**	-0.780**	0.404**	0.808**	1	
Organic C	-0.800**	-0.746**	-0.658**	-0.658**	0.392**	0.792**	0.800**	1
(c) SRF + Organic	Height	Diameter	TAGB	Root biomass	N	P	K	Organic C
Height	1							
Diameter	0.993**	1						
TAGB	0.72**	0.971**	1					
Root biomass	0.72**	0.971**	1.00**	1				
N	-0.327*	-0.297*	-0.479**	-0.479**	1			
P	-0.731**	-0.713**	-0.748**	-0.748**	0.452**	1		
K	-0.791**	-0.771**	-0.798**	-0.798**	0.569**	0.810**	1	
Organic C	-0.761**	-.0744**	-0.761**	-0.761**	0.420**	0.766**	0.829**	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter, TAGB and root biomass n = 30; soil nutrient content n = 5

While the correlations between growth, TAGB and root biomass towards soil N, P, K and organic C were highly negatively correlated under all age and fertilizer treatments at $p<0.05$. It was also observed that only mineral N in 1 y 8 m were negatively correlated and was not significant towards the growth parameters as well as for TAGB and root biomass at both soil depths. A similar trend was found for chengal seedlings under the different fertilizer treatments. It was also observed that the correlation between TAGB, root biomass and soil mineral content was greater in the 6 m old chengal seedlings compared to 1y 8m old seedlings. Furthermore, the correlation between the different fertilizer treatments was higher in the case of the combined fertilizers compared to applications of SRF and organic fertilizer alone. The correlation between soil mineral content and organic C were strongly and positively correlated to each other at both depths under all level of fertilizer application and age of chengal seedlings.

4.3.2.7 Correlation of growth towards TAGB, root biomass and soil physical properties

The correlation of growth towards TAGB, root biomass and soil physical properties for chengal seedlings at 6m and 1 year 8m are shown in Tables 4.35 and under the different fertilizer treatments in Tables 4.36. The results showed a strong significant relationship. Correlation between growth, TAGB and root biomass and the soil physical parameters were significant at $p< 0.01$ for CEC and clay and at $p < 0.05$ for silt, for all age and fertilizer treatments. However, growth, TAGB and root biomass were not significantly correlated with fine and coarse sand. It was also observed that CEC and clay were significantly negatively correlated to fine and coarse sand. However, all other soil parameters positively correlated towards each other.

Table 4.35: Correlation of growth towards TAGB, root biomass and soil physical properties of 6m and 1 year 8m seedlings

(a) 1 y 8 m	Height	Diameter	TAGB	Root biomass	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1								
Diameter	0.990**	1							
TAGB	0.968**	0.973**	1						
Root biomass	0.968**	0.973**	1.00**	1					
CEC	0.752**	0.722**	0.716**	0.716**	1				
Clay	0.340**	0.293**	0.308**	0.308**	0.315**	1			
Silt	0.832*	0.786*	0.785*	0.785*	0.777*	0.519*	1		
Fine sand	0.773	0.748	0.659	0.659	-0.506	-0.411	0.734	1	
Coarse sand	0.731	0.708	0.606	0.606	-0.512	-0.417	0.717	0.994	1
(b) 6 m	Height	Diameter	TAGB	Root biomass	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1								
Diameter	0.990**	1							
TAGB	0.961**	0.967**	1						
Root biomass	0.961**	0.967**	1.00**	1					
CEC	0.799**	0.785**	0.795**	0.795**	1				
Clay	0.442**	0.426**	0.443**	0.443**	0.298**	1			
Silt	0.911*	0.873*	0.845*	0.845*	0.794*	0.401*	1		
Fine sand	0.724	0.704	0.724	0.714	-0.525	-0.469	0.708	1	
Coarse sand	0.680	0.679	0.688	0.688	-0.540	-0.533	0.716	0.925	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter, TAGB and root biomass n = 30; soil physical properties n = 5

Table 4.36: Correlation of growth towards TAGB, root biomass and soil physical properties under different fertilizer treatments

(a) SRF	Height	Diameter	TAGB	Root biomass	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1								
Diameter	0.989**	1							
TAGB	0.964**	0.973**	1						
Root biomass	0.964**	0.973**	1.00**	1					
CEC	0.745**	0.770**	0.780**	0.780**	1				
Clay	0.450**	0.479**	0.465**	0.465**	0.410**	1			
Silt	0.810*	0.828*	0.845*	0.845*	0.838*	0.539*	1		
Fine sand	0.701	0.704	0.616	0.673	-0.680	-0.287	0.767	1	
Coarse sand	0.670	0.678	0.589	0.597	-0.645	-0.274	0.749	0.992	1
(b) Organic	Height	Diameter	TAGB	Root biomass	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1								
Diameter	0.988*	1							
TAGB	0.976**	0.975**	1						
Root biomass	0.976**	0.975**	1.00**	1					
CEC	0.800**	0.805**	0.843**	0.843**	1				
Clay	0.658**	0.642**	0.535**	0.535**	0.507**	1			
Silt	0.936*	0.932*	0.852*	0.852*	0.741*	0.580*	1		
Fine sand	0.654	0.695	0.673	0.616	-0.534	-0.428	0.660	1	
Coarse sand	0.596	0.633	0.597	0.589	-0.511	-0.387	0.543	0.989	1
(c) SRF + organic	Height	Diameter	TAGB	Root biomass	CEC	Clay	Silt	Fine sand	Coarse sand
Height	1								
Diameter	0.993**	1							
TAGB	0.972**	0.971**	1						
Root biomass	0.972**	0.971**	1.00**	1					
CEC	0.809**	0.798**	0.758**	0.758**	1				
Clay	0.322*	0.306*	0.373**	0.373**	0.216	1			
Silt	0.900*	0.888*	0.848*	0.761*	0.429*	0.267*	1		
Fine sand	0.805	0.789	0.813	0.813	-0.529	-0.391	0.827	1	
Coarse sand	0.766	0.750	0.782	0.782	-0.468	-0.354	0.797	0.996	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Growth parameter, TAGB and root biomass n = 30; soil physical properties n = 5

Furthermore, 6 m old chengal seedlings exhibited the highest correlation compared to the 1y 8m old seedlings. In addition to that, fertilizer applied in combination gave the highest correlation compared to SRF and organic fertilizer alone.

4.4 Discussion

4.4.1 Biomass of chengal seedlings under different light treatments in the nursery

Different light intensities at the nursery strongly affected the dry weight of biomass fractions (leaves, stem and root) and leaf number of chengal potted seedlings at 6 and 12 months with highest growth under 50% LI compared to seedlings grown under of 30% and 100% light intensities. As was discussed earlier in chapter 3, in the early stages of growth of the chengal seedlings, a light intensity of 50% exhibited the best growth compared to 30% LI and the least growth was observed under 100% light intensity for growth parameters namely height and diameter. These results showed same pattern and are in accordance to biomass quantification of chengal seedlings in the nursery. The results showed that the dry weight of the chengal species increased with increasing shade intensity, indicating that the seedlings are preferentially shade tolerant.

Plant has an optimal intensity of light to obtain the optimum gowth including its biomass content. Light is generally recognized as the most influential environmental factors that affect the growth of trees (Karsai et al., 2008; Neri et al., 2003). Seedling regeneration in a forest generally depends very much on light, which is the most limiting and fundamental resource in a forest ecosystem (Philipson, 2009). A study by Affendi et al. (2010), who studied the shade tolerant species *Orthosipon stamineus* and observed that the highest total biomass was recorded in plants under 50% light intensity compared to plants under 30% and 100% light intensity. In this study, the total biomass of chengal seedling under 30%, 50%, 100% LI were 70.45, 83.65, 63.97 g, respectively. Aerial biomass of seedling under 30%, 50%, 100% LI were 59.76, 66.91, 53.80 g, respectively. Lastly, root biomass of those seedlings under 30%, 50%, 100% LI were 10.69, 16.74, 10.17 g, respectively. These figures were much higher than the values recorded for *Orthosipon stamineus*, which recorded a total biomass of 31.08, 41.99 and 23.19 g for 30%, 50% and 100% LI, respectively. *Orthosipon stamineus* aerial biomass recorded 16.76, 23.03 and 11.75 for 30%, 50% and 100% LI, respectively. Lastly the root biomass was 13.33, 14.56 and 8.77 for 30%, 50% and 100% LI, respectively. The percentage increase of total biomass of chengal compared to *Orthosipon stamineus* was at least an average of 9%, 8% and 24% for the 30%, 50% and 100% light intensity treatments, respectively. Osunkoya et al. (2010) and Houter and Pons (2014) reported that plants at the lower end of the light gradient enhance their light interception, as light becomes a limiting source. Likewise, the study of Rawat et al. (2011) revealed that seedlings of climax species can tolerate shade better as indicated by greater biomass particularly in low light condition. According to Gregorio et al. (2011), light affects the synthesis of food within seedling and enhance assimilation of carbon dioxide. It interacts with air temperature in controlling growth rates, and increasing temperature increases the rate of photosynthesis. Plants have a mechanism to dispose excess excitation energy when the irradiance level was beyond light response curve. Lambers et al. (2008, 2011) pointed out that when these mechanisms worked, the quantum of photosynthesis was temporarily reduced. This often occurs at high irradiance in many plants.

The results of this study are also in agreement with the results reported by Khaliq et al. (2013), where tree species of *Acacia niltica, Prosopis cineraria* and

Leucana leucocephala's dry weights were highest under half shade treatment. Chanhsamone et al. (2012) studying *Hopea ordorata*, a light hardwood and fast growing species, reported a similar result, where the lowest biomass mean value was observed in plants under 30-50% light intensity, but showed a significant increase in total biomass when light intensity was increased. He also reported a significant difference in leaf number of plants grown under different light intensities. Dipterocarp seedlings showed the highest number of leaves under 50-70% light intensity treatment, followed by 30-50% LI and the lowest number was seen under 100% LI treatment.

Amongst others, similar results were reported by Philipson (2009) who showed that the number of leaves exhibited a strong relationship with species specific light intensity from family Dipterocarpaceae namely *Hopea, Shorea* and *Dryobalanops*. In this study, the chengal seedlings performed best under 50% LI and this indicates that it is a shade tolerant species and prefers low to moderate light intensity for optimum biomass production, during the early stages of its development.

It is well documented that light affect biomass allocation in plants (Poorter et al., 2012). Many studies previously have focused more on plant growth rather than plant biomass (Paine et al., 2012; Wright et al., 2011; Rincon & Huante, 1993; Popma & Bongers, 1991). AKECOP (2010), reported that the total biomass of leaves, stems and roots of two-year-old *Pterocarpus indicus,* a shade tolerant hardwood, were significantly affected by different light intensities of 30%, 65% and 100%. In addition, they reported that biomass allocation was found to be in the order of: leaves > stems > roots, similar to the results obtained in this study.

4.4.2 Biomass of chengal seedlings under different fertilizer treatments in the nursery and field

4.4.2.1 Nursery

Fertilizing chengal seedlings significantly increased the dry weight of leaves, stems and roots as well as leaf number of the potted seedlings in the nursery after 6 and 12 months. NPK Blue fertilizer recorded the biggest increase in dry weight of the biomass fractions compared to goat dung (organic fertilizer) and the control (no fertilizer). The average biomass dry weights of total biomass, aerial biomass and root biomass of the chengal seedlings under NPK Blue, goat dung and control treatments were 50.2, 32.76, 17.4:42.26, 31.34, 10.92: 36.15,26.18,9.97 g, respectively. These values are high but comparable to the data obtained in a study by Affendi et al. (2010) on *Orthosipon stamineus*, where goat dung and control registered (20.65, 10.09, 10.56 : 14.10, 6.31, 7.81) g for total biomass, aerial biomass and root biomass respectively. The percentage increase of total biomass of chengal compared to *Orthosipon satmineus* were at least on average, 50% and 61% for goat dung and control respectively. The higher percentage nutrient content of N, P and K have contributed to the higher total biomass of chengal treated with NPK Blue fertilizer compared to any other fertilizer.

Recently Focho et al. (2011), studying *Khaya ivorensis* seedlings, a medium, durable hardwood, in the nursery, reported that treatment with different levels of organic fertilizer, with different levels of mineral N and P, showed significant differences in dry weights of total biomass of leaves, stems and roots. The total biomass of the *Khaya ivorensis* seedlings with fertilizer recorded an average increment of 18 g and the control, 5 g, which were very low compared to the potted chengal seedlings in this study. Fertilizer studies on other pot-grown dipterocarp species have shown that an application of NPK at a rate of 10 g per plant, had a significant effect on the growth and biomass of the dipterocarp species 6 months after the treatments were given (Marzalina, 2013; Turner, 1993). Sundralingham (1983), Kumar et al. (2013) and Dong et al. (2014) also reported that application of NP (0.3 g N + 0.05 g P_2O_5) on pot-grown *Dryobalanops oblongifolia* and *Dryobalanops aromatica,* medium hardwood species, improved seedling growth and indirectly increased the biomass production of these seedlings after 6 months. These results suggested that NPK Blue fertilizer will have a greater impact on the biomass quantification of chengal potted seedlings compared to an organic fertilizer and control. The results could have been due to the NPK Blue fertilizer having a higher percentage of nitrogen and phosphorus than organic fertilizer, the latter containing only 11% of nitrogen and 5% of phosphorus. Phosphorus applied to potted seedlings had a significant positive effect on seedling performance following out-planting in dipterocarp species in peninsular Malaysia (Hashim et al., 2015; Kettle, 2010; Raja Barizan et al., 2000; Nussbaum et al., 1995). Differences in response to the fertilizers, by the different dipterocarp species, were not simply due to the amount or type of the fertilizer added, but also probably a result of the appropriate different levels of light intensity required by the different species.

Furthermore, a study by Irino et al. (2005) reported that the number of leaves under different organic and inorganic fertilizer treatments in pot-grown seedlings of *Dryobalanops lanceolata* were significantly different. They reported that seedlings given chemical (inorganic) fertilizer treatment recorded a higher number of leaves compared to seedlings given organic fertilizer. However, Focho et al. (2011) reported that treatments of *Khaya ivorensis* seedlings in the nursery with different levels of organic fertilizer (different levels of mineral N and P) showed significant differences with regard to leaf number compared to those treated with combination of higher level amount of N and P fertilizer. However, there were no significant differences for those seedlings which were not applied with any fertilizers.

In addition, a study by Napoles et al. (2014) on *Hopea plagata* showed that seedlings applied with fertilizer had higher sequestration of carbon compared to seedlings with no fertilizer. According to Lambers et al. (2008, 2011) factors such as inadequate supply of nutrients greatly increase the proportion of photosynthesis used in respiration and this was accounted by much stronger effect of nutrients on biomass allocation when compared with that of irradiance. According to Suzuki et al. (2010), N, P and K uptake by the roots and further the nutrients assimilation are integrated in the plant to match the nutrient demand of the seedlings. Furthermore, the stimulation of N, P, K uptake and assimilation by photosynthesis ensures that N, P, K uptake is correlated with carbon status. Hence, application of N, P, K fertilizer could significantly affect the biomass production of a seedling.

4.4.2.2 Field

Addition of fertilizer greatly affected the biomass production of chengal seedlings planted in the field. Seedlings fertilized with a combination of SRF and organic fertilizer, gave the highest and significant biomass production for AGB and root biomass, compared to application of SRF and organic fertilizer separately. The use of SRF + organic fertilizers in combination, produced 121.16 and 29.07 Mg ha^{-1} for TAGB and root biomass respectively and were higher by 15% and 38% compared to SRF and organic fertilizers applied separately, after 44 months of planting. These mean values recorded for biomass production are much higher than that recorded with 16 year old

Shorea leprosula planted in a multi storied forest, where it only recorded 59.62 and 19.80 Mg ha^{-1} for TAGB and root biomass (Heriansyah et al., 2013). The nutrient content of SRF which consisted of 19:10:13% nitrogen:phosphorus:potassium and goat dung with 11:5:11% nitrogen:phosporus:potassium have contributed to the highest biomass production in the field. The results have shown that an addition of extra nutrients could improve the growth performance and indirectly the biomass of chengal stands in logged over forest.

The results of this study can also be compared with other inorganic nutrient addition experiments with dipterocarp species. A number of studies have shown an increase in the biomass of *Dryobalanops* species, by at least 30%, with additions of N, P and K (Dong et al., 2014; Kumar et al., 2013; Hashim & Hughes, 2010; Brearley et al., 2007; Yap et al., 2000; Yap and Moura-Costa, 1996; Sundralingham, 1983) to more than 200% (Nussbaum et al., 1995) on degraded soils. However, Bungard et al. (2002) and Santiago & Goldstein (2016) did not see a growth response when N, P and K were added to *Dryobalanops lanceolata* in the forest understorey, as well as for *Alstonia spatulata* and *Parartocarpus venenosus* in a peat swamp forest, but there was a change in the photosynthetic physiology, with an increased rate of photosynthetic induction. In the studies of Yap & Moura-Costa (1996), Yap et al. (2000) and Bungard et al. (2002), it was suggested that nitrogen was the primary limiting nutrient to the growth of *Dryobalanops lanceolata*. Nitrogen, phosphorus, and potassium are three important nutrients, which are required in larger quantities than other nutrients, which are commonly considered to be deficient in most soils for field and vegetable crops, bedding plants, and turf. Even though hundreds of field experiments have shown that most soils contain sufficient levels of phosphorus and potassium for trees and large shrubs, complete fertilizers (N, P, K) are still universally recommended for planting trees especially in a logged-over forest (Janowiak & Webster, 2010; Swanson & Rosen, 1989).

The decrease in soil nutrient content with increasing forest age may relate to changes in biomass and nutrient stocks in the aboveground parts of the secondary forest. In addition, rapidly increasing aboveground biomass and nutrient stocks usually occur in tropical secondary forests during the first 10 to 20 years after degradation (Kenzo et al., 2011; Johnson & Curtis, 2001). These rapid accumulations in aboveground matter may be achieved by rapid nutrient absorption from the soil. Therefore, application of combination fertilizer with extra nutrient has compensated with the nutrient absorption from soil and accumulated the biomass and carbon stocks of chengal planted in the logged-over forest. The increase in biomass production could be attributed to the fact that nutrients were more readily available when organic and inorganic fertilizers were combined. The addition of organic fertilizer increased the water holding capacity and reduced the incidence of leaching thereby making more nutrients available to the soil (Eifediyi & Remison, 2010). Stuart (2000), mentioned that combination of inorganic fertilizer, which comprises more mineral nutrient and organic material improved and rejuvenated the physical condition, soil mineral, texture of the soil and as well as the soil fertility. When a crop plant is grown with a limiting supply of an essential nutrient, it produces less biomass than if the limiting nutrient were more available.

4.4.3 Effect of chengal seedling age on biomass quantification in the field

Chengal seedling age definitely affected biomass quantification in the field. Older 1y 8m seedlings contributed to the highest allocation of biomass quantification and carbon stock at all months compared to 6m old seedlings. The biomass and carbon stock quantification ratio of 1y 8m was higher by 11.3 - 33.9 % compared to 6m old seedlings after 44 months of planting. This result was as predicted and exhibited a similar pattern as growth parameters of chengal seedlings in the field, since biomass quantification are directly calculated using an equation, which incorporates basal diameter as one of the factors. After 44 months of planting, the older and bigger 1y 8m seedlings registered an aerial (leaves and stem) and root biomass of 108.95 and 26.15 g respectively, whilst the younger and smaller seedlings had an aerial and root biomass of 90.28 and 21.60 g, respectively. These results concurred with those reported by Philipson (2009). His study on Bornean Dipterocarpaceae seedlings namely species of *Shorea, Hopea* and *Dryobalanops* after one year in a shade house, significantly recorded a high relationship on large seedling size to its growth. Larger seedlings produces higher increment of height and diameter compared to a smaller seedling. All seedlings of *Hopea plagata, Shorea macrophylla, Shorea leprosula, Shorea johorensis* and *Dryobalanops lanceolata* having larger sizes produced more mass than smaller seedlings. It was evident that smaller seedlings did not catch up or overtake larger seedlings within the period of one year. The shallower slope of relationship between seedlings size and total seedling mass indicated that larger seedling individuals produced more mass than smaller seedling individuals. Size advantage bestowed from a greater maternal investment in seed size enables the larger seeded individuals to grow faster and stay larger than the smaller-seeded species (Philipson, 2009).

This agreement in results can be explained where larger seedlings species produce bigger plants as well as lose less mass in relative terms during that transition from seed to seedlings and later to saplings. Therefore, having more dry weight as well as carbon stock in larger plants compared to smaller ones (Turnbull et al., 2012; Cornelissen, 1996). The growth and biomass patterns in this study of older chengal were also of the advantages of greater seedlings size, such as the ability to intercept more light than those below or for deeper rooted seedlings with the ability to absorb more water in times of low soil water potential (Ruger et al., 2011; Turner, 2001).

4.4.4 Effect of age and fertilizer treatments on carbon stock of chengal in the field

Carbon stock as stated by Chave et al. (2005) is 47 - 50% of biomass. Tree biomass is defined as the total mass of living organic matter in tree produced by photosynthesis and can be expressed as oven dried biomass per unit area. In this study, carbon stock of chengal seedlings in logged-over forest was influenced by different age and fertilizer treatment. As can be predicted, similar pattern results as biomass were gained for chengal carbon stocks in the field. Older and bigger seedlings contributed to a higher mean of carbon stock compared to a smaller and younger seedling by 17.2% after 44 months of planting in the field. Combination of fertilizer of both SRF + organic also impacted the carbon stock of chengal the most compared to only application of SRF and only organic fertilizer by 14.6% and 37.9% respectively. The mean carbon stock of chengal planted regardless of age and fertilizer treatment recorded in this study for total above ground and root carbon stock (below ground) were 47.02 Mg ha^{-1} and 11.29 Mg ha^{-1}. These values are considered very high compared to a study by Kirby and Potvin (2007), where total above ground and root carbon stock for saplings with DBH of 1–10 cm were (13.1 ± 1.2) Mg ha^{-1} and (3.1 ± 0.3) Mg ha^{-1} respectively. These values are way higher by 72.2 % and 73.0% for both above ground and root carbon stock respectively. The result of lower C value in Kirby and Potvin (2007) study was due to the forest was actively managed by community members from timber and non-timber forest products. Although selective logging removes only a limited number of desirable trees from a forest leaving an intact, but “thinned” forest canopy, it can have a negative impact on forest C stocks.

Another research by Lee et al. (2015) at Kuala Belalong, a lowland mixed dipterocarp forest showed that all species with the DBH range of (1.0 - 9.9) cm only recorded a total above carbon stock of (29.2 ± 1.2) Mg ha^{-1} lower by 38% compared to chengal in our study. Where else, belowground biomass recorded 32.6 Mg ha^{-1} which is higher than chengal by 65%. Even though the root carbon stock value of chengal is much lower, this value is comparable to other species since chengal in this study are only 44 months after planting with the mean basal diameter of 2.96 cm compared to the species in Lee’s study where the carbon stock values covered the DBH range of (1.0 - > 100) cm for all species. Other than that, the different values obtained in Lee’s and our study might be due to chengal in this study was planted at a cleared area and the light penetration towards under canopy trees were more. Therefore, after initial stages of chengal establishment, light became essential and the growth of these stands were greater leading to greater biomass and carbon stock. Dipterocarp species in Lee’s study were at a forest canopy of 30-40m in height and the density of tall trees was high.

Heriansyah et al. (2013) reported on *Shorea leprosula* carbon content (a medium hardwood and fast growing species), where at the age 16 years, those trees measured a total carbon of 34.76 Mg ha^{-1} with 24.86 Mg ha^{-1} of aboveground biomass and 9.90 Mg ha^{-1} of root biomass. Chengal despite having slow growth and at a younger age, still indicated a higher production of carbon stock content compared to an older age of *Shorea leprosula.* As described by Hamdan et al. (2015) in a lowland dipterocarp forest in Pahang, trees with a DBH < 10 cm are considered as saplings. In his study, saplings contributed to 1% (2.46 Mg ha^{-1}) of the total AGB in the forest after ten years of logging using the equations developed by Kato (1978) and Chave et al. (2005). Another study by Ngo et al. (2013) in the secondary forest of Singapore after 10-20 years of logging, indicated that saplings of 1-10 cm DBH contributed to 11.53 Mg ha^{-1} of total AGB.

Initially, combination fertilizer has influenced the carbon stock value of chengal after 44 months of planting compared to only application of SRF and organic fertilizer. This result is concurred by a study done by Heriansyah et al. (2013), where combination organic material fertilizer of 67% compost gave the highest biomass increment which indirectly increases the carbon stock value. Therefore, it can also be concluded that combination of inorganic fertilizer, which comprises more mineral nutrient and organic material improved and rejuvenated the physical condition, soil mineral, texture of the soil and as well as the soil fertility. When a crop plant is grown with a limiting supply of an essential nutrient, it produce less biomass than if the limiting nutrient were more available (Stuart, 2000).

4.4.5 Effect of light and fertilizer treatments on chengal seedlings plant mineral content in the nursery

Different light and fertilizer treatments contributed to a significant difference in leaf, stem and root mineral content treated after 12 months in the nursery, whereby light intensity of 50% gave the highest plant mineral content compared to 30% LI with the lowest under 100% LI. Fertilizer treatments also had a significant impact on the mineral content of chengal seedlings. As was reported in the results section, NPK Blue recorded the highest values compared to goat dung and control. Control with no fertilizer applied gave the lowest mineral content.

Responses to nutrient addition (fertilizer application) by both temperate and tropical tree species are known to depend on light availability (Mayor et al., 2014; Yavitt et al., 2011; Bungard et al., 2000), with more responses usually occurring in moderate to higher light levels (Coomes & Grubb, 2000). Light affects nutrient uptake indirectly through photosynthesis, which provides energy (ATP) for active transport, and produces carbon skeletons that are necessary for incorporation of nutrient ions into larger molecules (e.g., amino acids and proteins) as well as increases the growth rate thus increases the need for nutrients. Optimum light exposure leads to ideal level of photosynthetic light saturation and also optimum quantum efficiency which generates better ATP.

It has also been shown that application of fertilizer on *Shorea curtisii* in small canopy openings and *Hopea beccariana* under closed canopy (under low light intensity) showed no significant improvement in growth (Dong et al., 2014). The absence of a clear response observed was probably due to the very low (below 30% LI) or very high light level (above 70% LI) rather than the level of nutrients, as the seedlings were unable to respond to the added nutrients (fertilizers). It was thus believed that fertilizing seedlings under lowest and highest light level will not be significant and beneficial to the growth of dipterocarp seedlings. This can be seen from the results obtained in this chapter, where the mineral content recorded was lowest under 100% and 30% LI even when given sufficient fertilizer.

Amongst others, Kumar et al. (2013) and Dong et al. (2014) found that nitrogen rather than phosphorus was the most important element required for improved growth of potted *Shorea ovalis* and *Hopea ordorata* seedlings. Similarly, Gregorio-Perez et al. (2011) reported that potted *Shorea palosapis* seedlings showed improved growth and increased nutrient uptake at higher fertilizer levels, particularly when moisture supply was abundant. Nutrient supply type and rates to the soil ultimately govern the amount of nutrients acquisition by plants (Lambers et al., 2008). In this study, chengal seedlings were fertilized with NPK Blue which had higher concentrations of mineral nutrients have generated more uptake of nutrient by roots to the other parts of the seedlings. The results of leaves:stem:root mineral ratio percentage of chengal seedlings for all light and fertilizer treatments were 53.0:26.9:20.1% for N, 46.7:21.2:15.1% for P and 63.7:35.1:18.2% for K, respectively. Indicating in general that leaves had double N, P and K compared to stem and root. During early development of seedlings, leaves represent a major store of nutrients compared to stem and roots (Abdallah et al., 2010).

Similar findings to that reported in this study have been reported in several previous studies on tropical conifers and broad leaved species, where the highest concentrations of N, P and K were reportedly found in foliage and lower in bark, branch and stem (Alvarado, 2016; Xu-hai, 2011; Drechsel & Zech, 1993). Rates of nutrient uptake depend on the quantity of root surface area and the uptake properties of this surface (Lambers et al., 2008). Once nutrients arrived at the root surface, these must pass through the plasma membrane of the root cells. As with carbon intake through photosynthesis, the rate of nutrient uptake depends on both the concentration in the environment and the demand by the plant as well as on the inherent capacity of a plant to take up certain nutrients. The plant's demand is determined by its growth rate and the concentration of the nutrients in the tissue. At a high internal concentration, the capacity for uptake of the nutrient tends to be down-regulated so as to avoid nutrient toxicity. Despite this feedback mechanism, plants may show luxury consumption of specific nutrient (e.g., absorption at a higher rate than required to sustain growth), leading to accumulation of that nutrient as shown in this study of chengal.

4.4.6 Effect of different age and fertilizer of chengal seedlings on soil mineral content from nursery to field

Soil mineral content from chengal potted seedlings to planted chengal under different fertilizer treatments and age of those saplings had influenced the soil mineral content. NPK Blue was found to impact the soil mineral content the most compared to goat dung and control for chengal potted seedlings. In the field, combination fertilizer contributed to greater soil mineral content compared to SRF and the least was under organic fertilizer for both depths. Combination fertilizer which contains more mineral concentration of N, P, and K than only SRF and organic has enriched the soil more and better for the uptake of chengal seedlings (Hamzah et al., 2009). The soil mineral content of 0-20 cm was higher by (16, 27, 9 and 14) % for N, P, K and organic C, respectively compared to 20-40 cm depth regardless of age and fertilizer treatments of chengal seedlings. This is because in any type of forest, the top 6" of soil contains the most nutrients needed for plant growth. Other than that, the litter fall, dry wood and other organic living or dead materials which fall to the floor of the forest even on a degraded forest contributes to improving and enriching the top soil rather than a deeper soil depth (Campbell et al., 2010). It was also observed that, the percentage of total P was higher by 99% compared to N, K and organic C for soil treated under different light, fertilizer and age of chengal seedlings in the nursery and field. The proportion percentage ratio of N:P:K:organic C were recorded as (99:0.08:0.1:0.7)% for all soil of chengal seedlings at all light levels, fertilizer and age treatments.

This similar findings is also expressed by Turner & Wright (2014) where addition of fertilizer to dipterocarp seedlings significantly increased the concentration of mineral P by at least 46% compared to other minerals (N,K and organic C) in the soils of a lowland forest. Turner et al. (2014) found that soil organic P was highly and significantly affected by addition of fertilizer, whereby mineral N, K and organic C were not affected but varied seasonally. Overtime, all soil organic minerals decreased after one year of measurement period in the field. On the other hand, exchangeable bases and other minerals of N, P and organic C were lower at the field compared to the nursery. This may be due to some pioneer trees such as Macaranga, grew rapidly, and all the minerals were absorbed by the trees (Hattori et al., 2013). A study by Liu et al. (2010), on a maize crop land resulted in a significant change in soil mineral properties of N, P, K and organic C after application of combination of NP fertilizer (organic) and farmyard manure (inorganic) compared to those fertilizer applied singly and also without any fertilizer applied. In addition organic fertilizer NP contributed higher soil mineral content compared to only application of inorganic fertilizer. All soil properties of N, P, K and organic C increased compared to the initial soil content and decreased throughout measurement period. Application of NPK Blue fertilizer for chengal potted seedlings and later combination fertilizer to chengal seedlings in the field generally increased the soil NPK and organic C to a much greater extent than that of inorganic or organic fertilizer alone. Firstly, it increased the growth in term of height and diameter as well as the biomass content. The inputs of above and below ground organic residues (e.g., roots) are increased, therefore N, P, K and organic C contents are raised. Secondly, combination fertilizer added plots might have slower breakdown rate (less and constant mineralization rate). Similarly in a long term experiment by Masto et al. (2006), he observed that the NPK was considerably greater in soils receiving farmyard manure (organic) along with NPK fertilizer in plots receiving merely NPK fertilizer or organic fertilizer alone. The soil mineral contents of N, P, K and organic C were also found to decrease throughout measurement period. The decrement was mainly due to leaching of litter fall on the forest ground. Furthermore, planting of chengal were done at an open space and there were not many pioneer species or other big trees which could possibly contribute to litter falls even though fertilizer were applied at initial time of planting (Jean Dalmo et al., 2015)

Other than that, it has also been observed that there was a near 100% increment on soil mineral content of chengal potted seedlings in the nursery from 6th to 12th month under different light and fertilizer treatment. As we know, many biotic and abiotic factors affect the nutrient (N,P,K) uptake of a plant including light intensity that allow absorption of amino acid (Jean Dalmo et al., 2015). In this study, 100% increment of soil mineral from 6th to 12th month observed were mainly due to the continuous monthly fertilizer application on chengal seedlings throughout the measurement period in the nursery. Even though there was nutrient uptake by chengal plants from the soil but the addition of fertilizer has enhanced the mineral content.

On the contrary, soil mineral content of chengal seedling in the field was found to decrease by nearly 50% from 22nd month up to 44 months after planting for both depths of 0-20 cm and 20-40 cm (Table 4.26). As we are concerned, the soil in the field is subjected to environmental factors such as heavy rain, leaching, erosion and others. Furthermore, fertilizer was only applied once during the initial time of planting. Leaching of fertilizers in the forest is possible, therefore the decrement occurrence is higher (Raja Barizan et al., 2000).

Meanwhile age of chengal was found not to affect the soil mineral in the field except for mineral N. In this study, the age group of 1y 8 m and 6 m seedlings may need the same requirements of all the minerals NPK and organic C regardless of different fertilizer application. The higher soil N mineral observed in this study is similar to the results by Bhandari et al. (2002), where he found that total N was higher when combination fertilizer were applied together with inorganic fertilizer compared to only application of both fertilizers singly. This may be due to particularly slow release of N from the fertilizers, resulting in smaller losses of N compared to other minerals.

4.4.7 Effect of different age and fertilizer of chengal seedlings on soil physical characteristics from nursery to field

Soil physical characteristics of chengal planted in the field did not vary significantly under different age and fertilizer treatment for two depths of 0-20 cm and 20-40 cm. The lack in difference between nutrient contents of soil also suggests that, all nutrients were taken up in proportions to its availability and needs. The percentage of coarse sand of potted chengal in the nursery was higher by an average of 30% compared to fine sand for both months regardless of fertilizer treatments. Meanwhile, the percentage of coarse sand at the field was higher by an average of 21% compared to fine sand for 0-20 cm depth, at 34% for 20-40 cm depth at both months regardless of age and fertilizer treatments. Silt and clay were recorded to have the higher value at all months regardless of fertilizer and age treatment. Basically soil with heavy clay has more positions to hold cation, thus the soil had higher CEC. These findings were also supported by Raja Barizan et al. (1998), where the analysis of soil showed that the percentage of coarse sand to be higher in soils compared to fine sand. It was also recorded in that study that silt and clay recorded a high concentration given different fertilizer treatments.

Second layer of soil depth of 20-40 cm was also observed to have lower concentrations of all soil physical elements compared to upper/first layer of 0-20 cm depth. As explained earlier the organic and inorganic matters from litter fall and other living organism in soil has increased the soil physical texture and properties of first layer of depth compared to a deeper one. Other than that, all soil physical elements in the field recorded higher concentrations compared to the soil of potted chengal. Based on these data, the soil at the planting site displayed favourable conditions for dipterocarp especially chengal tree planting due to the relatively high levels of CEC, increasing concentrations of soil physical elements even before planting up to 44th months of planting. This directly indicates that an appropriate soil texture (higher percentage of coarse sand compared to fine sand) and inclination had prevented substantial loss of soil nutrients by leaching (Hattori et al., 2013)

Soil physical characteristics of chengal seedlings did not differ significantly under different age group. However, smaller and younger chengal contributed to the highest value for all soil physical characteristics value for both depths compared to an older and bigger seedling in the field. However, a research done by Chen et al. (2010) on forest plantation in China found a significant effect of stand age to soil physical properties which were grouped to three classes of age stands 12-14 years young, 20-25 years mid-aged and 32-40 years old. The results of the analysis revealed a strong stand age effect on the content of coarse and fine sand, silt and clay, but no effect of interaction between the site and stand age. In particular, the relative amount of fine sand and silt increased in the old plantations and coarse sand decreased. In this study, chengal age of 1y 8 m and 6 m did not differ much in the age and therefore did not affect any changes on the soil physical characteristics regardless of fertilizer application as unless there was a major disturbance on the environment or to the soil through leaching or erosion. It was also observed that soil physical elements of chengal potted seedlings during one year in the nursery and it also increased throughout measurement period of 44 months in the field. On the contrary, Chen et al. (2010) reported a significant decrease of silt and clay fractions in young plantations (12-20 years) throughout, suggesting the likely role of wind erosion of soil particles. Dong et al. (2014), has similarly reported that human disturbance associated with logging activities apparently promotes wind erosion by decreasing herb cover and increasing soil bare time. Our study plot of chengal has only been established for 44 months, therefore the stand age is still younger compared to that study by Liu et al. (2010) and to date there were no anthropogenic factors recorded at the study site.

Meanwhile, the soil pH of potted seedlings and planted chengal was only affected by fertilizer applications and decreased throughout planting period. Soil pH became less acidic with the increment of soil physical characteristics under different fertilizer and age in the nursery as well as in the field. The acidic nature of the soils might be due to the loss of exchangeable bases through uptake by plants and leaching under different environment (Hamzah et al., 2009). Similarly, Liu et al. (2010) found that soil pH values were lower by the addition of farmyard manure (organic fertilizer) and inorganic fertilizer on maize crop land compared to those applied by inorganic and organic alone. In addition, the soil pH was observed to decrease from the initial time of planting. The nitrogenous fertilizers could decrease soil pH (Hati et al., 2008). This is mainly due to the fact that most fertilizers supply N as NH_4^+ first, which upon oxidation releases H^+ ions (Magdof et al., 1997).

4.4.8 Relationship between growth, TDW and plant mineral content in the nursery and field

Light, fertilizer and age of chengal were significantly correlated between growth parameters, total dry weight and plant mineral content (N, P, & Organic C) at $p< 0.01$ (height and diameter) and $p<0.05$ for total dry weight and plant minerals. Fox et al., (2012) and Ruiz-Jaen and Potvin, (2011) in their study also support the relationship found in this study, where trees accumulate nutrients as their biomass increases. Based on the dry weight of plant, the highest accumulation of nutrients will be parallel with the growth. A study by Irino et al. (2005) also supports the results from this study where, pot-grown *Dryobalanops lanceolata* seedlings with controlled release fertilizer in the nursery showed a good performance in terms of growth and biomass accumulation. This is because of the sufficient amounts of nutrients accumulated in plants with a sound shoot form at the nursery stage.

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 amount of N, P, K in the soil was due to a 'dilution effect', the relative dry matter of the seedlings accumulated more rapidly than the rate of nutrient accumulation. This phenomenon was also verified by Clark et al. (2015) and Yang et al. (2012). Meanwhile, a research done by Raja Barizan et al., 1998 also verifies the findings on age of seedlings. The total dry weight of seedlings of *Hopea ordorata* was higher than the smaller ones but these smaller seedlings had higher concentrations of N, P, K and organic C than the larger seedlings. These same phenomena were also observed for *Dryobalanops oblongifolia*. Application of fertilizer significantly increased the biomass of the seedlings overtime but concentrations of minerals were diluted with age of the seedlings. It has often been observed that the young plants contain higher concentrations of N, P and K than older plants (Clark et al., 2015; Yang et al., 2012).

4.4.9 Relationship between growth, TDW and soil mineral content and soil physical properties in the nursery and field

Growth, total dry weight, soil mineral content and soil physical properties were correlated significantly among them from nursery to field. The application of both inorganic and organic fertilizer both in the nursery and field has influenced the correlation of chengal seedlings towards growth, TDW, root biomass as well as the soil mineral and physical concentration. These results agree with Gaiser et al. (2013) where, they explained that plant productivity is linked closely to organic matter. Organic matter also contributes to the stability of soil aggregates and pores, through the bonding or adhesion properties of organic materials. Moreover, organic matter intimately mixed with mineral soil materials has a considerable influence in increasing moisture holding capacity. In soils with less compaction, plant roots can penetrate and flourish more readily. High organic matter increases productivity and in turn, high productivity increases organic matter. Negative correlations of chengal growth parameters, TAGB and soil nutrient content towards chengal biomass and soil organic carbon under different age and fertilizer treatments might be due to biomass transfer. Biomass transfer from soil and root due to tree residuals and application of fertilizers at different levels and intensities may have contributed to depletion of soil organic carbon in the logged-over forest (Mathayo et al., 2016). Other than that, the negative correlations might be linked to the differences in soil types and environmental variables (Mann & Berg, 2014). The authors also mentioned that the soil organic carbon trend relates to precipitation and soil moisture content, thus this may have contributed to the deceleration of decomposition of organic matter. Even though, some litter falls were observed at the study site, but leaching due to heavy rains and slight erosions have resulted in depletion of soil organic carbon.

The correlation trend of growth, TAGB and root biomass towards soil physical elements where CEC and clay were significantly and negatively correlated to fine and coarse sand is also explained by Fulton et al. (2011). In which he pointed out that the amount of organic matter as well as the type and amount of clay largely determine the CEC of a soil. Soils which have a large amount of sand with very little clay or organic matter have little CEC or a reservoir to hold cationic nutrients. The high correlation between CEC and clay in this study also suggest that a larger fraction of negative charges is derived both from organic matter and clay minerals (Tanaka et al., 2009). It is noteworthy to note that the negative charge derived from organic matter and clay content is regarded as an important factor for nutrient retention capacity and is probably influencing the fertility status of the soils.

It was observed that silt and sand (fine and coarse) were positively correlated. Meanwhile, clay was negatively correlated with fine and coarse sand. This concurred with the study by Raja Barizan et al. (2008) in Hutan Simpan Berkelah, Pahang where sand and silt correlated positively. In her study, sand and silt increased and clay decreased after 2 years of planting in a logged-over forest. She mentioned that sand and silt in the forest especially at the edges are usually prone to wind erosion, therefore, silt would be leached first. But this is contrary with forest soil in a logged-over forest of Hutan Simpan Tekai, where planting was done in an open area with a canopy gap. The canopy gap is still covered by big trees and pioneer species, therefore wind erosion occurrences were rare.

4.5 Conclusion

After one year growing chengal potted seedlings in nursery and 44 months after planting chengal in logged over forest, fertilizer application, light exposure and seedling age at initial time of potting and planting, have produced various results. Adoption of NPK Blue fertilizer at nursery stage under partial light exposure of 50% has contributed to the highest dry weight, leaf number, plant mineral content of (N, P, K) and soil mineral nutrient especially N and other minerals of P, K, organic C. Meanwhile, bigger and older seedlings affected and increased the biomass, carbon stock as well as the foliar mineral content in the field compared to a smaller and younger seedling. Age group was also found not to affect the soil physical elements namely silt, clay, fine and coarse sand throughout planting period in the field. Soil pH varied at a less acidic value from nursery to field, given different fertilizer applications. All other experimental independent parameters factors of light intensity (30 and 100) % and application of organic and inorganic fertilizer singly have contributed to the lowest value for all investigated parameters of biomass, carbon stock, plant mineral content, soil mineral and physical elements in nursery as well as in the field. The results suggest that for a better yield of chengal stands in term of biomass production, application of NPK Blue fertilizer given 50% LI in the nursery should be adopted. Meanwhile, applying combined fertilizer and also opting for a bigger seedlings during initial time at planting would improve biomass growth and quality chengal stands in a logged over forest. The results from this chapter could also be essential if these factors of light, age and fertilizer be tested on physiological parameters of chengal seedlings in the nursery and planted in logged-over forest. Few scientific studies have indicated strong correlations between physiology and biomass allocation and their equal importance in determining growth rate of shade tolerance species. Therefore, the following chapter shall discuss and determine how physiological characteristics of chengal species which is known to favor shade is affected by different light, age and fertilizer treatments in the nursery as well as in logged-over forest.

CHAPTER 5 : PHYSIOLOGICAL PARAMETERS OF CHENGAL SEEDLINGS GROWN IN THE NURSERY AND FIELD UNDER DIFFERENT AGE, LIGHT AND FERTILIZER TREATMENTS

5.1 Introduction

Photosynthesis is an important process that is pivotal in the development of complex life forms on this planet. It results in the production of sugars, amino acids, fatty acids and a host of other compounds required in the myriad growth and maintenance processes in living organisms and is essential for plant growth and development (Zeinalov et al., 2005). Generally, an increase in photosynthesis would result in an increase in plant growth and development. However, it has been shown that a high photosynthetic rate does not necessarily translate into high wood production or yield unless the plants were given proper treatments starting from the nursery up to the planting site (Smith, 2005). Nevertheless rates of photosynthesis and other physiological parameters vary with tree species. A comprehensive compilation on photosynthesis and other physiological parameters of coniferous and tropical trees has been documented the last couple of decades (Santiago & Goldstein, 2016; Ceulemans & Saugier, 1991). As for dipterocarps, there is scarce information on its physiological parameters, especially regarding its photosynthetic characteristics.

Light is one of the most important environmental factors affecting plant survival, growth, reproduction and distribution. Light intensity affects photosynthesis and in turn, is related to the growth performance of plants, especially of seedlings. Moreover, to sustain higher photosynthetic capacity or survival, plants modify their morphology under different light conditions (Tuba & Lichtenthaler, 2011; Deng et al., 2006). For example, plants grown under low light intensities have lower growth (Devkota et al., 2010; Lentz & Cipolinni, 1998). However, different species, respond differently to light intensity. Light-demanding species are more flexible in both morphology and growth in response to light change than shade tolerant species (Valladares & Niinemets, 2008; Portsmuth & Niinemets, 2007; Lortie & Aarssen, 1996). The response of herbaceous crop and vegetable plants to shading has been well documented but much less is known with regard to tree species of dipterocarps. Pallardy (2010) cited that shading definitely affects the morphological and physiological performance of developing plants. Shade increases shoot growth at the expense of root growth, hence decreasing the absorption surface relative to transpiration surface. As for chengal species, it is well known that at a younger stage, it is shade tolerant but as it grows, the resistant decreases. As light intensity increases, the rate of photosynthesis, transpiration and stomatal conductance will increase as long as other factors are in adequate supply.

Plant nutrition is another important factor that determines plant growth and production. Apart from carbon, hydrogen and oxygen, which are obtained from the air, plants require about 17 macro and micronutrients for healthy growth, depending on the plant species. Macronutrients such as nitrogen play the most recognized role in the plant for its presence in the structures of the chlorophyll and protein molecules. In addition, nitrogen is also found in such important molecules as purines, pyrimidines, and coenzymes. The porphyrin structure found in chlorophyll and cytochromes are essential in photosynthesis and respiration (Latique et al., 2013). Other important macronutrients are phosphorous (P) and potassium (K) which together with nitrogen (N) constitutes N, P, K found in most chemical fertilizers used. It is well known that fertilizer addition typically increases plant growth, but less is known about the optimum amount and ideal type of fertilizer that should be used to affect positively both the growth and physiological attributes of plants under different light availability conditions (Turnbull et al., 2007; Rosati et al., 2000).

Age is another important factor that determines plant growth, as its physiology and response to environmental change, alters with time, particularly in trees. In fact little has been documented on how age and size of trees are related to their physiology overtime (Niinemets, 2010). Many questions also have been raised as to whether the changes in tree physiology are age dependent or altered physiological and environmental stresses due to tree height. Correlation analyses using large datasets on tree height and age have suggested that tree size and age highly correlate with foliar modifications (Ambrose et al., 2009; Niinemets, 2002). A lot of work on age related physiology have been done with angiosperms, but very little has been documented on dipterocarps. In *Acer pseudoplatanus* and *Fraxinus excelsior,* large old trees exhibited lower photosynthetic rates than young trees suggesting that tree size brought about the reduction in photosynthesis in the older trees (Abdul-Hamid & Mencuccini, 2009). It has also been suggested that the age factor affecting the photosynthesis characteristics is only significant during the first year of tree development (Ambrose et al., 2009; Mencuccini et al., 2007). Thus, both age and the environment play a role in the observed decline in photosynthesis in older to young trees, but clearly more work with different age and size is needed. This is to gain a more conclusive insight into the relative significance of tree size and age in determining the variation in physiological characteristics during tree growth and maturation.

Plant growth of chengal in relation to its physiological processes under different light, fertilizer and age group are very essential in successfully establishing these stands in logged-over forest. Therefore, this study was carried out to determine the physiological parameters of potted chengal seedlings in the nursery under optimum light intensity and fertilizer treatment and the best age and fertilizer treatment in the field. The photosynthetic light response of chengal seedlings of different ages, under different light intensity and fertilizer treatments from nursery to field will also be analyzed.

5.2 Methodology

5.2.1 Chengal nursery establishment and experimental design

The Forest Research Institute Malaysia (FRIM) nursery was chosen as the location for the nursery experiments. A total of 720 chengal seedlings from Hutan Simpan Tembat, Kenyir were used to establish the nursery at the Forest Research Institute of Malaysia (FRIM). The experimental design is a randomized complete block design (RCBD) factoring; 3 light intensity × 3 fertilizer × 2 harvest cycle × 40 seedlings (see 3.1.3).

5.2.2 Chengal field establishment and experimental design

The Tekai Forest Reserve, located in Jerantut, central in the state of Pahang was the chosen site for the field study. The study plot was located in Plot 4, Compartment 89B, in the Tekai Forest Reserve, Jerantut, Pahang (Figure 3.5), as described in 3.3.4.

5.2.3 Physiological parameters measurement in nursery and field

Net photosynthetic rate (P_n), transpiration rate (E), stomatal conductance (G_s) and CO_2 concentration (Ci) were measured using the LI-COR 6400 (LI-6400). The measurements were the same for chengal potted seedlings in the nursery and planted chengal in the field. For both nursery and field, a total of three seedlings from each treatment and three fully matured leaves per seedling were used for the measurements. Measurements were carried out from 0900 hr to 1400 hr, when the photosynthetic rate was generally high (Kenzo et al., 2007). For the development of the light response curve (LRC), light intensities measured, varied from 2000, 1800, 1500, 1000, 800, 400, 200 and 0 µmol m^{-2} s^{-1}. Net photosynthetic (P_n) at each PPF was recorded when it was stable (usually 3–5 min), with CO_2 concentration inside the leaf chamber maintained at 380 µmol mol^{-1}.

During the measurements, the ambient air humidity was (60 - 63)% and leaf temperature was about 26-27ºC in both nursery and field. Mean maximum air temperatures in the nursery are as in Figure 3.2 (nursery) and Figure 3.7 (field). Photosynthetic parameters were derived from each light response curve (LRC) by fitting a linear regression line between the 0 – 200 µmol m^{-2} s^{-1} light range, with the light compensation point (LCP) (µmol photons m^{-2} s^{-1}) determined when y=0 and the dark respiration rate (R_d) (µmol CO_2 m^{-2} s^{-1}) determined when x=0. Apparent quantum efficiency (QE) was calculated as the initial slope of the curve. The maximum photosynthetic rate (A_{max}) (µmol m^{-2} s^{-1}) was estimated for selected chengal seedlings as the asymptote of the light respone curve, while the light level was the light saturation point (LSP) (µmol photons m^{-2} s^{-1}). Before the photosynthetic light response value was determined, each plant was maintained at maximum irradiance until net photosynthetic rate became constant, a process requiring 25 to 30 min. The relationship between net photosynthetic and transpiration rate was expressed as water use efficiency (WUE). Leaf area index (LAI) of chengal seedlings were measured using the LAI-2000 Plant Canopy Analyser.

All physiological and LAI data collection on potted chengal seedlings in the nursery were done prior to growth parameter measurements at 1st, 6th and 12th months. Meanwhile, chengal seedlings in the field were measured at 12th, 22nd and 44th month after planting in the field.

5.2.4 Data analysis and interpretation in nursery and field

The data collected in nursery for chengal potted seedlingss were subjected to two-way analysis of variance (ANOVA) and Generalized Linear Model (GLM) to test the significant difference of light and fertilizer treatments on physiological parameters and LAI as well as physiological attributes derived from LRC. As for the light and fertilizer effect on the parameters mentioned above, Least Significant Difference (LSD) and Waller-Duncan's Multiple Range Test (DMRT) under GLM were used. Chengal planted seedlings in the field under different age group and fertilizer treatmentts were also analyzed using two-way analysis of variance (ANOVA) and Generalized linear model (GLM) to test the significant difference between those treatments given. As for the fertilizer effect on the above parameters, the Least significant difference (LSD) and Waller-Duncan's Multiple Range Test (DMRT) under GLM were used. While for age treatments, post hoc comparison test could not be performed since there were only two independent variables. Therefore, only the mean values were compared and the significant levels determined based on ANOVA.

Pearson correlation analyses were also used to explore the relationship among and within growth parameters (data from Chapter 3) and physiological parameters under different light, age and fertilizer treatments the light and fertilizer treatments for chengal seedlings in the nursery and field.

5.3 Results

5.3.1 Nursery

5.3.1.1 Effect of light and fertilizer treatments on physiological parameters

The physiological parameters, A_n, E, G_s and LAI, of chengal potted seedlings in the nursery revealed significant differences under different light and fertilizer treatments in all ages observed (Table 5.1). Interactions between both light and fertilizer treatments also had a significant effect on all the parameters at $p<0.05$ by month. All the physiological parameters increased from the 1st to the 12th month in the nursery. This indicated that both light and fertilizer treatments give a positive influence on the physiological parameters of chengal seedlings in the nursery within the first year of its growth.

Chengal seedlings treated with different light regimes showed that, exposure to 50% light intensity contributed to the highest mean in the physiological parameters at the 1st, 6th and 12th month of growth. The other light intensities tested (30% and 100%) gave a similar significant increment, but the mean values of the physiological parameters were much lower compared to treatment with 50% light intensity. The use of 100% light intensity registered the lowest A_n, E, G_s as well as LAI at all months (Table 5.2). At 12 months, even though the pattern observed was of highest physiological parameters contribution, the mean value of all the physiological parameters were the highest under 50% LI, followed by 30% LI and the least was under 100% LI. In contrast, exposure to low light (30%) exhibited the highest WUE whilst the highest exposure (100%) recorded the lowest value. The WUE was also observed to decrease slightly throughout the 12 months growth in the nursery, by an average of 0.6%.

Chengal seedlings treated under different fertilizer regimes of NPK Blue fertilizer (inorganic), goat dung fertilizer (organic) and control (no fertilizer applied) recorded a significant increment in the physiological parameters and LAI at the 1, 6 and 12 months of growth with an exception to WUE (Table 5.3). The NPK Blue fertilizer registered the highest increment in the A_n, E, G_s as well as the LAI, recording the highest values compared to goat dung and control for all the months. There were slight differences in physiological parameters obtained in chengal seedlings treated with goat dung fertilizer and control eventhough the values recorded were significant. WUE were not significantly different throughout the measurement period in the nursery but the value was highest in NPK Blue treatment with values higher by an average of 2.3% and 13.6% compared to goat dung and control. The values decreased throughout 12 months period in the nursery.

5.3.1.2 Effect of light and fertilizer treatments on LRC

The LRC of the chengal seedlings, grown under different light and fertilizer treatments, after one year in the nursery are as shown in Figures 5.1 and 5.2. All the parameters derived from the LRC which included maximum photosynthetic rate (A_{max}), Light Compensation Point (LCP), Light Saturation Point (LSP), dark respiration (R_d), quantum efficiency and WUE were significantly different under the different light and fertilizer treatments at the 1st, 6th and 12th month growth in the nursery (Table 5.4). The net photosynthetic rates (A_n) increased rapidly as Photosynthetic Photon Flux (PPF) increased from 0 to 2000 µmol m^{-2} s^{-1} for all the chengal seedlings treated under the different light and fertilizer treatments. It was also observed that the A_{max} rate increased from the 1st to the 12th month regardless of treatment. In contrast, the LCP, LSP, R_d and QE decreased throughout the 12 months of growth in the nursery (Table 5.5 and Table 5.6).

Chengal seedlings treated with different light regimes reached their LSP between 560 to 620 µmol m^{-2} s^{-1}, with 100% light intensity exhibiting the highest point followed by 50% and lowest 30% (Table 5.5). Mean values of all the physiological parameters were observed to decline significantly as the light intensity decreased from 100% to 30%. This indicated that higher light intensity increased the A_{max}, LCP, LSP, R_d, QE and WUE. Exposure to 100% light intensity produced seedlings with the highest A_{max}, 6.5% and 16.9% higher on average compared to seedlings under 50% and 30% LI treatments respectively throughout the experimental period. An increment in A_{max} by 29.6 and 30.4 % was recorded respectively from the first to 12 months. LCP was highest under 100% LI, 4.8% and 14.1% higher compared to 50% and 30% LI treatments respectively. R_d decreased after 12 months by an average of 27.1% throughout in the nursery. The highest dark respiration was observed under 100% LI, 13.3% and 46.7% higher compared to 50% and 30% LI respectively. QE ranged from 0.019 to 0.025 µmol m^{-2} s^{-1} with highest value under 100% LI and lowest under 30% LI. QE declined in the nursery with an average decrement of 17.5%.

Table 5.1 : Summary of ANOVA of physiological parameters for chengal potted seedlings

Source of variance	df	F-value[1]				
		Physiology parameters				
		Net Photosynthetic rate	Transpiration rate	Stomatal conductance	LAI	WUE
1st month						
LIGHT	2	558.63*	636.54*	653.88*	1154.68*	57.41*
FERTILIZER	2	535.87*	662.5*	745.88*	1036.25*	5.63 ns
LIGHT*FERTILIZER	4	155.32*	217.44*	335.48*	547.42*	4.41 ns
6th month						
LIGHT	2	352.22*	346.55*	412.63*	678.69*	44.15 *
FERTILIZER	2	325.87*	316.87*	403.54*	549.74*	4.36 ns
LIGHT*FERTILIZER	4	126.34*	121.18*	228.67*	368.59*	3.68 ns
12th month						
LIGHT	2	206.35*	218.56*	211.57*	347.52*	48.66 *
FERTILIZER	2	187.52*	203.44*	176.56*	255.41*	47.15 ns
LIGHT*FERTILIZER	4	144.68*	148.63*	142.14*	226.38*	32.48 ns

* significant at $p < 0.05$

Table 5.2: Effect of light intensity treatments on physiological parameters of chengal potted seedlings

Physiological parameters	Light intensity		
	30%	50%	100%
1st month			
Net photosynthetic rate	3.58 ± 0.45 **b**	4.15 ± 0.52 **a**	3.14 ± 0.26 c
Transpiration rate	1.14 ± 0.15 **b**	1.35 ± 0.17 **a**	1.02 ± 0.09 **c**
Stomatal conductance	0.057 ± 0.007 **b**	0.067 ± 0.008 **a**	0.050 ± 0.004 **c**
LAI	4.15 ± 0.21 **b**	4.53 ± 0.41 **a**	3.90 ± 0.18 **c**
WUE	3.09 ± 0.04 **a**	3.07 ± 0.03 **b**	3.07 ± 0.03 **b**
6th month			
Net photosynthetic rate	4.29 ± 0.54 **b**	4.99 ± 0.62 **a**	3.76 ± 0.32 **c**
Transpiration rate	1.39 ± 0.18 **b**	1.62 ± 0.20 **a**	1.23 ± 0.10 **c**
Stomatal conductance	0.069 ± 0.009 **b**	0.080 ± 0.001 **a**	0.040 ± 0.005 **c**
LAI	4.97 ± 0.25 **b**	5.43 ± 0.49 **a**	4.68 ± 0.22 **c**
WUE	3.09 ± 0.02 **a**	3.07 ± 0.03 **b**	3.06 ± 0.04 **b**
12th month			
Net photosynthetic rate	6.44 ± 0.61 **a**	6.47 ± 0.38 **a**	5.76 ± 0.99 **b**
Transpiration rate	2.10 ± 0.20 **a**	2.11 ± 0.32 **a**	1.89 ± 0.12 **b**
Stomatal conductance	0.103 ± 0.009 **a**	0.104 ± 0.016 **a**	0.093 ± 0.006 **b**
LAI	5.46 ± 0.29 **b**	5.95 ± 0.58 **a**	5.17 ± 0.50 **c**
WUE	3.07 ± 0.03 **a**	3.06 ± 0.03 **b**	3.05 ± 0.02 **b**

Means with different letter are significantly different at $p < 0.05$, values are ± SD, n=27

Table 5.3: Effect of fertilizer treatments on physiological parameters of chengal potted seedlings

Physiological parameters	Fertilizer treatments		
	NPK Blue	Goat dung	Control
1st month			
Net photosynthetic rate	4.03 ± 0.56 **a**	3.70 ± 0.48 **b**	3.14 ± 0.34 **c**
Transpiration rate	1.31 ± 0.18 **a**	1.20 ± 0.16 **b**	1.02 ± 0.11 **c**
Stomatal conductance	0.065 ± 0.009 **a**	0.059 ± 0.008 **b**	0.050 ± 0.005 **c**
LAI	4.48 ± 0.40 **a**	4.22 ± 0.28 **b**	3.87 ± 0.15 **c**
WUE	3.08 ± 0.04 **a**	3.08 ± 0.05 **a**	3.08 ± 0.03 **a**
6th month			
Net photosynthetic rate	4.84 ± 0.67 **a**	4.44 ± 0.58 **b**	3.77 ± 0.41 **c**
Transpiration rate	1.58 ± 0.22 **a**	1.45 ± 0.19 **b**	1.23 ± 0.13 **c**
Stomatal conductance	0.077 ± 0.011 **a**	0.072 ± 0.009 **b**	0.061 ±0.007 **c**
LAI	5.38 ± 0.47 **a**	5.06 ± 0.34 **b**	4.65 ± 0.18 **c**
WUE	3.06 ± 0.04 **a**	3.06 ± 0.04 **a**	3.07 ± 0.03 **a**
12th month			
Net photosynthetic rate	6.65 ± 0.68 **a**	5.93 ± 0.92 **b**	5.10 ± 0.45 **c**
Transpiration rate	2.17 ± 0.22 **a**	1.98 ± 0.30 **b**	1.93 ± 0.15 **c**
Stomatal conductance	0.107 ± 0.011 **a**	0.095 ± 0.015 **c**	0.098 ± 0.012 **b**
LAI	5.93 ± 0.52 **a**	5.56 ± 0.37 **b**	5.10 ± 0.16 **c**
WUE	3.06 ± 0.05 **a**	2.99 ± 0.06 **b**	2.64 ± 0.08 **c**

Means with different letter are significantly different at $p < 0.05$,values are ± SD,n = 27

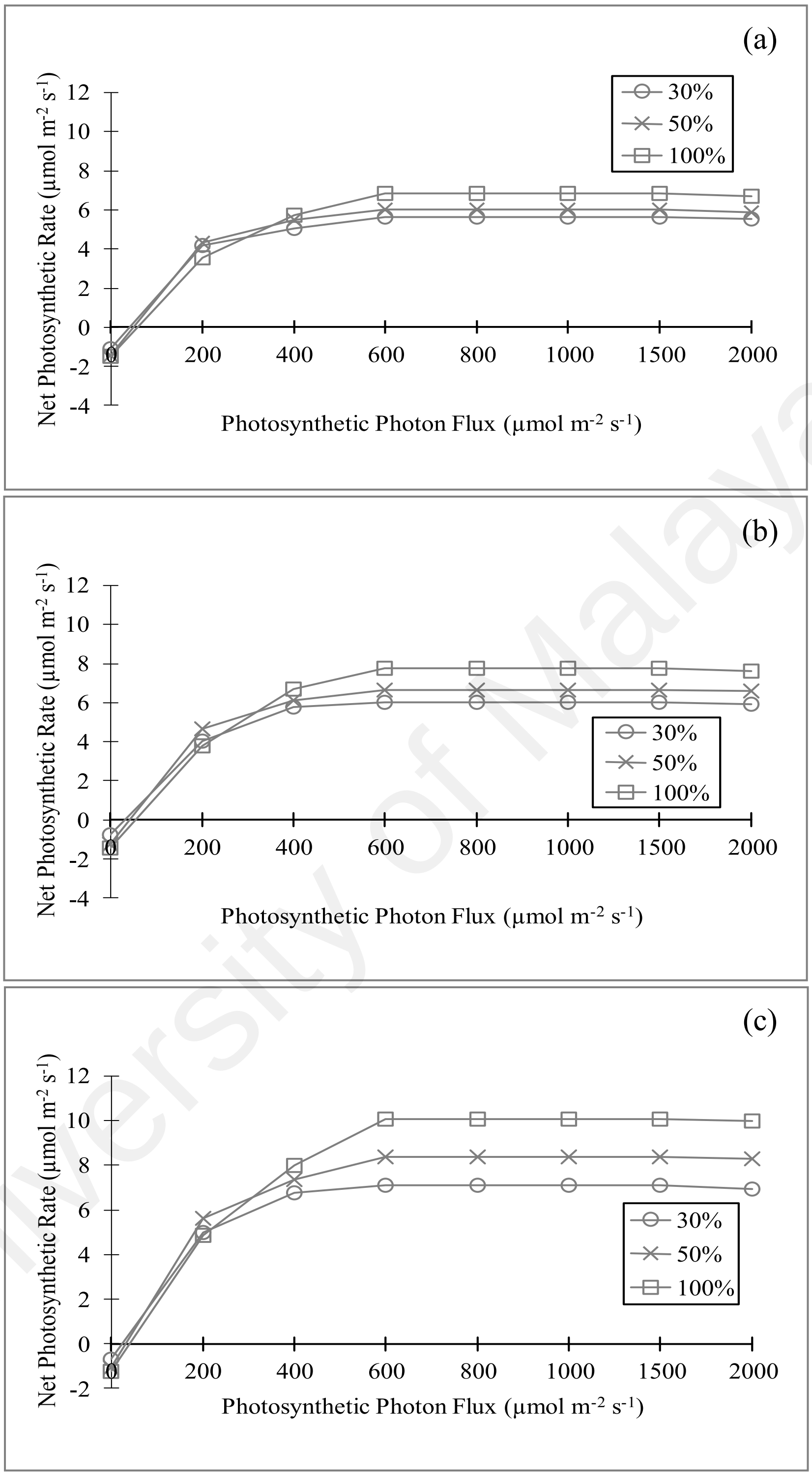


Figure 5.1: Photosynthetic LRC for chengal seedlings of different light intensity and plant age (a) 1 month. (b) 6 months. (c) 12 months after potting in the nursery. The relationship between net photosynthetic rate and photosynthetic photon flux were fitted by non-linear regression equation with n = 27

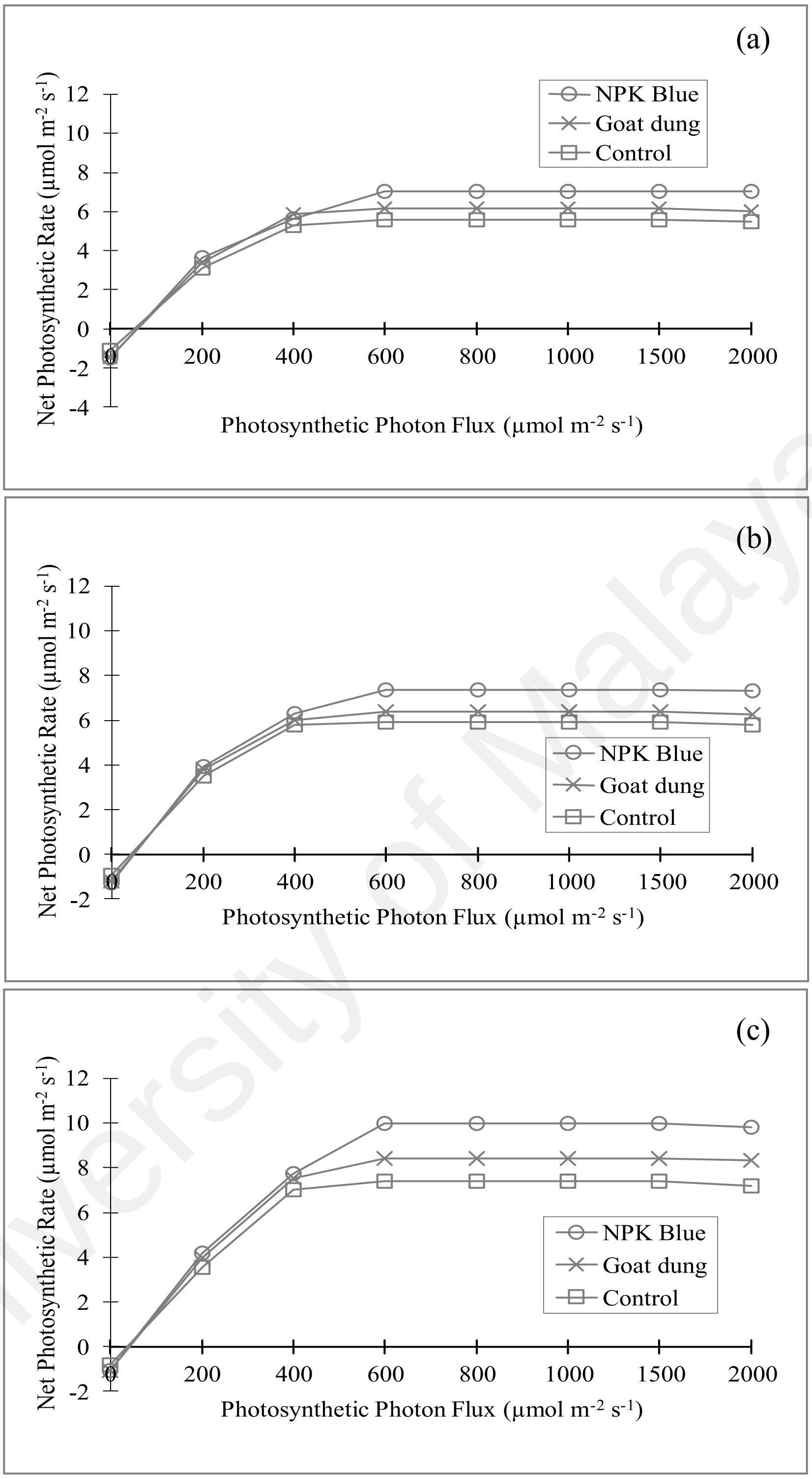


Figure 5.2: Photosynthetic LRC for chengal seedlings under different fertilizer and plant age (a) 1 month. (b) 6 months. (c) 12 months after potting in the nursery. The relationship between net photosynthetic rate and photosynthetic photon flux were fitted by non-linear regression equation. Value are means for each measurement with n = 27

Table 5.4: Summary of ANOVA of LRC derived parameters for chengal potted seedlings

Source of variance	df	F-value[1]				
		Physiological parameters				
		Maximum photosynthetic rate	Dark respiration	Light compensation point	Light saturation point	Quantum efficiency
1st month						
LIGHT	2	558.63*	264.10*	636.54*	653.88*	328.40*
FERTILIZER	2	535.87*	74.42*	662.5*	745.88*	86.77*
LIGHT*FERTILIZER	4	155.32*	3.52*	217.44*	335.48*	44.38*
6th month						
LIGHT	2	352.22*	251.26*	346.55*	412.63*	307.29*
FERTILIZER	2	325.87*	65.84*	316.87*	403.54*	77.74*
LIGHT*FERTILIZER	4	126.34*	3.24*	121.18*	228.67*	36.87*
12th month						
LIGHT	2	206.35*	226.70*	218.56*	211.57*	246.35*
FERTILIZER	2	187.52*	60.21*	203.44*	176.56*	68.55*
LIGHT*FERTILIZER	4	144.68*	3.11*	148.63*	142.14*	33.17*

* significant at $p < 0.05$

Table 5.5: Effect of light intensity treatments on LRC derived parameters in chengal potted seedlings

Physiological parameters ($\mu mol\ m^{-2}\ s^{-1}$)	Light intensity		
	30%	50%	100%
1st month			
Maximum photosynthetic rate	5.65 ± 0.17 **c**	6.02 ± 0.30 **b**	6.86 ± 0.42 **a**
Dark respiration	0.91 ± 0.17 **c**	1.45 ± 0.22 **b**	1.68 ± 0.23 **a**
Light compensation point	5.88 ± 0.17 **c**	6.51 ± 0.29 **b**	6.85 ± 0.23 **a**
Light saturation point	590 ± 15 **c**	600 ± 26 **b**	620 ± 36 **a**
Quantum efficiency	0.022 ± 0.007 **c**	0.024 ± 0.006 **b**	0.025 ±0.007 **a**
6th month			
Maximum photosynthetic rate	6.03 ± 0.19 **c**	6.65 ± 0.33 **b**	7.74 ± 0.47 **a**
Dark respiration	0.78 ± 0.14 **c**	1.25 ± 0.19 **b**	1.44 ± 0.20 a
Light compensation point	4.94 ± 0.15 **c**	5.46 ± 0.25 **b**	5.76 ± 0.25 **a**
Light saturation point	570 ± 15 **c**	590 ± 26 **b**	600 ± 36 **a**
Quantum efficiency	0.021 ± 0.005 **c**	0.022 ±0.008 **b**	0.023 ±0.007 **a**
12th month			
Maximum photosynthetic rate	7.10 ± 0.28 **c**	8.37 ± 0.41 **b**	10.07 ± 0.71 **a**
Dark respiration	0.64 ± 0.12 **c**	1.08 ± 0.17 **b**	1.24 ± 0.18 **a**
Light compensation point	4.06 ± 0.18 **c**	4.51 ± 0.25 **b**	4.71 ± 0.21 **a**
Light saturation point	560 ± 10 **c**	578 ± 28 **b**	590 ± 30 **a**
Quantum efficiency	0.019 ± 0.005 **c**	0.021 ± 0.004 **b**	0.022 ± 0.005 **a**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD, n = 27

Table 5.6: Effect of fertilizer treatment on LRC derived parameters in chengal potted seedlings

Physiological parameters (µmol m^{-2} s^{-1})	Fertilizer treatments		
	NPK Blue	Organic	Control
<u>1st month</u>			
Maximum photosynthetic rate	7.03 ± 0.66 **a**	6.17 ± 0.51 **b**	5.59 ± 0.34 **c**
Dark respiration	1.51 ± 0.36 **a**	1.42 ± 0.41 **b**	1.11 ± 0.28 **c**
Light compensation point	6.64 ± 0.45 **a**	6.49 ± 0.49 **b**	6.10 ± 0.33 **c**
Light saturation point	610 ± 36 **a**	595 ± 32 **b**	580 ± 13 **c**
Quantum efficiency	0.021 ± 0.006 **a**	0.020 ± 0.005 **a**	0.018 ± 0.007 **b**
<u>6th month</u>			
Maximum photosynthetic rate	7.38 ± 0.73 **a**	6.40 ± 0.56 **b**	5.92 ± 0.38 **c**
Dark respiration	1.30 ± 0.30 **a**	1.22 ± 0.35 **b**	0.95 ± 0.24 **c**
Light compensation point	5.58 ± 0.38 **a**	5.45 ± 0.41 **b**	5.13 ± 0.28 **c**
Light saturation point	600 ± 34 **a**	580 ± 32 **b**	570 ± 13 **c**
Quantum efficiency	0.020 ± 0.005 **a**	0.020 ± 0.005 **a**	0.018 ± 0.004 **b**
<u>12th month</u>			
Maximum photosynthetic rate	10.00 ± 1.04 **a**	8.43 ± 0.72 **b**	7.42 ± 0.56 **c**
Dark respiration	1.09 ± 0.29 **a**	1.06 ± 0.32 **a**	0.80 ± 0.23 **b**
Light compensation point	4.64 ± 0.28 **a**	4.46 ± 0.36 **b**	4.18 ± 0.24 **c**
Light saturation point	580 ± 36 **a**	565 ± 27 **b**	560 ± 30 **b**
Quantum efficiency	0.019 ± 0.005 **a**	0.018 ± 0.007 **b**	0.016 ± 0.004 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD, n=27

Different fertilizer regimes significantly influenced all the physiological parameters derived from the LRC throughout the growth period in the nursery (Table 5.6). Mean values of all the physiological parameters except for A_{max} decreased significantly within the first year with seedlings given NPK Blue fertilizer exhibiting the highest mean followed by goat dung treatment and the lowest was observed when no fertilizer was applied. Seedlings treated with NPK Blue exhibited highest A_{max}, 3.8 and 9.1 % higher compared to goat dung and control respectively. The increment from the 1^{st} to the 12^{th} month in the nursery was at an average of 29.7% regardless of fertilizer application. LCP was highest under NPK Blue as well, 2.3% and 8.1% higher compared to goat dung fertilizer and control treatments respectively. It decreased from the 1^{st} to the 12^{th} month between30.1 to31.5%. Similarly R_d decreased by an average of 27.0% after 12 months in the nursery with the highest value recorded in chengal treated with NPK Blue which was 4.4% and 26.5% higher compared to goat dung and control respectively. QE ranged from 0.016 to 0.021 µmol m^{-2} s^{-1} with the highest observed under NPK Blue fertilizer treatment and the lowest in control. QE decreased over 12 months in the nursery with an average decrement of 10.2%.

5.3.1.3 Correlation between physiological parameters and LAI in the nursery under different light intensity and fertilizer treatments

Correlation between the physiological parameters with regards to P_n, E, G_s, WUE and LAI for potted chengal seedlings under different light intensity and fertilizer treatments in the nursery are shown in Table 5.7 and Table 5.8. The physiological parameters and LAI showed some specific associations which varied with the different light and fertilizer regimes given. A highly significant relationship between the physiological parameters and LAI at $p<0.01$ was recorded for all the light intensity and

Table 5.7: Correlation between physiological parameters and LAI in the nursery under different light intensity treatments after 12 months of potting

(a) <u>30% LI</u>

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.912**	1			
Stomatal conductance	0.824**	0.781**	1		
WUE	-0.844**	-0.803**	-0.749**	1	
LAI	0.786**	0.772**	0.748**	-0.792**	1

(b) <u>50% LI</u>

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.945**	1			
Stomatal conductance	0.833**	0.847**	1		
WUE	-0.551**	-0.631**	-0.547**	1	
LAI	0.806**	0.843**	0.628**	-0.464**	1

(c) <u>100% LI</u>

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.876**	1			
Stomatal conductance	0.807**	0.749**	1		
WUE	-0.806**	-0.795**	-0.711**	1	
LAI	0.801**	0.811**	0.724**	-0.785**	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Physiology parameters and WUE n = 135 and LAI n = 45

Table 5.8: Correlation between physiological parameters and LAI in the nursery under different fertilizer treatments after 12 months of potting

(a) NPK Blue

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.917**	1			
Stomatal conductance	0.838**	0.788**	1		
WUE	-0.624**	-0.744**	-0.776**	1	
LAI	0.781**	0.772**	0.748**	-0.543**	1

(b) Goat dung

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.922**	1			
Stomatal conductance	0.821**	0.835**	1		
WUE	-0.773**	-0.631**	-0.547**	1	
LAI	0.796**	0.808**	0.789**	-0.573**	1

(c) Control

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.865**	1			
Stomatal conductance	0.803**	0.769**	1		
WUE	-0.839**	-0.766**	-0.704**	1	
LAI	0.784**	0.772**	0.726**	-0.773**	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level;Physiology parameters and WUE n = 135 and LAI n = 45 fertilizer treatments. The P_n, E, G_s and LAI positively correlated, showing there are strong and significant relationships between these parameters under all the different light intensity and fertilizer treatments. However, they were negatively correlated with WUE regardless of the different light intensity and fertilizer treatments. It was also observed that the correlation of physiological parameters and LAI were higher under 50% LI compared to 30% and 100% LI treatments. Furthermore, it was also observed that the correlation under the different fertilizer treatments was greater for NPK Blue compared to goat dung and control.

5.3.2 Field

5.3.2.1 Effect of different age and fertilizer on physiological parameters

Seedling age and fertilizer treatment in the field contributed to a significant variance on all physiological parameters, namely P_n, E, G_s and LAI. Interactions between both age and fertilizer treatments also recorded a significant effect on all physiological parameters and LAI at $p<0.05$ throughout the measurement period of 44 months after planting in the field (Table 5.9). The physiological parameters of the planted chengal increased throughout the planting period from 12 to 44 months in the field.

Tables 5.10 and 5.11 show the mean values for chengal seedlings from the 1^{st} to the 44^{th} month after planting in the field under different age group and fertilizer treatments. All the physiological parameters were observed to increase from the 12^{th} to the 44^{th} month of growth under different age group and different fertilizer treatments. It was observed that 6 months old chengal seedlings exhibited the highest mean of

Table 5.9: Summary of ANOVA of physiological parameters for chengal seedlings planted

Source of variance	df	F-value[1]				
		Physiological parameters				
		Net Photosynthetic rate	Transpiration rate	Stomatal conductance	LAI	WUE
BLOCK	2	4.27 ns	10.27 ns	2.59 ns	1.19 ns	13.70ns
AGE	1	1447.9*	1995.9*	429.9*	787.7*	385.77*
FERTILIZER	2	1423.5*	3844.7*	547.3*	1559.9*	780.75*
BLOCK*AGE*FERTILIZER	4	1.72 ns	0.02 ns	0.99 ns	0.39 ns	0.18ns
AGE*FERTILIZER	2	53.9 *	35.5*	11.1*	10.7*	25.40*

* significant at $p < 0.05$

Table 5.10: Effect of age treatment on physiological parameters of chengal seedlings

Physiological parameters	Age group	
	1 y 8 m	6 m
<u>12th month</u>		
Net photosynthetic rate	5.72 ± 0.51	6.20 ± 0.30
Transpiration rate	2.45 ± 0.25	2.68 ± 0.21
Stomatal conductance	0.092 ± 0.007	0.099 ± 0.008
LAI	5.42 ± 0.27	5.67 ± 0.24
WUE	2.33 ± 0.04	2.31 ± 0.05
<u>22nd month</u>		
Net photosynthetic rate	7.50 ± 0.41	8.02 ± 0.33
Transpiration rate	2.88 ± 0.29	3.14 ± 0.24
Stomatal conductance	0.118 ± 0.031	0.148 ± 0.256
LAI	5.88 ± 0.26	6.16 ± 0.25
WUE	2.60 ± 0.04	2.55 ± 0.03
<u>44th month</u>		
Net photosynthetic rate	8.16 ± 0.41	8.66 ± 0.26
Transpiration rate	3.42 ± 0.36	3.88 ± 0.39
Stomatal conductance	0.172 ± 0.027	0.196 ± 0.026
LAI	7.08 ± 0.39	7.38 ± 0.33
WUE	2.39 ± 0.03	2.23 ± 0.05

Means values are ± SD, n=27

Table 5.11: Effect of fertilizer treatments on physiological parameters of chengal seedlings

Physiological parameters (μmol m^{-2} s^{-1})	Fertilizer treatments		
	SRF	Organic	SRF + Organic
12th month			
Net photosynthetic rate	5.88 ± 0.26 **b**	5.53 ± 0.39 **c**	6.47 ± 0.17 **a**
Transpiration rate	2.51 ± 0.12 **b**	2.34 ± 0.19 **c**	2.84 ± 0.15 **a**
Stomatal conductance	0.093 ± 0.005 **c**	0.089 ± 0.004 **b**	0.106 ± 0.005 **a**
LAI	5.45 ± 0.18 **c**	5.31 ± 0.13 **b**	5.88 ± 0.13 **a**
WUE	2.34 ± 0.04 **b**	2.36 ± 0.05 **a**	2.27 ± 0.04 **c**
22nd month			
Net photosynthetic rate	7.54 ± 0.33 **b**	7.40 ± 0.27 **c**	7.78 ± 0.22 **a**
Transpiration rate	3.23 ± 0.15 **b**	3.14 ± 0.20 **c**	3.30 ± 0.13 **a**
Stomatal conductance	0.122 ± 0.021 **b**	0.107 ± 0.016 **c**	0.171 ± 0.011 **a**
LAI	5.92 ± 0.15 **c**	5.78 ± 0.17 **b**	6.35 ± 0.15 **a**
WUE	2.33 ± 0.05 **b**	2.35 ± 0.05 **a**	2.35 ± 0.04 **a**
44th month			
Net photosynthetic rate	8.19 ± 0.28 **b**	8.18 ± 0.35 **b**	8.65 ± 0.18 **a**
Transpiration rate	3.75 ± 0.43 **b**	3.51 ± 0.18 **c**	3.99 ± 0.16 **a**
Stomatal conductance	0.174 ± 0.015 **b**	0.159 ± 0.011 **c**	0.220 ± 0.012 **a**
LAI	7.13 ± 0.22 **b**	6.87 ± 0.17 **c**	7.71 ± 0.11 **a**
WUE	2.18 ± 0.04 **b**	2.33 ± 0.03 **a**	2.16 ± 0.03 **c**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD, n=27

physiological parameters, specifically P_n, E, G_s and LAI throughout, compared to 1 year 8 months old seedlings. The reversed pattern was recorded for WUE where 1y 8m old chengal showed higher values compared to 6 m seedlings with an increase of 7% after 44 months planting. The WUE values were observed to decrease throughout planting (Table 5.10).

Chengal seedlings treated under different fertilizer regimes with SRF, organic fertilizer and a combination of both SRF and organic fertilizer, recorded a significant increase in the physiological parameters and LAI at 12, 22 and 44 months of growth (Table 5.11). Seedlings treated under the combination of fertilizers recorded the highest value for physiological parameters compared to the single application of SRF and the lowest was observed in seedlings treated under only organic fertilizer, for all months. In contrast, the trend recorded for WUE varied where organic fertilizer application contributed to the highest WUE compared to the application of SRF and a combination of SRF and organic fertilizer, with an increment of 6% and 7%, respectively. The difference in the readings were small at the beginning of planting from the 12th to the 22nd month. The values were also observed to decrease throughout the planting period.

5.3.2.2 Effect of different age and fertilizer treatments on the LRC

The LRC shown by the seedlings under the different age and fertilizer treatments, 44 months after growing in the field, are as shown in Figure 5.3 and Figure 5.4. A significant difference was found for all physiological parameters derived from the LRC, which are A_{max}, LCP, LSP, R_d and QE in the seedlings under the different age

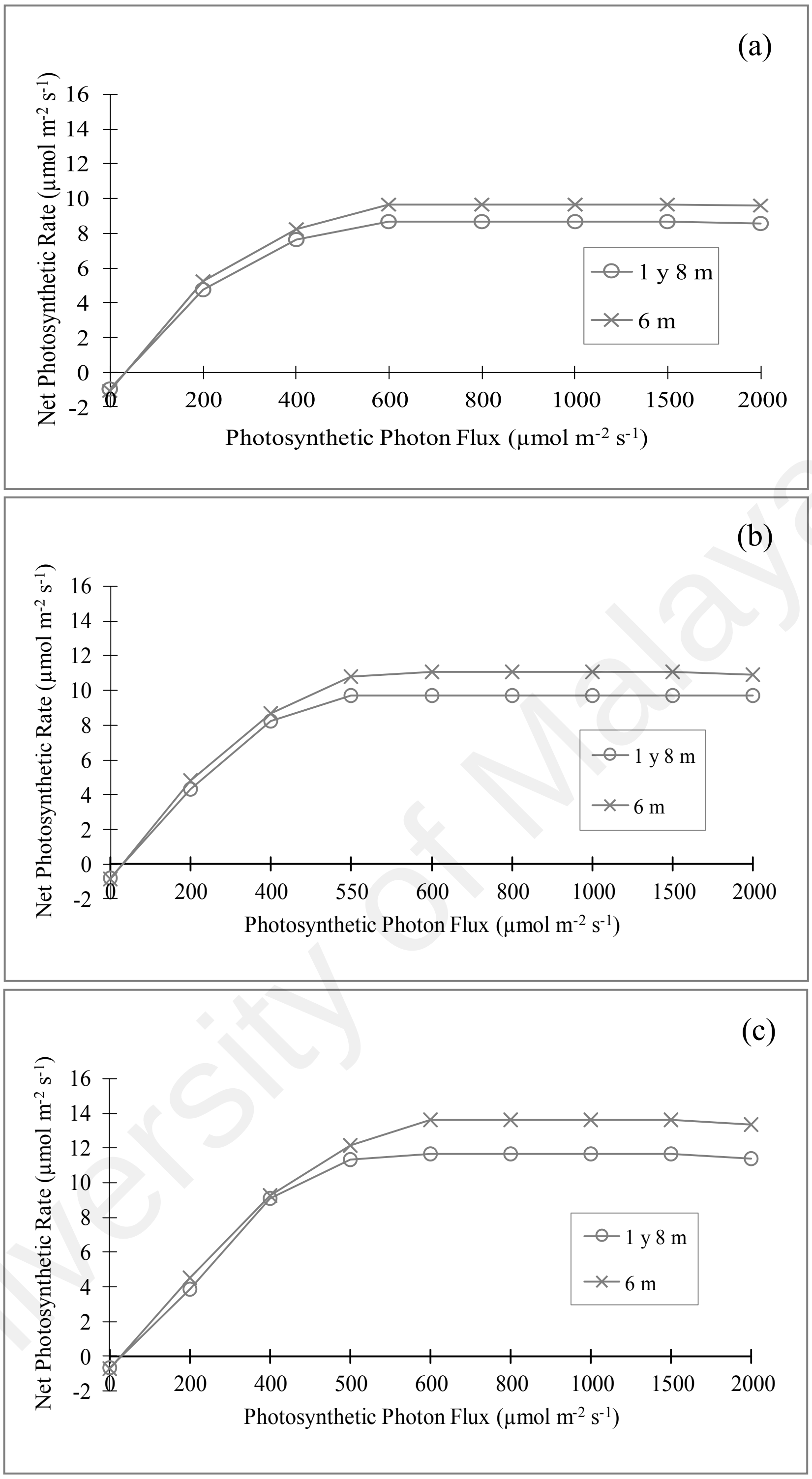


Figure 5.3: Photosynthetic LRC of chengal seedlings under different age groups (a) 12 month. (b) 22 months. (c) 44 months after planting in the field. The relationship between net photosynthetic rate and photosynthetic photon flux were fitted by non-linear regression equation with n = 27

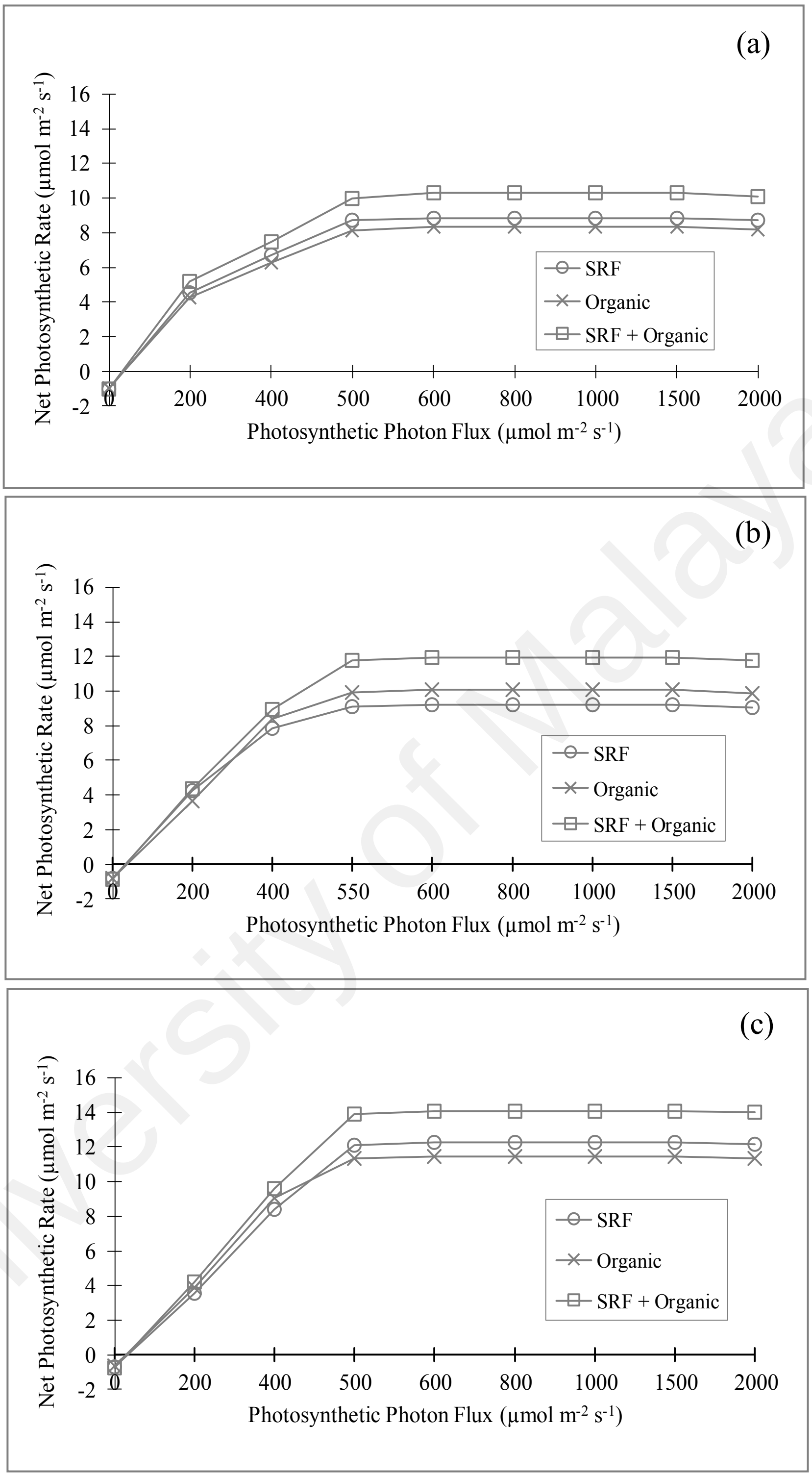


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Figure 5.4: Photosynthetic LRC of chengal seedlings under different fertilizer treatments (a) 12 month. (b) 22 months. (c) 44 months after planting in the field. The relationship between net photosynthetic rate and photosynthetic photon flux were fitted by non-linear regression equation with $n = 27$

group and fertilizer regimes, at the 12^{th}, 22^{nd} and 44^{th} month after growing in the field (Table 5.12). A_{max} increased from the 12^{th} to the 44^{th} month for both chengal seedlings treated under different light and fertilizer treatments (Table 5.13 and Table 5.14). Mean values for all other parameters, viz. LCP, LSP, R_d, QE and WUE decreased throughout the 44 months in the field.

Age of chengal seedlings significantly affected A_{max}, LCP, LSP, R_d and QE, where the younger and smaller sized chengal exhibited maximum mean values compared to the older and bigger sized seedlings (Table 5.13). The younger chengal seedlings recorded the highest A_{max}, 3.3% higher compared to the 1 year 8 months seedlings throughout measuring period. An increment of 19.8% in A_{max} was recorded from 12 to 44 months. The LCP in 6 months old seedlings was higher by 6.4% compared to 1 year 8 months old seedlings. The percentage decreased from the 12^{th} to the 44^{th} month by approximately 7.2%. R_d decreased by 30.7% after 44 months with the highest recorded in 6 month old chengal seedlings, which was 10.9% higher compared to the 1 year 8 month old seedlings. The LSP in the 6 month old seedlings was also higher compared to the older chengal seedlings 2.6% with rates of 536 and 522 $\mu mol\ m^{-2}\ s^{-1}$ respectively. QE ranged from 0.017 to 0.022 $\mu mol\ m^{-2}\ s^{-1}$ with the higher value observed in seedlings aged 6 months. It decreased throughout growth in the field with an average decrement of 18.6%.

Chengal seedlings planted in the field treated with different fertilizer regimes exhibited significantly different physiological parameters derived from the LRC at all months (Table 5.14). All physiological parameters mean values, with the exception of Amax, declined significantly throughout the experimental period in the field, with seedlings given the combination of SRF and organic fertilizer showing the highest mean

Table 5.12: Summary of ANOVA of LRC derived parameters for chengal seedlings

Source of variance	df	F-value[1]				
		Physiological parameters				
		Maximum photosynthetic rate	Dark respiration	Light compensation point	Light saturation point	Quantum efficiency
BLOCK	2	18.65ns	7.86ns	1.65ns	23.81ns	1.48ns
AGE	1	412.25*	529.01*	369.34*	183.86*	195.31*
FERTILIZER	2	460.93*	77.74*	739.75*	336.36*	235.90*
BLOCK*AGE*FERTILIZER	4	2.19ns	0.37ns	1.92ns	0.75ns	1.29ns
AGE*FERTILIZER	2	25.21*	0.06ns	2.22ns	31.77*	22.42*

* significant at $p < 0.05$

Table 5.13: Effect of age on the LRC derived parameters of chengal seedlings

Physiological parameters ($\mu mol\ m^{-2}\ s^{-1}$)	Age group	
	1 y 8 m	6 m
12th month		
Maximum photosynthetic rate	8.65 ± 0.32	9.67 ± 0.23
Dark respiration	0.96 ± 0.04	1.06 ± 0.03
Light compensation point	4.17 ± 0.32	4.45 ± 0.22
Light saturation point	581 ± 17	600 ± 11
Quantum efficiency	0.024 ± 0.09	0.027 ± 0.09
22nd month		
Maximum photosynthetic rate	9.70 ± 0.41	11.07 ± 0.28
Dark respiration	0.79 ± 0.03	0.89 ± 0.04
Light compensation point	3.89 ± 0.37	4.13 ± 0.31
Light saturation point	544 ± 26	559 ± 16
Quantum efficiency	0.022 ± 0.18	0.024 ± 0.10
44th month		
Maximum photosynthetic rate	11.67 ± 0.34	13.60 ± 0.22
Dark respiration	0.65 ± 0.05	0.74 ± 0.04
Light compensation point	3.86 ± 0.23	4.15 ± 0.33
Light saturation point	522 ± 23	536 ± 15
Quantum efficiency	0.020 ± 0.15	0.023 ± 0.09

Means values are ± SD, n=27

Table 5.14: Effect of fertilizer treatments on the LRC derived parameters of seedlings

Physiological parameters ($\mu mol\ m^{-2}\ s^{-1}$)	Fertilizer treatments		
	SRF	Organic	SRF + Organic
12^{th} month			
Maximum photosynthetic rate	9.32 ± 0.24 **b**	9.18 ± 0.24 **c**	9.74 ± 0.14 **a**
Dark respiration	1.01 ± 0.05 **ab**	0.99 ± 0.06 **b**	1.03 ± 0.05 **a**
Light compensation point	4.27 ± 0.17 **b**	4.02 ± 0.21 **c**	4.64 ± 0.12 **a**
Light saturation point	591 ± 16 **b**	578 ± 17 **c**	603 ± 10 **a**
Quantum efficiency	0.023 ± 0.07 **b**	0.021 ± 0.09 **c**	0.026 ± 0.08 **a**
22^{nd} month			
Maximum photosynthetic rate	10.06 ± 0.30 **b**	9.20 ± 0.29 **c**	11.91 ± 0.16 **a**
Dark respiration	0.84 ± 0.05 **b**	0.81 ± 0.06 **c**	0.86 ± 0.04 **a**
Light compensation point	3.87 ± 0.18 **b**	3.69 ± 0.19 **c**	4.45 ± 0.11 **a**
Light saturation point	550 ± 13 **b**	530 ± 16 **c**	575 ± 10 **a**
Quantum efficiency	0.021 ± 0.12 **a**	0.020 ± 0.11 **b**	0.023 ± 0.08 **a**
44^{th} month			
Maximum photosynthetic rate	12.28 ± 0.19 **b**	11.44 ± 0.30 **c**	14.07 ± 0.17 **a**
Dark respiration	0.70 ± 0.05 **b**	0.65 ± 0.06 **c**	0.74 ± 0.05 **a**
Light compensation point	3.89 ± 0.19 **b**	3.77 ± 0.14 **c**	4.35 ± 0.25 **a**
Light saturation point	522 ± 13 **b**	512 ± 12 **c**	553 ± 6 **c a**
Quantum efficiency	0.020 ± 0.10 **ab**	0.19 ± 0.11 **b**	0.021 ± 0.06 **a**

Means in each column with different letter are significantly different at $p < 0.05$, values are ± SD, n=27

followed by those treated with a single application of SRF and the lowest was observed with the application of only organic fertilizer. Seedlings treated with the combination of fertilizers exhibited the highest A_{max}, 4.2 and 5.8 % higher compared to the single application of SRF and organic fertilizer respectively. The increment in A_{max} from the 12^{th} to the 44^{th} month after growing in the field, was on average 19.8%, regardless of fertilizer applied. LCP was highest under the combination of fertilizers as well, and higher by 8.0% and 13.4% compared to SRF and organic fertilizer respectively. LCP decreased from the 12^{th} to the 44^{th} month by 7.2 % while R_d at 44 months decreased by an average of 30.7% throughout in the field. The highest point was recorded in chengal seedlings treated with the combination of fertilizers which was 3.2% and 7.3% higher compared to the separate application of SRF and organic fertilizer, respectively. QE ranged from (0.016 to 0.023) μmol m^{-2} s^{-1} with the highest observed in plants under the combination of fertilizers and the lowest under the single application organic fertilizer. It declined throughout planting in the field with an average decrement of 14.1%.

5.3.2.3 Correlation between physiological parameters and LAI under different age and fertilizer treatments in the field

The correlation between physiological parameters of P_n, E, G_s, WUE and LAI for planted chengal seedlings under different age and fertilizer treatments in the field was deduced (Table 5.15 and Table 5.16). The physiological parameters and LAI showed some specific associations which varied with age and fertilizer regimes given. However, these associations were not significantly different between planted chengal in the field and potted chengal in the nursery (Tables 5.7 and 5.8). Other than that, in the field, a significantly high relationship between physiological parameters and LAI at $p< 0.01$ was recorded for both age group and fertilizer treatments. The Pn, E, Gs, WUE and LAI were positively correlated amongst them, showing there was a strong and

Table 5.15: Correlation between physiological parameters and LAI under different age treatments after 44 months of planting

(a) 1 year 8 month

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.694**	1			
Stomatal conductance	0.652**	0.637**	1		
WUE	-0.483**	-0.601**	-0.654**	1	
LAI	0.677**	0.650**	0.640**	-0.754**	1

(b) 6 month

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.619**	1			
Stomatal conductance	0.695**	0.610**	1		
WUE	-0.546**	-0.665**	-0.546**	1	
LAI	0.669**	0.660**	0.648**	-0.632**	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; Physiology parameters and WUE n = 729 and LAI n = 81

Table 5.16: Correlation between physiological parameters and LAI under different fertilizer treatments after 44 months of planting

(a) SRF

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.625**	1			
Stomatal conductance	0.647**	0.643**	1		
WUE	-0.488**	-0.666**	-0.751**	1	
LAI	0.660**	0.662**	0.547**	-0.565**	1

(b) Organic

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.753**	1			
Stomatal conductance	0.658**	0.621**	1		
WUE	-0.331*	-0.561**	-0.546**	1	
LAI	0.693**	0.679**	0.635**	-0.657**	1

(c) SRF + Organic

	Net photosynthesis	Transpiration	Stomatal conductance	WUE	LAI
Net photosynthesis	1				
Transpiration	0.791**	1			
Stomatal conductance	0.674**	0.642**	1		
WUE	-0.685**	-0.689**	-0.623**	1	
LAI	0.653**	0.631**	0.659**	-0.605**	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level;Physiology parameters and WUE n = 486 and LAI n = 54 significant relationship between these parameters under the different age and fertilizer treatments. However, these parameters were negatively correlated with WUE regardless of age and fertilizer treatments. It was also observed that the correlation between physiological parameters and LAI were higher for the 12 months chengal seedlings. In addition, it was also recorded that the correlation between P_n, E, G_s, WUE and LAI under the different fertilizer treatments was greater for the combined fertilizer treatment compared to the single SRF and organic fertilizer treatment.

5.4 Discussion

5.4.1 Physiological parameters of chengal seedling under different light, fertilizer and age in the nursery and field

5.4.1.1 Effect of light on physiological parameters and LAI in the nursery

Light intensity treatments in the nursery significantly influenced the physiological parameters of P_n, E, G_s, WUE and LAI of chengal potted seedlings. Chengal seedlings treated under shaded treatments of 50 % light intensity exhibited the highest mean physiological parameters including LAI throughout 12 months in the nursery, followed by 30% LI and the lowest was observed in plants treated under 100% LI (Table 5.2). A research done by Kenzo et al. (2011) on dipterocarp seedlings, *Dyera costulata* and *Gonystylus affinis,* also reported that the net photosynthetic rate of the seedlings grown under different canopy openness (light exposure) varied after 12 months of growth. They observed seedlings measured rates between an average of 4.11, 4.88 and 4.01 µmol m^{-2} s^{-1} and 2.11, 2.45 and 0.85 µmol m^{-2} s^{-1} under 20, 40 and 100 % LI for both species, respectively. Partial shade has contributed to the highest rate. Kenzo et al. (2011) mentioned that the higher photosynthetic rate may correspond to the high growth rate of both *Dyera costulata* and *Gonystylus affinis*. Both species showed higher growth performance under relatively shaded conditions 30-40 % canopy openness. The maximum seedling height reached 3.9 m under small gap conditions. Several researchers have reported that increasing the gap size had a negative effect on height growth for some dipterocarp seedlings including *Neobalanocarpus heimii* (Kenzo et al., 2007; Ueda et al., 1997; Tuomela et al., 1996).

Other than that, the effect of light on transpiration was similar to effect of light on photosynthetic rate and is essentially a function of stomatal opening when the leaf temperature is held constant (Ulqodry et al., 2014; Ku et al., 1977). The transpiration rates recorded for the chengal potted seedlings are also comparable to other dipterocarp species, namely *Shorea dasyphylla, Shorea leprosula* and *Shorea ovata*, recorded in a research by Mun et al. (2011) which reported transpiration rates of 1.24, 1.79 and 1.84 $\mu mol\ m^{-2}\ s^{-1}$ for the three species, respectively, compared to the average range of 1.89 - 2.11 $\mu mol\ m^{-2}\ s^{-1}$ for chengal seedlings under different light intensities. She claimed that the low results of transpiration rates in her study were due to the plants' mechanism to survive and grow better in competitive environment. Those *Shorea* species illustrate that type of mechanism and coupled with higher rate of photosynthesis and LAI. Meanwhile, other non - dipterocarp species, such as *Vigna sinensis* seedlings recorded their highest transpiration rates under partial light intensity of 50% and the lowest transpiration rate under 100% LI (Neri et al., 2003). He stated that typical changes of transpiration as a function of incident light intensity. The rates varied with increasing and decreasing light intensity with highest at 50% and lowest at 100% LI at a different temperature. Transpiration in his study was found to be more dependent on temperature rather than on light-level. This is in line with relation to this observation, G_s recorded for one year chengal potted seedlings, where it was observed to be in the range of 0.093 - 0.104

μmol m^{-2} s^{-1} with the lowest under 100 LI and the highest under 50% LI. These values were higher compared to the very low rates recorded for Amazonian rainforest tree species of *Hymenaea courbaril* and *Hymenaea parvifolia,* 0.005 and 0.01 μmol m^{-2} s^{-1} under 100% and 6% of light exposure, respectively, after one year of growth in a shade house. In that study, the author stressed that both species had lower stomatal conductance and lower intercellular CO_2 concentrations.

In addition, WUE was found to be slightly increasing under more shaded light exposure for chengal seedlings in the nursery even though it was not significant under the different light treatments. Seedlings under 30% LI recorded the highest WUE whilst seedlings under 100% LI, the least. WUE was also observed to decrease slightly throughout the 12 months growth period in the nursery by an average of 0.6%. A study on citrus grown under different shading nets by Medina et al. (2002) reported a slight increment of 13.3% of WUE values in shaded plants (50% shading) compared to control (no shading) and found that despite an increased stomatal conductance of citrus in shaded condition, the transpiration rates were only 10-20% higher. The slight increase in transpiration rates under shade was due to lower leaf and air temperatures that brought about a lower lead-to-air vapor pressure gradient, and hence lower evaporative demand. Meanwhile, WUE increased slightly in shaded plants due to the greater influence of shading on CO_2 assimilation rather than on the transpiration. This can also be explained by the fact that WUE was being maximized by minimal stomata opening when temperature and light were optimal (Neri et al., 2003).

Moreover, the P_n, E and G_s, observed for chengal, which were higher than those rates recorded by studies mentioned above, could be due to the thinner leaves, which would have a greater ability to control the leaf temperature through transpiration.

Moreover, stomatal oscillations were often observed in seedlings grown under sun than shade conditions (Langenheim, 2003). Photosynthetic and transpiration rates as well as stomatal conductance are eventually the result of the difference in carbon gain. The difference in stomatal conductance were in parrallel with photosynthetic increment and therefore any light exposure within the stomatal limitation will also increase the physiological activity of the tree (Leakey et al., 2009). Therefore, chengal potted seedlings under partial shade is seen to exhibit the highest carbon gain, which indirectly maximize the photosynthetic activity of the seedlings compared to seedlings under the least and highest light esposure at the nursery level.

The LAI recorded for chengal potted seedlings after one year in the nursery were between 5.17 - 5.95 with the highest LAI under 50% LI and the least was under 100% LI. The shaded chengal seedlings under 30-50% LI produced larger leaves in order to capture more light, probably because of a shade avoidance mechanism. Plants grown in lower light conditions tended to show more vegetative growth, such as leaf area, petiole length and internode length rather than reproductive growth (Ballare & Casal, 2000). Joesting et al. (2009) reported in his study that the specific leaf area increased with shade for shade tolerant species of *Fagus grandifolia* and *Acer rubrum*. A similar result was observed in this study for chengal seedlings where LAI increased in seedlings given lower light treatments. A study by Poorter et al. (2009) on the shade tolerant species of *Cariniana micrantha* and *Theobroma speciosum* (understorey species) reported that LAI reached an optimum value under partial shade, between 30-50 % LI and decreased under full light (100%). Most species have been reported to show a decrease in LAI with increasing irradiance (Niinemets, 2010; Poorter et al., 2009). Another study by Anjana and Pramod (2010), reported that species of *Centella asiatica* showed significantly lower specific leaf area (SLA) under high light intensity. This suggested that leaf anatomical differences in low quantum flux density, reflects a strategy to increase the species competitive ability under low light through an increase in leaf area (Poorter et al., 2009). The higher values for SLA in more shaded treatments are due to the increase in leaf area and a reduction in thickness caused by shading, while leaves in the sun are usually thicker than those growing in the shade (Niinemets, 2010). An increase in SLA is a common response observed in plants under low light conditions and is usually associated with extra layers of mesophyll and cuticle. (Devkota et al., 2010; Stoneman & Dell, 1993).

5.4.1.2 Effect of fertilizer on physiological parameters and LAI in nursery and field

NPK Blue fertilizer gave the highest increment of the physiological parameters compared to goat dung and control throughout measurements in the nursery with an exception to WUE (Table 5.3). The P_n of chengal potted seedlings recorded in this study was between 5.10 - 6.65 µmol m^{-2} s^{-1} with the highest values observed in seedlings given NPK Blue fertilizer and the lowest in the control. These values are slightly higher by at least 12 % compared to a study by Feng et al. (2008) on *Shorea leprosula* and *Shorea oleosa* treated with NPK fertilizer (17:17:17%) nitrogen:phosphorus:potassium which recorded an average of 2.06 - 5.87 µmol m^{-2} s^{-1} and 1.84 - 4.03 µmol m^{-2} s^{-1}, respectively. Equally important, chengal seedlings in the field under combination of fertilizers accreted the physiological parameters giving the highest value compared to the application of SRF and the lowest was under organic fertilizer for all months (Table 5.1). In contrast, organic fertilizer gave the highest WUE compared to other fertilizer application. P_n chengal planted seedlings in the field ranged between 8.18 - 8.65 µmol m^{-2} s^{-1} at 44 months of planting, with the highest rates observed in seedlings given the combination of fertilizer, followed by only organic fertilizer and the lowest under SRF application. A study by Kenzo et al. (2007) also observed a P_n of between 4.53 - 5.56 µmol m^{-2} s^{-1} for *Shorea ovata* species planted in the degraded forest of Niah Forest Reserve, Sarawak. Correspondingly, Irino et al. (2005) reported *Dryobalanops lanceolata* planted also in the Niah Forest Reserve, recorded photosynthetic rates of 5.91- 6.82 µmol m^{-2} s^{-1} when given a controlled release fertilizer (12:14:12%) NPK, respectively, after 34 months of planting. These rates are lower by 40.7 and 25.8%, for *Shorea ovata* and *Dryobalanops lanceolata,* respectively, compared to chengal in this study. Chlorophyll, the pigment responsible for capturing the light energy that drives photosynthesis, also contains nitrogen in its molecular structure. As such, increasing N supply has often been associated with increasing photosynthetic activity (Havlin et al., 2005). It affects the chlorophyll concentration in mesophyll cells, and therefore an adequate supply of this element allows leaf tissues to capture more light and display a dark green color (Havlin et al., 2005; Lawlor, 2002). When plants are N deficient, they have fewer chloroplast components to invest towards photosynthesis. Their growth habits are poorer, their tissues become chlorotic, and they will often have an unthrifty, spindly appearance. Chlorosis often begins in older tissues first as proteins in these areas are broken down and converted to soluble N so the plants may translocate recycled N into newer, active meristematic tissues (Havlin et al., 2005).

Moreover, transpiration rate (E) of chengal planted in the field also showed the same trend as photosynthetic rates in the field. The rates measured for chengal planted seedlings which recorded 3.51 - 3.99 µmol m^{-2} s^{-1} for organic fertilizer treatment and the combination of fertilizer treatment were 25.6% higher compared to *Hopea nervosa* planted in an open planting given different fertilizer treatments (Ang & Maruyama, 1993). The apparent high cost of plant water loss may have another benefit besides CO_2 absorption and it may affect the acquisition and transport of nutrients by the plant. The mass flow of nutrients such as N, Ca, Mg, and S to root surfaces is attributed to transpirational water uptake by the plant (Havlin et al., 2005). Since mass flow of soil solution nutrients is affected by transpiration, the rate at which water evaporates from the leaves determines the rate that soil water reaches the roots. Therefore, transpiration rate affects the amount of nutrients that come into contact with the root (Havlin et al., 2005).

As suggested by Kenzo et al. (2007), changes of WUE differed significantly between species from the nursery to after planting for dipterocarp species namely *Dryobalanops beccarii* and *Shorea macrophylla*. It was also observed that *Shorea macrophylla* had higher WUE in the nursery but the value decreased after planting throughout the experimental period. Both *Dryobalanops beccarii* and *Shorea macrophylla* showed a low tolerance to leaf dessication after outplanting (Maruyama et al., 1997). These species require large amounts of water to maintain a high carbon assimilation rate in logged forest. Similar results were observed for chengal seedlings from nursery up to planting in the field. A planting trial in a secondary forest conducted by Ang & Maruyama in a book writen by Okuda et al. (2003), where he planted *Shorea platyclados and Shorea assamica* given NPK and organic fertilizer reported similar findings, where the WUE were (2.19 and 1.91) respectively. In the same study, *Shorea macroptera* and *Hopea nervosa* recorded WUE of (1.26 and 0.78) respectively. This was on average 43 and 65% higher compared to *Shorea macroptera* and *Hopea nervosa* respectively. The different results obtained between those species were due to species site matching and not on any fertilizer applications. *Shorea platyclados* and *Shorea assamica* both were suitable and confined to be planted on the upper dipterocarp forest zone, having a higher altitudunal distribution than any other *Shorea* and *Hopea*. Therefore, those results were predicted. Furthermore, higher P_n and higher WUE in both

Shorea platyclados and *Shorea assamica* could have contributed to their higher survival and better growth. The superiority in photosynthetic efficiency of those species could be the main factor that contributes to its succesful establishment in an open conditions.

Other than that, water uptake by roots in plant is the main source of H_2O, for hydration of plant tissues and as substrate for photosynthetic reductant generation and O_2 evolution. Roots are also the main mean of acquisition of soil N, P, K, Mg, Ca and many more macronutrients. It is well known that WUE increases with reduction in water and light supply, as well as N reduction in the soil (Niu et al., 2011; Ponton et al., 2002). The impact of a reduced supply of water and N on the relationship between the instanteneous measure of water and N-use efficiencies will depend on the circumstances that give rise to the observed variation in WUE. In this study of chengal, the lesser mineral N % in organic fertilizer has produced higher WUE compared to SRF and combination fertilizer in the field. Increased in WUE observed in N-stress (lesser N mineral) is essentially resulted from reduced stomatal condutance. Greater reductions in photosynthetic capacity at the mesophyll level than in stomatal conductance means that the overall WUE has increased while growth rate decreased (Kerstiens, 2006).

Furthermore, after one year growing in the nursery, the G_s in seedlings given NPK Blue fertilizer, were 21% higher compared to seedlings of *Shorea leprosula* given NPK fertilizer (14:13:13%) planted in lowland diterocarp of Ayer Hitam Forest Reserve in a study conducted by Hazandy et al. (2011). G_s of chengal seedlings in the field ranged between 0.159 - 0.220 mmol m^{-2} s^{-1}, similar to that reported by Hazandy et al. (2011) on *Shorea platycados*, *Shorea assamica* and *Anisoptera marginata* at (0.15, 0.21 and 0.17) mmol m^{-2} s^{-1} respectively, given controlled release fertilizer. The results of Hazandy's and ours might be due the fact that the similar environmental conditions (annual rainfall and temperature) of our plot and Ayer Hitam Forest Reserve. The WUE of planted trees was being maximized by minimal stomata opening when temperature and light were optimal (Neri et al., 2003).

The LAI recorded for chengal potted seedlings after one year in the nursery were between 5.10 - 5.93 with the highest LAI recorded in seedlings treated with NPK Blue fertilizer and the lowest in seedlings without any fertilizer application. The application of organic fertilizer accreted the LAI, giving the highest value compared to SRF application, while the lowest was observed in chengal seedlings treated with combination fertilizer. The chengal seedlings, regardless in the nursery or planted in the field, have LAI values comparable to those of dipterocarp seedlings as reported by Wong et al. (2005). The LAI of chengal potted seedlings and planted chengal in this study were on average, 5.53 and 7.24, respectively. The LAI recorded by Mun et al. (2011) on *Shorea dasyphylla, Shorea leprosula* and *Shorea ovata* were at 4.15, 3.63 and 3.04, respectively. These LAI of chengal and *Shorea* species indicated a positive relationship between growth, leaf photosynthesis and LAI. Mun et al. (2011) asserted that leaf area determines light interception and thus influences biomass production of plants which were given extra nutritional fertilizers. It also plays an important role in determining plant CO_2 uptake through photosynthetic process. Thus species with higher photosynthetic rate generally have higher LAI.

Another study by Leakey et al. (2009) on *Shorea leprosula* seedlings in the nursery, given organic and NPK fertilizer (14:13:13%) showed higher LAI values of 9.4 - 11.0, regardless of light intensity treatment. In terms of growth, ample N increases the number of cells per leaf and the cell size. As the result of this, the leaf area increases (Lawlor, 2002). Hossain et al. (2010) found that leaves with low nitrogen had a lower turgor and slower leaf enlargement than the leaves with high nitrogen. Furthermore, with increasing LAI, more solar radiation is intercepted by the plant and used for photosynthesis (Lawlor et al., 2009). Plants, therefore, grow better. In this study, chengal seedlings treated with fertilizers has shown an increase in leaf area. Elsewhere, under high N-supply (NPK fertilizer), *Shorea leprosula* species showed the greatest ability to increase photosynthetic capacity per unit leaf area when irradiance was not the primary limiting factor (Feng et al., 2008; Bungard et al., 1997).

5.4.1.3 Effect of age on physiological parameters in the field

As was shown in the results, the physiological parameters and LAI of chengal seedlings in the field showed a significant increase from 12^{th} to 44^{th} months of growth in the different age groups (Table 5.10). The P_n of chengal potted seedlings recorded in this study was 8.16 and 8.66 μmol m^{-2} s^{-1} in the 1y 8 m and 6 m old seedlings, respectively. The rates seen in the younger and smaller seedlings were 6% higher compared to the bigger and older seedlings. Other than that, the E rates recorded for 6 m old chengal seedlings was 12% greater compared to 1y 8m old chengal. Ishida et al. (2006) study on *Dryobalanops aromatica* species found that the age of seedlings (old versus young) differed significantly. The seedlings recorded a decrease in E rates as the seedlings matured (from young to old) from an average of 8.03 - 11.8 μmol m^{-2} s^{-1} to 5.89 -7.79 μmol m^{-2} s^{-1}, a decrease of around 70%. Meanwhile, the P_n of *Dryobalanops aromatica* of young to old leaves were at an average of 6.5 – 8.0 μmol m^{-2} s^{-1} to 4.6 – 6.8 μmol m^{-2} s^{-1} respectively. Moreover, the planted chengal seedlings showed a higher G_s in 6 m old seedlings compared to 1 y 8 m old seedlings, 0.196 and 0.172 μmol m^{-2} s^{-1}, respectively. This was a difference of 12% between the younger and older seedlings. The same study on *Dryobalanops aromatica* species by Ishida et al. (2006) showed similar results, where the rate was at an average of 0.02 - 0.07 μmol m^{-2} s^{-1} for older seedlings and 0.1 - 0.5 μmol m^{-2} s^{-1} for young seedlings. Ishida et al., (2006) found that younger leaves had higher chlorophyll content and that has contributed to the light harvesting efficiency at a low light availability. The ratio of chlorophyll/N acts an indicator of the allocation of leaf nitrogen to chlorophyll-protein complexes. He also suggested that *Dryobalanops aromatica* amount of leaf nitrogen was allocated preferentially to chlorophyll-protein complexes under shaded conditions. The shade-acclimation ability of the younger leaves may be larger than other species because it has high slopes between LCP and canopy openness and also the efficiently allocated leaf nitrogen to chlorophyll-protein complexes.

The LAI recorded for chengal seedlings grown in the field varied according to age group. LAI of 6 m old seedlings was higher compared to 1 y 8 m old chengal. Eichhorn et al. (2007) reported that young and expanded leaves of *Shorea leprosula* seedlings planted in secondary logged-over forest in Sabah recorded a higher LAI compared to the mature leaves. He pointed out that when leaves go through senescence (older leaves), some nitrogen in the leaf is resorbed while the other remaining in the leaf is lost from plants with shedding. Leaf aging has a significant effect on photosynthesis even when environmental factors do not change. Hikosaka et al. (1994) studied leaf senescence in the vine *Ipomoea tricolor* grown horizontally under different shading. When all leaves were exposed to full sunlight, allocation of leaf nitrogen was affected by nutrient availability. At a lower nitrogen availability, nitrogen was translocated from old to new leaves, leading to a steeper gradient of leaf nitrogen content. While at a high nitrogen availability, the oldest leaves retained a high nitrogen content, which was comparable to that of new leaves. Leaf area in the canopy increases with the production of new leaves, which is proportional to the rate of photosynthesis in the canopy. Uptake of nitrogen from the soil increases the amount of nitrogen in the canopy. Consequently, a new canopy of younger leaf has an optimal and greater LAI with an optimal amount of nitrogen from the soil.

The opposite pattern was recorded for WUE, where 1y 8m old chengals exhibited higher values compared to 6 m chengal, by a difference of 7% after 44 months planting. The WUE values were observed to decrease throughout the planting period. The WUE values of the chengal seedlings are comparable to that reported for the seedlings of *Dryobalanops aromatica* species by Ishida et al. (2006), where the older leaves showed higher WUE compared to younger leaves and it decreased throughout the experimental period. He claimed that the lower transpiration rates with higher photosyntetic rates of *Dryobalanops aromatica* has also increased the WUE of older leaves compared to younger ones. Older leaves which has established and adapted well to the harsh environment has the capacity of losing lesser water through transpiration than a younger leaf.

Reich et al. (2009) reported similar results and suggested that gradual changes in physiological parameters such as photosynthetic capacity and transpiration, were influenced by age. Ishida et al. (2006) suggested that leaf chlorophyll content differences between younger and older leaves could be associated with the differences in the physiological activities. For example, the younger leaves were lighter green in colour and exhibited low chlorophyll content but high chlorophyll a/b ratio in which contributes to higher photosynthetic capacity. Whilst, the older leaves were darker green and had a higher chlorophyll content but lower chlorophyll a/b ratio.

5.4.1.4 Light response curve under different light regimes

The A_{max} value for chengal potted seedlings in the nursery, at light saturation was found to be significantly different under the different light intensity treatments in the nursery. The A_{max} recorded was inversely related to shade tolerance and was highest under 100% LI treatment and lowest under 30% LI (Figure 5.1 and Table 5.4). This was to ensure that the species make more efficient use of high light intensity. The A_{max} ranged from 8.13 - 9.9 µmol m^{-2} s^{-1} at light saturation between 560-620 µmol m^{-2} s^{-1}. The A_{max} values increased while light saturation point decreased after 12 months growth in the nursery. Kenzo et al. (2008) had reported that chengal species in a degraded tropical secondary forest in Peninsular Malaysia, showed an A_{max} range between 3.57 – 7.04 µmol m^{-2} s^{-1}. The lower and varied A_{max} rate in his study was due to the species suffering chronic photoinhibition to strong light under high canopy openness. In addition, midday depression of photosynthesis may be clear in chengal under a large gap, because the depression was marked in chengal compared with other dipterocarp species under open dry conditions (Ishida et al., 2006). Therefore daily carbon gain of chengal may be limited under strong light conditions such as a large canopy gap. An increase in photosynthetic activity capacity is a key mechanism that aids acclimation to high irradiance, optimum fertilizer application, and those species that can increase photosynthetic capacity on a leaf area basis also tend to respond favorably to growth (Muller et al., 2011). A study by Tolentino et al. (2006) on *Anisoptera thurifera* and *Hopea plagata* also recorded a similar A_{max} of 8.36 and 7.21 µmol m^{-2} s^{-1}, respectively with the light saturation point approximately at 600 µmol m^{-2} s^{-1}. The higher LSP implied that the chengal seedlings were adjusting to the higher light intensity. Usually plants showing high P_n will also show high LSP (Tolentino et al., 2006).

Likewise, the LCP, R_d and QE of chengal seedlings were found to be higher under lower light intensity for chengal seedlings in the nursery but decreased throughout the 12 months of growth indicating that photosynthetic efficiency increased under shaded conditions (Larcher, 2003). The LCP recorded for chengal seedlings were between (4.06 - 4.71) µmol m^{-2} s^{-1} with the lowest value observed under 30% LI and the highest under 100% LI. Comaparatively, Kenzo et al. (2011) also reported that light compensation decreased significantly with decreasing canopy openness for *Dyera costulata* and *Dipterocarpus baudii*. High chlorophyll content in the leaves also facilitated acclimation under low light conditions (Halik & Hirsch, 2011). In general, high chlorophyll content in the leaves contributed to high light capturing ability and reduced the leaf light compensation value (Kenzo et al., 2006).

In addition, the R_d rates were found to be low under lower light intensity for chengal seedlings in the nursery. A study by Joesting et al. (2009) on shade tolerant species of *Acer rubrum* found that the R_d rates were lower in leaves from the shade treatments than in those raised in full daylight. In general, the lowest rates were found in the leaves kept in deepest shade (3% LI) and the highest in the open (100% LI). Shade leaves are thinner and contain less tissue per unit of leaf area than sun leaves. Their lower rates of dark respiration can therefore be attributed to this anatomical feature.

Moreover, the QE of a LRC provides a measure of the efficiency of light absorption and utilization by the leaves at low intensities. The steeper the slope of the curve, the greater the photochemical capacity of the leaf. The results in this study, concurred with that done by Joesting et al. (2009) where, the QE values were higher for *Fagus grandifolia* (a shade tolerant species) grown under lower light intensities (30 - 50%) with the highest value observed under 50% LI. Leaves of shade grown plants have greater photochemical capacities than those of plants raised in the open thus indicating a degree of shade adaptability in all species.

Among other established characteristics of shade tolerance of land plants are the decreased R_d, LCP and LSP (Valladares & Niinemets, 2008). Not only because these features are always seen in shade-tolerant plants but also because they play pivotal functional roles in shade tolerance, and represent the most fundamental criteria for shade tolerance. Valladares and Niinemets (2008) elaborated the ‘carbon gain hypothesis’ in shade tolerance as the maximization of light harvesting and efficient use of captured light in photosynthesis with decreased respiration costs for maintenance. According to this hypothesis, any trait that enhances the light use efficiency and hence the carbon gain, would increase the shade tolerance of the species. This study demonstrated that chengal species maximized light capturing under low light, 30-50 % (Table 5.2). The reduced LCP and LSP, which are the simple measure of shade tolerance and low R_d rates (Figure 5.1) under lower light intensities, have enabled the chengal seedlings to be more efficient.

5.4.1.5 Light response curve under different fertilizer regimes

The same trend was found for LRC developed for chengal potted seedlings in the nursery up to chengal planted in the field, 12 and 44 months after growing in the nursery and field respectively. The LCP, LSP, R_d and QE were observed to decline by months. On the contrary, A_{max} increased throughout the measurement period for both chengal in the nursery (Figure 5.2 and Table 5.4) and field (Figure 5.4 and Table 5.13). Irino et al. (2005) expressed the same results for *Dryobalanops lanceolata* where application of higher amount of controlled release fertilizer had increased the A_{max} of both seedlings in the nursery and field by 55.4 and 9.6 %, respectively, compared to control (without any application of fertilizer). *Dryobalanops lanceolata* recorded an average A_{max} of 6.77 and 7.21 µmol m^{-2} s^{-1} both in the nursery and field, respectively. In our study, potted seedlings treated with NPK Blue exhibited highest A_{max} rate by an increment of 3.8 and 9.1 % compared to goat dung and control, respectively. In the field, chengal seedlings treated with combination fertilizer contributed to highest A_{max} by an average increment of 4.2 and 5.8 % compared to only SRF and only organic fertilizer, respectively. Additionally, the study by Irino et al. (2005) on *Dryobalanops lanceolata* recorded dark respiration rate of 0.84 and 1.48 µmol m^{-2} s^{-1} for the nursery and field, respectively, given controlled release fertilizer. These rates are similar to the one recorded for chengal potted seedlings and planted seedling in this study of (0.65 - 0.74) µmol m^{-2} s^{-1}. In our study, chengal R_d at 12 months decreased by an average of 27.0% throughout in the nursery and highest point was of chengal treated with NPK Blue which was higher by 4.4% and 26.5% compared to organic and control, respectively. The dark respiration at 44 months decreased by an average of 30.7% throughout the field and the highest point was of chengal treated with combination fertilizer, which was higher by 3.2% and 7.3% compared to only SRF and only organic fertilizer, respectively. Irino et al. (2005) indicated that the results of *Dryobalanops lanceolata* on higher A_{max} and R_d values obtained was due to the leaf N accumulated with the N content. A_{max} increased with the N content of the plant leaves. Therefore, the saplings measured a higher photosynthetic activity, which was recovered by N supply from additional controlled fertilizer.

Correspondingly, the seedlings LCP was the highest under NPK Blue as well and higher by 2.3% and 8.1% compared to organic fertilizer and control, respectively. Meanwhile, under combination fertilizer, LCP was higher by 8.0% and 13.4%

compared to only SRF and only organic fertilizer, respectively. The percentage decreased from 12^{th} to 44^{th} months by 7.2 % and it was observed that the LCP at 44 months after planting was lower than in the nursery. A study by Kenzo et al. (2007) on *Shorea* species found that the LCP was higher in the nursery and dropped after planting in the field. Fertilizing the seedlings from nursery to the planting site has contributed to an increased N in the leaves and directly increased the chlorophyll content. Large leaf chlorophyll content helps maintain low light compensation and acclimatize to the open conditions in the field (Larcher, 2003).

The study by Kenzo et al. (2008) concurred the results of chengal seedling potted and planted physiological activity where, it was observed that larger chlorophyll content and chlorophyll to N ratio in the leaves are related to lower light compensation, light saturation and dark respiration value and permitted better acclimation of those seedlings towards optimal light conditions. Applying higher N-supply has accommodated better N ratios in the leaves and directly exhibited all physiological parameters values both in the nursery and field.

An inclined harm to photodamage in plants grown at low compared with higher growth light exposure is common across a range of species (Oguchi et al., 2011; Oquist et al., 1992). To a large extent, this increased susceptibility can be attributed to the greater partitioning of internal leaf resources under low light towards light capture and away from processes associated with light energy utilization or dissipation (Shimizu et al., 2006; Bjorkman & Demmig-Adams, 1995). An increased susceptibility to photodamage in plants grown was also found at a low N supply compared to a higher N (Feng et al., 2008; Bungard et al., 1997). Therefore, fertilizing chengal seedlings with NPK Blue fertilizer and combination fertilizer of (SRF and organic) containing higher N nutrient was seen could increase physiological characteristics of the species given more exposure to light.

5.4.1.6 Light response curve under different age group

Younger and smaller size of chengal (6 month old) significantly affected the LCP, LSP, R_d and QE exhibited maximum mean value compared to a an older and bigger size (1 year 8 month old) (Figure 5.4a and Table 5.14). Another perspective is given by Bruce et al., (2005) on native plant of *Phaseolus vulgaris*, he reported an A_{max} rate of 5.5 and 2.17 µmol m^{-2} s^{-1}, respectively for young and old leaves of those seedlings. The A_{max} of younger leaves was higher by nearly 60% compared to older leaves regardless of any treatments given. Chengal seedlings age 6 months attributed to highest A_{max} by an increment of 3.3% compared to 1 year 8 months seedlings throughout measuring period, 11.90 and 11.57 µmol m^{-2} s^{-1}, respectively. Furthermore, the R_d decreased by 30.7% throughout the planting period and the highest point was of 6 month old chengal which was higher by 10.9% compared to 1 year 8 month old. These results are also in agreement with *Acacia auriculariformis* in a research by Bruce et al. (2005), where younger leaves contributed a higher R_d rate by 7.0% compared to an older leave regardless of any treatments given. The difference in A_{max} and dark respiration between an older and younger leaves was largely due to the alternative path of electron transport in mitochondria. The older leaves underwent slow hardening at the nursery (exposure to sunlight by phase from low to high light) and planted in the field might have caused a complete elimination of the cytochrome path that returned with a recovery phase in the light (Bruce et al., 2005).

Age related changes in light compensation, light saturation and quantum efficiency were also similar to those previously reported by Langenheim (2003) for other species of Amazonian rainforest tree species namely *Hymenaea courbaril* and *Hymenaea parvifolia*. The light compensation recorded by both species recorded were 15.0 and 8.00 µmol m^{-2} s^{-1} and 13.00 and 9.00 µmol m^{-2} s^{-1} for young and old leaves, respectively. These rates of young leaves were higher by 47 and 31 % compared to older leaves for *Hymenaea courbaril* and *Hymenaea parvifolia*, respectively. In this study of chengal, age 6 months seedlings LCP was better and higher by 6.4% compared to 1 year 8 months old planted chengal. The percentage decreased from 12th to 44th month by approximately 7.2% in the field. The LSP of 6 month old was also at maximum and better compared to old chengals. The increment of a 6 month chengal was higher by 2.6% compared to old chengal with respective rates of 536 and 522 µmol m^{-2} s^{-1} for 6 m and 1 y 8 m old chengal. Similar results were claimed by Langenheim (2003) on *Agathis robusta* which recorded a light saturation point of 200 - 500 µmol m^{-2} s^{-1} at 2-fold in young leaves compared to old leaves grown under full sunlight. All the physiological characteristics of young and old seedlings of chengal data suggest that high photosynthetic capacity, provided optimal G_s, would account to the high response to PFD. These young leaves of chengal had higher G_s and higher intercellular CO_2 concentrations than mature leaves. These physiological attributes of light compensation and light saturation between treatments were at their maximum in young leaves and declined with increasing age. The effect of age on all these characteristics can be explained by the high dark respiratory rates with minimal QE (Langenheim, 2003).

5.5 Conclusion

This study has shown that the growth and establishment of shade tolerant chengal in logged-over forest which has a very slow growth rate could be improved with an ideal light exposure, optimum fertilizer and with an appropriate age. The result of the study suggests that light, fertilizer treatment and plant age had a significant influence on the growth performance and physiological parameters namely Pn, E, Gs, WUE, A_{max}, R_d, LCP, LSP, QE and LAI of chengal seedlings raised in the nursery and out-planted in logged-over forest. The older and bigger seedling exhibited enhanced growth compared to younger seedlings. In contrast, younger and smaller chengal seedlings exhibited higher physiological characteristics compared to older chengal seedlings. A combination of SRF and organic fertilizer treatment gave better growth performance and increased the physiological characteristics compared to only application of SRF and organic fertilizer singly. An ideal light level of 50% given NPK Blue fertilizer in the nursery has showed the best growth of chengal potted seedlings compared to those seedlings given only organic fertilizer under the lowest exposure of 30% and highest exposure of 100% light. Therefore, it can be concluded that the adoption of partial light exposure and NPK Blue fertilizer in the nursery and later using older seedlings supplied with a combination of SRF and organic fertilizers can lead to an increase in growth and survival of the planted chengal seedlings in logged-over forest.

CHAPTER 6 : GENERAL DISCUSSION

Many studies have investigated the effects of light, fertilizer and age group on the establishments of dipterocarp seedlings, including their biomass fractions, plant mineral content, physiological attributes and soil characteristics throughout growth in the nursery to plantation in logged over forest. This study specifically focuses on chengal seedlings which have been scarcely studied in order to accentuate its poor growth and survival under harsh and different light conditions. It is hypothesized that the growth performance, biomass allocations, soil mineral and physical properties, plant mineral content as well as the physiological parameters of chengal seedlings in the nursery and logged-over forest would be greatly affected by light, fertilizer and age.

Interactions between light and fertilizer treatments of chengal potted seedlings in the nursery positively affected growth (Table 3.6), number of leaves, biomass fraction of leaves, stem and root (Tables 4.1 and 4.2), soil mineral content (Table 4.11), plant mineral content (Table 4.5), photosynthetic rate, transpiration rate, stomatal conductance, WUE, LAI (Table 5.1) and as well as physiological components derived from photosynthetic Light Response Curve (LRC), namely A_{max}, R_d, LCP, LSP and QE after 12 months grown in the nursery (Table 5.4). Chengal seedlings in the nursery under 50% light intensity treated with NPK Blue fertilizer gave the best growth performance and increment for the parameters tested, namely height and diameter (Tables 3.7 and 3.8), biomass fractions (Tables 4.3 and 4.4), plant mineral content (Tables 4.6 and 4.7), soil mineral content (Tables 4.12 and 4.13) as well as the physiological parameters (Tables 5.2 and 5.3) recorded which included the photosynthetic response curve (Figures 5.1 and 5.2), compared to the other light and fertilizer treatments. Soil physical properties were found not to be significantly different under the different light intensity and fertilizer treatments (Tables 4.9 and 4.10).

Chengal seedlings planted in logged over forest for 44 months showed that growth (Table 3.12), biomass and carbon stock of AGB and root (Table 4.18), as well as physiological characteristics (photosynthetic rate, transpiration rate, stomatal conductance and WUE), LAI (Table 5.9) including physiological components derived from photosynthetic LRC, (A_{max}, LSP and QE) with the exception of R_d, and LCP, were positively affected by the interaction of age and fertilizer (Table 5.12). However, the age of chengal seedlings did not affect the soil mineral content in the field even though fertilizer application showed significant increment throughout planting (Table 4.24). Similarly, soil physical properties were found not to be significantly different between the two age groups and fertilizer treatments (Tables 4.27 and 4.28). Chengal aged 1 y 8 m exhibited the best growth (Tables 3.13 and 3.14), biomass and carbon stock of AGB and root when given the combination of SRF and organic fertilizer treatment compared to the smaller and younger seedlings aged 6 m treated with either SRF or organic fertilizer singly (Tables 4.19 and 4.20). However, the 6 m chengal seedlings exhibited better photosynthetic (Tables 5.10 and 5.11) and physiological attributes (Tables 5.13 and 5.14) and soil mineral content (Tables 4.25 and 4.26) compared to the 1 y 8 m seedlings.

It has been documented that the growth rate of dipterocarps is influenced by sunlight availability at all stages of development, both in the nursery or in the field (Utsugi et al., 2009). As saplings, dipterocarps are able to survive and in fact thrive under the canopy, when the species are shade tolerant and grow optimally under relatively lower light intensities of between 30-50 %, with the best under 50% light

(Oshima et al., 2015). Even though chengal has been associated with having a slow growth rate, in this study it has been found that the growth rate of chengal seedlings is comparable to other medium and fast growing dipterocarps, namely *Hopea* and *Shorea* species.

It can be inferred from this result, that light intensity contributes greatly to its growth, development and maturity. It has been well documented that light intensity levels can have a significant effect on photosynthetic rates and other physiological and enzyme activities in a plant, which are directly related to the plant's ability to grow. For example, the LRC for all plants will show that photosynthesis will increase with increasing light intensity up to a point when it reaches light saturation and that faster growing plants will usually exhibit greater rates of CO_2 assimilation or photosynthesis (Lachapelle & Shipley, 2012; Heldt & Piechulla, 2011). Furthermore, many enzyme activities in plants (including those of the so-called dark reactions of photosynthesis, the Calvin cycle) are activated by light (Heldt & Piechulla, 2011). In addition to this, photosynthesis in shade leaves reaches light saturation at lower light intensities than sun leaves and as a result shade leaves subjected to high light intensities can cause photoinhibition and photo-bleaching of the leaves if exposed for a length of time (Heldt & Piechulla, 2011).

Nevertheless when the growth and shade tolerance of a species are to be correlated, it should be noted that the shade tolerant species are those that are facultatively adapted to shade and are different from the obligate shade species that grow and reproduce under shade throughout their lifetime (Fitter & Hay, 2012). Beneragama and Goto (2010) reported that higher shade tolerance of a species is associated with a lower potential for growth under shade in a study with 15 rain forest tree species that demonstrated species having low light compensation points (LCP) are characterized by low growth rate. Moreover, it has been shown that certain shade tolerant species may survive in shaded habitats for years without considerable growth (Turjaman et al., 2006). This is in accordance with the notion that the shade tolerance of a species is not related to growth but to persistence or survival in shade (Poorter et al., 2009).

General trends have indicated that under experimentally controlled conditions, maximum A_{max} is a good measure of the shade tolerance of a species (Urban et al., 2007). In our study, the shade tolerant chengal seedlings was found to have maximum A_{max} rates at a relatively higher light intensity of 100% LI than was expected for a shade species. The average increment were at 6.5% and 16.9% compared to 50% and 30% LI. Ratios between rates of A_{max}, P_n, E and G_s rates at saturating light intensities also suggested that the trends were towards WUE. It showed that the young shade tolerant seedlings are capable of adapting to a harsh environment, provided that proper silviculture management (with adequate and optimum light and fertilizer) is given at nursery level before out-planting.

Several researchers have reported that the height and diameter of chengal seedlings were lower under strong light conditions compared to other late successional tree species, including other dipterocarp trees (Kenzo et al., 2007). These responses indicated that chengal may be categorized as a low productivity species with regard to photosynthesis and is less tolerant to photoinhibition under strong light conditions, during its early growth stage. This means that the species may need some prior treatments such as a long hardening period and shading under a canopy of nurse plants, before the planting stage, to avoid environmental stress to the leaves when the seedlings are planted in strong light conditions (Kenzo et al., 2007).

This study has shown that raising and nursing chengal seedlings in the nursery and in a logged over forest with the application of an appropriate and optimum amount of fertilizer required by the seedlings, produced quality seedlings in term of greater growth performance, higher biomass content, better physiological characteristics, improved soil mineral content and properties as well as higher plant mineral contents. It was observed that the application of NPK Blue fertilizer in the nursery showed the best growth performance of 4.5 and 52.3 % higher and diameter of 3.9 and 35.3 % greater, compared to organic fertilizer and control treatments, respectively. A combination of SRF and organic fertilizers in the field resulted higher growth of 3.9 and 14.6 % for height and 6.1 and 17.9 % for diameter compared to stands applied with SRF singly and organic fertilizer singly. The optimum level of light intensity and the right amount and type of fertilizer in the nursery produced fit seedlings that when planted in a logged over forest produced a well-developed root system and bigger plant stem and diameter. This also reduced the cost of fertilising seedlings in the field. Vigorous seedlings have a high potential for growth and survival when planted in the field. A healthy seedling, however, must be well supplied with all the nutrients in proper proportions (Afa et al., 2011). If a given nutrient is deficient, seedlings may compensate to some extent by increasing their capacity to take up the deficient ion. Islam et al. (2014) amongst others, have suggested that improving the fertility of nursery soil is essential to guarantee the production of high quality seedlings for nursery establishment. Most tropical soils and forest are deficient in N and P and uptake of these nutrients by plant roots from litter is slow and limited. As a result, inadequate management of nursery soil can result in the depletion of site fertility and reduction in seedling growth (Hoque et al., 2004; Ang & Maruyama, 1993).

Fertilizer studies on other pot-grown dipterocarp species have shown that an application of NPK, had a significant effect on the growth and biomass of the dipterocarp species 6 months after the treatments were given (Turner et al., 2006). NPK fertilizer is primarily composed of three main elements: Nitrogen (N), Phosphorus (P), and Potassium (K), each of these being essential in plant nutrition (Datnoff et al., 2007). Among other benefits described by Datnoff et al. (2007) N helps plants grow quickly, while also increasing the production of seed and fruit, and bettering the quality of leaf and forage crops. It is also a component of chlorophyll, the substance that gives plants their green color, and also aids in photosynthesis. P mineral where else is also a key player in the photosynthesis process, plays a vital role in a variety of the things needed by plants. P supports the formation of oils, sugars, and starches. The transformation of solar energy into chemical energy is also aided by phosphorus, as well as is development of the plant, and the ability to withstand stress. Additionally, P encourages the growth of roots, and promotes blooming. K mineral which is known as potassium, the third essential nutrient plants demand, assists in photosynthesis, fruit quality, the building of protein, and the reduction of disease.

In this study, chengal seedlings fertilized with NPK improved seedling growth and indirectly increased biomass production after 12 months by 4% and 21% on shoot biomass as well as 37% and 42% on root biomass compared to an organic fertilizer and control. NPK Blue fertilizer has also exhibited a greater impact on the plant mineral content and soil mineral content of chengal potted seedlings compared to an organic fertilizer and control. It could possibly be due to the NPK Blue fertilizer having a higher percentage of N and P than the organic fertilizer, the latter containing only 11% of nitrogen and 5% of phosphorus. P applied to potted seedlings had a significant positive effect on seedling performance following out-planting in two dipterocarp species in Peninsular Malaysia (Turner et al., 2006; Raja Barizan et al., 2000; Nussbaum et al., 1995). Fertilizing the chengal seedlings in the nursery improved and fertilized the soil for the uptake of nutrients in the tree. Nevertheless the differences in response to fertilizers, by different dipterocarp species that has been reported, are probably not simply due to the amount or type of fertilizer used, but also probably a result of the appropriate different levels of light intensity required by the different species. Addition of fertilizer greatly affected the biomass production of chengal seedlings planted in the field and the soil mineral content. Seedlings fertilized with a combination of SRF and organic fertilizers posted significantly higher biomass production for AGB and root biomass, compared to application of SRF and organic fertilizer singly by 15% and 38%, respectively. The nutrient content of SRF which consisted of 19:10:13% nitrogen:phosphorus:potassium and organic with 11:5:11% nitrogen:phosporus: potassium contributed to the highest biomass production in the field. An addition of extra nutrients could improve the growth performance and indirectly the biomass of chengal stands in logged over forest. However, the required optimal amount of fertilizer of stock plants should be determined for planting in the field. Application of too much fertilizer can affect the survival of stock plants as was reported in experiments with *Dyera costulata,* where the survival percentage was significantly reduced when more fertilizer were applied (Aminah & Lokmal, 2002). The highest survival and growth increment observed with chengal seedlings in our study shows that the combination of SRF (200 g) and organic fertilizers (200 g), which contains sufficient amounts of N, P, and K, than only SRF (400 g) and organic fertilizers (500 g) singly, has enriched the soil better for the growth of chengal seedlings.

Moreover, the application of NPK Blue fertilizer for chengal potted seedlings in the nursery followed by a combination of SRF and organic fertilizers in the field have also accreted the physiological parameters including the components derived from the LRC compared to the other application of fertilizer. Similar findings were observed by Irino et al. (2005) who reported that application of controlled release fertilizer showed the most favourable results in terms of survival and growth of dipterocarps in the field. They suggested it was due to the enhancement of photosynthetic activity and nutrient status of the plants. Fertilizing the seedlings from nursery level up to the field in our study contributed to an increased N in the leaves and directly increased the chlorophyll content. Higher leaf chlorophyll content helps maintain low light compensation and acclimatize plants to the open conditions in the field (Larcher, 2003).

Our study has also showed that the older chengal seedlings (1y 8 m) performed significantly better than the 6 m old seedlings, in terms of growth, biomass and carbon stock of AGB and root as well as WUE. However, the 6 m seedlings exhibited better photosynthetic and physiological characteristics, LAI and soil mineral content compared to the 1 y 8 m seedlings. A general recommendation on the age of the stock to be planted out is not possible considering the great variation in early development by the different species. In any planting trial, the homogenous size of planting stocks at planting is very critical. As far as the age of the planting stock is concerned, Yamada et al. (2014) and Shaharudin (2011) found that for most of the dipterocarp species *(Dryobalanops aromatica, Shorea leprosula and Shorea pauciflora*) planting stock between 3 to 8 months old is the most suitable. Others have concluded that planting stock only a few months old is more likely to survive than older material (Skarpe & Hester, 2008; Hodgson & Eggers, 1937). Meanwhile, Raja Barizan and Shamsudin (2001) recommended that big saplings with the height and diameter of 1 m and 1 cm respectively are optimum for planting in the field, in order to minimize early tending following planting. Since improved planting techniques do not require frequent, repeated returns to the forests for silvicultural treatments, bigger and older chengal saplings are best suited to be planted and proven to exhibit higher mean increment in height and diameter. Furthermore chengal seedlings of 1y 8m are able to withstand intensive weed growth compared to the younger and smaller 6m old stands. This reduces the amount of weeding and thus it is preferable to plant seedlings which are large enough to overcome weed competition at an early stage.

Furthermore, the lower photosynthetic values observed in the older seedlings compared to the younger ones, might be due to leaf thickness. Lower photosynthetic rates could also account for the lower values for stomatal conductance (Langenheim, 2003). Ishida et al. (2006) reported that leaf chlorophyll content differences in the younger and older leaves of the seedlings could also be associated with the variation in physiological activities. The younger leaves were lighter green and had a lower chlorophyll content but a higher chlorophyll a/b ratio, whilst the older leaves were darker green and had a higher chlorophyll content, albeit lower chlorophyll a/b ratio and higher a/b ratio contributes to higher photosynthetic capacity. All the physiological characteristics of the younger and older chengal seedlings suggests that the higher photosynthetic capacity provided optimal stomatal conductance and accounts for the high response to PFD. The younger leaves showed higher stomatal conductance and higher intercellular CO_2 concentrations than the mature leaves. The physiological attributes of light compensation and light saturation were at their maximum in the younger leaves and lower in the older leaves. Reich et al. (2009) had earlier reported that gradual changes in the physiological parameters of photosynthetic capacity and transpiration have been observed to be influenced by age of the tree.

CHAPTER 7 : CONCLUSION

7.1 Conclusion

This study has shown that the survival and growth performance of the shade tolerant chengal species, which has a very slow growth rate, can be improved under optimum light intensity and fertilizer conditions at the appropriate age, from as early as the nursery stage up to outplanting in a logged-over forest. The result of the study also showed that light, age and fertilizer treatment had a significant influence on the growth performance, biomass allocations, soil mineral and physical properties, plant mineral content as well as on the photosynthetic and physiological parameters of chengal seedlings in the nursery and in a logged-over forest. Chengal seedlings in the nursery, under 50% light intensity treated with 10g of NPK Blue fertilizer exhibited the best growth performance in terms of plant height and diameter, biomass fractions, plant mineral content, soil mineral content as well as the physiological parameters, which included the light response curve, compared to other light and fertilizer treatments. The older and bigger chengal seedlings, aged 1y 8 m, showed enhanced growth, biomass and carbon stock of AGB and root when given a combination of SRF (200 g) and organic fertilizer (200 g) compared to the younger and smaller seedlings aged 6 m treated with either SRF or organic fertilizer singly. However, 6 m chengal seedlings exhibited higher physiological parameters and soil mineral content compared to the older 1 y 8 m seedlings. Therefore, it can be concluded that the adoption of 50% light intensity together with the application of NPK Blue fertilizer will produce quality and fit seedling in the nursery that will establish and grow well after outplanting. Quality planting stocks from the nursery of older age, supplied with the right combination of SRF and organic fertilizers, will lead to an increase in growth and survival of the planted chengal seedlings in a logged over forest.

7.2 Limitation of the study

One of the limitations of the study was the accessibility to the experimental site. The logged over forest of Tekai Forest Reserve was 13 km from the main roads. The logging roads and the only bridge which connected the road in the forest were ruined and collapsed due to heavy rainfall and flooding. Therefore, growth and physiological data measurements were delayed and postponed for a year.

7.3 Future directions and Recommendations

This dissertation research has provided evidence and essential knowledge on the establishment of a dipterocarp species that is near extinction, in a logged-over forest. Chengal, a heavy hardwood known for its slow growth performance could be successfully established and out-planted in a logged-over forest, given the proper management at the nursery. The established database from this study on growth, biomass fractions, physiological parameters and characteristics, as well as the soil characterization from the nursery to the field, will be useful for the Forestry department in their endeavour to manage successfully chengal seedling growth from the nursery to the harsh environment of a logged over forest. The chengal plot used in this study could also be used as a demonstration plot for future educational and Research and Development purposes.

Nevertheless, there are few future directions in which the study could be further enhanced and improved. Firstly, the study done on biomass and carbon stock in the field was only done on Chengal seedlings planted within 1.72 ha of Tekai Forest Reserve. It would be more conclusive if all five carbon pools of aboveground biomass, belowground biomass, soil carbon, deadwood biomass and litter were done to cover the forest cover carbon determination, especially in a logged-over forest. Secondly, the biomass and carbon stock calculation for the Chengal seedlings were done using an allometric equation developed by Kirby and Potvin (2007). It will be interesting if the destructive method was employed whereby saplings are harvested, as it has been reported to improve accuracy. Thirdly, it is recommended that the study should widen the growth data (height, diameter, volume) and its relation to the photosynthetic and physiological parameters to other species of dipterocarps. Finally, the existing study should be continued to be enumerated at regular intervals and the data analyzed promptly in order to improve our limited knowledge of the various factors which influence the growth and development of dipterocarp species in logged-over forest.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

1. **Farah Shahanim, M.M.,** Raja Barizan, R.S., Normaniza, O., & Nasrulhaq Boyce, A. (2017). Growth and physiological assessment of chengal seedlings planted under different age groups and fertilizer treatments in logged over forest. *Austrian Journal of Forest Science, 134*(3), 225-244.

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