UNIVERSITI PUTRA MALAYSIA

EFFECTS OF DIFFERENT LIGHT INTENSITIES, FERTILIZER LEVELS AND SHADING PERIODS ON THREE SHADE-TOLERANT TREE SPECIES UNDER CONTROLLED ENVIRONMENT

SHERZAD OMAR HAMAD

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By

SHERZAD OMAR HAMAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To our Prophet Muhammad who encourages us to learn and educate.
To the spirit of my father, Omar Hamad Omar, and my kind and beloved mother, Zulaikha Othman Ismail, her prayers have been a great role to my success today.
To my brothers and sisters, loved them heartily.
To my loved wife, Chnar Ahmed Kareem, who always supports me.
To my children, Chra, Mohammed and Zhyar who are bright my eyes.
Also, to all my friends and anyone who supports my even if with a word.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy.

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September 2016

Chairman : Associate Professor Mohd Zaki Hamzah, PhD
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With the increasing demand of heavy hardwood timbers in the world market annually, many of the shade-tolerant tree species such as *Neobalanocarpus heimii*, *Shorea materialis* and *Intsia palembanica* in Malaysia have faced serious extinction. The overall objective of this study was to improve growth and physiological properties of the aforementioned species through better understanding of their ecophysiology and growth requirements.

For this purpose, two experiments were conducted in the shade house and open area, where the first research was done to investigate the effect of different light intensities, and fertilizer levels on the survival rate, growth performance and physiological traits of the three species; the second research was performed to identify the effect of four shading periods on the survival rate, growth, biomass, leaf morphology and leaf physiology of the selected species.

The first experiment results after six months of the study indicated that the survival percentage of *S. materialis* and *I. palembanica* was 100% under all treatments. However, the survival percentage of *N. heimii* was significantly affected only by the light intenities, where its highest survival rate was 100% under 30% and 50% RLI, while the lowest survival rate was 74.07% at 100% RLI. All growth parameters and most physiological traits of these three species were significantly higher at both shade conditions (30% and 50% RLI) than full sunlight. Application of various fertilizer levels had a different effect on the growth and physiological properties of the species. Nevertheless, most parameters were enhanced by the application 1 and/or 2g NPK monthly.

The results of the second experiment after twelve months showed that the survival rate of *S. materialis* and *I. palembanica* was 100% under all shade periods.

Conversely, the survival rate of *N. heimii* was significantly reduced to 66.66% in zero shade periods while it was 100% in other shade periods. Seedlings of the three species grown under the shade for six, nine, and twelve months were significantly recorded higher height, diameter, and leaf numbers compared to those that have not been under shade. Stem mass, leaves mass, root mass and total plant mass were also affected by different shade periods. The highest value of these parameters were found in nine months under shade for *N. heimii,* and *S. materialis,* and six months under shade for *I. palembanica* while the lowest value of their biomass allocation were observed in zero month under shade. These three species displayed typical responses to direct sunlight after the canopy openings such as increases in RMR, R:SR and stomatal density and reduction in leaf area, SLA, LAR, and chlorophyll content except SLA, and LAR of *I. palembanica* at the first canopy opening. Photosynthetic rate and stomatal conductance of the three species indicated that their photosynthesis apparatus can acclimate to direct sunlight, especially after the second and third canopy opening.

In conclusion, growth and physiological properties of the three species were improved by application of 1g and 2g fertilizer under 30% and 50% RLI. In addition, the species could acclimatise to direct sunlight after they had been grown under shade (30% - 50% RLI) for six to nine months additionally (to their shade periods prior the study) due to their ability to adjust their morphological and physiological behaviors in accordance with changing light condition.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN PELBAGAI KEAMATAN CAHAYA, ARAS BAJA DAN TEMPOH TEDUH PADA TIGA SPESIES POKOK YANG TAHAN-TEDUHAN DI DALAM KEADAAN TERKAWAL

Oleh

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Dengan permintaan kayu balak keras yang tinggi dalam pasaran dunia setiap tahun, banyak spesies pokok berdaya-toleransi teduh ini *Neobalanocarpus heimii*, *Shorea materialis* dan *Intsia palembanica* menghadapi masalah ancaman kepupusan yang serius. Objektif keseluruhan kajian ini adalah untuk meningkatkan pertumbuhan dan ciri-ciri fisiologi spesies yang dinyatakan di atas melalui lebih memahami ekofisiologi dan keperluan tumbesaran mereka.

Untuk tujuan ini, dua eksperimen telah dijalankan di dalam *rumah* yang teduh dan kawasan terbuka. Eksperimen pertama telah dijalankan untuk mengkaji kesan pelbagai keamatan cahaya, dan pelbagai aras baja NPK ke atas kadar kemandirian, prestasi pertumbuhan dan ciri-ciri fisiologi ketiga-tiga spesies pokok ini. Eksperimen kedua dijalankan untuk mengkaji kesan empat tempoh teduhan ke atas kadar kemandirian, pertumbuhan, bio-jisim, morfologi daun dan fisiologi daun spesies yang sama. Untuk mengesahkan kajian ini, parameter di atas disukat selama enam bulan dalam kajian pertama dan dua belas bulan dalam kajian kedua.

Keputusan eksperimen pertama selepas enam bulan mendapati bahawa peratusan kemandirian *S. materialis* dan *I. palembanica* adalah 100% dalam semua rawatan. Namun demikian, peratusan kemandirian benih *N. heimii* terjejas secara ketara hanya dengan keamatan cahaya. Kadar kemandirian tertinggi *N. heimii* ialah 100% dalam kedua-dua keadaan teduh, 30% dan 50% RLI, sementara kadar kemandirian terendah ialah 74.07% pada 100% RLI. Semua parameter pertumbuhan dan ciri fisiologi ketiga-tiga spesies adalah lebih tinggi dalam kedua-dua keadaan teduh (30% and 50%RLI) dari cahaya penuh. Aplikasi pelbagai aras baja mempunyai kesan yang berbeza ke atas pertumbuhan dan ciri-ciri fisiologi ketiga-tiga spesies berkenaan. Namun demikian, kebanyakan parameter ditingkatkan lagi dengan aplikasi 1g hingga 2g NPK setiap bulan.

Keputusan eksperimen kedua selepas dua belas bulan menunjukkan bahawa kadar kemandirian *S. materialis* dan *I. palembanica* ialah 100% di bawah semua tempoh teduhan. Sebaliknya, kadar kemandirian *N. heimii* berkuran secara signifikan kepada 66.66% dalam tempoh teduh sifar sementara 100% dalam tempoh teduh lain. Benih ketiga-tiga spesies yang ditanam di bawah cahaya teduh untuk enam, sembilan dan duabelas bulan melaporkan ketinggian, diameter dan bilangan daun yang meningkat dengan ketara berbanding dengan spesies yang tidak ditanam di bawah teduh. Jisim pucuk, jisim daun, jisim akar, dan jisim pokok secara keseluruhannya juga dijejaskan oleh tempoh teduhan yang berlainan. Nilai paling tinggi untuk kesemua parameter ini ditemui pada sembilan bulan di bawah teduhan untuk pokok *N. heimii,* dan *S. materialis,* dan enam bulan di bawah cahaya teduh untuk *I. palembanica* sementara nilai terendah pembahagian biojisim diperhatikan pada bulan sifar di bawah teduhan untuk kesemua spesies. Ketiga-tiga spesies ini mempamerkan respon lazim kepada cahaya matahari terus selepas pembukaan kanopi seperti peningkatan dalam RMR, R:SR dan ketumpatan stoma dan pengurangan keluasan daun, SLA, LAR, dan isi kandungan klorofil melainkan SLA dan LAR untuk *I. palembanica* pada pembukaan kanopi pertama. Kadar fotosintetik dan konduktan stomata ketiga-tiga spesies menunjukkan bahawa alat fotosintesis boleh sesuai dengan cahaya matahari terus, terutama selepas pembukaan kanopi kedua dan ketiga.

Kesimpulannya, pertumbuhan dan ciri-ciri fisiologi daripada tiga spesies telah bertambah baik dengan penggunaan 1g dan 2g baja di bawah 30% dan 50% RLI. Di samping itu, spesies boleh menyesuaikan diri kepada cahaya matahari langsung selepas mereka telah ditanam di bawah naungan (30% - 50% RLI) selama enam ke sembilan bulan sebagai tambahan kepada tempoh pokok di bawah teduh sebelum kajian bermula, kerana kemampuan mereka untuk menyesuaikan mereka morfologi dan fisiologi tingkah laku mengikut perubahan keadaan cahaya.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
a. s. l.	Above Sea Level
cm	Centimeter
ºC	Degree Celsius
D.F	Degree of freedom
F	Fertilizer NPK
FAO	Food and Agriculture Organization
g	Gram
L	Light intensity
LAR ($cm^2.g^{-1}$)	leaf area ratio: ratio between leaf area and total dry mass per plant
LMR ($g.g^{-1}$)	Leaf mass ratio: ratio between leaf dry mass and total dry mass per plant
m	Meter
mm	Millimeter
µmol	Micromole
NPK	Nitrogen Phosphorus Potassium
#	Number
P	Probability value
PAR	Photosynthetic Active Radiation
PPFD	Photosynthetic Photon Flux Density
R:S	Root to shoot mass ratio: ratio between root dry mass and shoot (stem and leaves) dry mass per plant
RGR	Relative Growth Rate
RLI	Relative Light Intensity
RMR ($g.g^{-1}$)	Root mass ratio: ratio between root dry mass and total dry mass per plant
s^{-1}	Per second
SAS	SAS Statistical Analysis System
SHP	Shade period
SLA ($cm^2.g^{-1}$)	Specific leaf area: ratio between leaf area and leaf dry mass per plant
SMR ($g.g^{-1}$)	Stem mass ratio: ratio between stem dry mass and total dry mass per plant
SPAD	A portable instrument that uses to measure chlorophyll content.

CHAPTER 1

INTRODUCTION

1.1 General Background

Forest is defined by FAO (2010) as a land that covers more than 0.5 hectares with trees higher than 5 meters and their crowns cover more than 10%. It excludes urban parks, orchards, and other agricultural tree crops. Based on this definition, the world's total forest area in 2015 was about 3.9 billion hectares or about 31% of the global land area. The tropical forests represent 44% of the total forest area in the world as they cover approximately 1.7 billion hectares which are about 13.5% of the earth's land area (Keenan et al., 2015). The tropical rainforests are located in four biogeographic realms; the Neotropical, the Afrotropical, the Indomalayan and the Australian realms (Butler, 2007; Primack and Corlett, 2005). The Malaysian tropical forest belongs to the Indomalayan realms was approximately covering 20.456 million hectares i.e. 62% of Malaysia's total land surface in 2010 (FAO, 2011)

According to Whitmore (1990), tropical forests are the richest ecosystems on the earth's land area in terms of components and biodiversity. Tropical rainforests have many significant benefits to the global ecosystem and human life. For instance, 50% to 90% of the world's species live inside these forests. Tropical rainforests are considered as the core that controls the global and local climate systems by acting as heat and water pumps. They also reduce the effect of global warming through absorbing significant amount of carbon dioxide. Moreover, they are excellent source of oxygen, foods, medicines, and high-quality timers in the world. Tropical rainforests protect earth's land from the floods, droughts, and erosion (Butler, 2014; Drinnen, 2000; WWF-Global, 2015).

Particuary, the tropical rainforests of Southeast Asia (including Malaysia) are believed to be the oldest and one of the most biologically diverse in the world (WWF-Malaysia, 2015). The tropical forests in Peninsular Malaysia are considered as one of the wealthiest forests in the world. They contain approximately 94 woody families from 760 genres and 4100 species (Lim and Faridah, 1992). Despite the importance of the forests, the world's forest areas especially tropical rainforests are being reduced annually by human activities. One of the main causes that contributes to the forests degradation is the deforestation due to the advance of the agriculture frontier, overexploitation of forest for wood and energy, poor forest management, and forest fires (WWF-Germany, 2005). Over the past twenty-five years (1990 - 2015), the global forest area declined by 3%, and the tropical forest area dropped by an average of 7.8 million hectares per year (Keenan et al., 2015).

As a part of the total, Malaysia's tropical forest area was not far from the degradation. Over the past two decades (1990 - 2010), about 1.92 million hectares i.e. 8.6% of the total forest area in Malaysia have been decreased due to deforestation (Blaser et al., 2011). According to Butler (2013), Malaysia had the world's highest rate of forest loss between 2000 and 2012, as the forest loss increased about 14.4% compared to 2000. Butler (2015) also reported that Malaysia is one of the top 15 countries of forest loss between 2012 and 2014, where Malaysia’s tropical forest reduced by 484,770 hectares annually. Moreover, the remaining forests face dangers due to the unsustainable management and, illegal logging (WWF-Malaysia, 2015).

Tropical forest loss leads to a decline of timber production and an increase of the species extinction (Butler, 2012). This decline leads also to many environmental problems such as flooding, erosion, landslides, desertification and other natural disasters (Kobayashi et al., 2001). Consequently, some shade-tolerant species particularly, trees that provide heavy hardwood timbers are facing a serious risk of extinction due to the increasing demand in the world market annually. For instance, *Neobalanocarpus heimii* is believed that has been extinct in Thailand and Singapore (Oldfield et al., 1998), whereas, this species has been listed as vulnerable in Peninsular Malaysia because of overexploitation and poor regeneration (L. S. L. Chua, 1998). *Shorea materialis* is another shade-tolerant species that has been listed as critically endangered in Peninsular Malaysia due to the overutilization (Ashton, 1998; Oldfield et al.; 1998). It is also believed that *Intsia palembanica* species would face endangered in the very near future due to the illegal logging (Wong et al., 2009). Therefore, restoration of these species is an important process to keep their populations away from extinction and to produce high-quality timbers with accordance to the domestic and international markets demand.

Nevertheless, in order to achieve a successful forest restoration programs, foresters have to acquire the silvic knowledge that governs regeneration and growth of the species, which include knowledge on roles of biotic and abiotic factors. Among these factors, the quantity of light and nutrient are the most important factors that affect the plant growth and physiology (Kozlowski et al., 1997; Silva and Uchida, 2000).

Light influences growth performance directly through its impacts on the photosynthesis, respiration, stomatal conductance, and chlorophyll synthesis (Kozlowski and Pallardy, 1997a; Kramer and Kozlowski, 1960). Additionally, it also impacts the plant growth indirectly through its affects on other climatic factors such as air and soil temperature, humidity and soil moisture (Mori, 1979). Several studies have been carried out to determine the effect of different light intensity on the survival, growth and physiology of some late successional tree species. For instance, Sulaiman (1997) stated that the seedlings of *Shorea acuminata* planted under 2-9% RLI had better growth than those under 20-55% RLI. Moreover, Collet et al. (2002) showed that the stem of *Fagus sylvatica* seedlings grown under 36.6 % RLI were higher and thicker than those planted under 9.1% RLI. Tong (2006) reported that the optimum height, diameter, and leaf numbers of *Shorea roxburghii* were at 50% RLI, whereas the optimum growth properties of *Dyera costulata* and *Eusideroxylon zwageri* were at 25% RLI. One and two years after planting, Barizan and Newbery

(2008) discovered that seedlings of *Hopea odorata* and *Dryobalanops oblongifolia* in 20-55% RLI and 8-9% RLI had significantly higher survival rate than those in 2-3% RLI. They also found that the height, diameter, leaf number, stem mass, leaf mass and root mass of these two diptirocarp species grown under 20-55% RLI were significantly greater than those under 2-9% RLI. Aminah et al. (2013) revealed that survival rate, height and diameter increments of *Neobalanocarpus heimii* seedlings under 25%, 50%, and %100 RLIs were not significantly differed from each other. In contrast, Shahanim et al. (2014) demonstrated that seedlings of *N. heimii* grown at 50% RLI had significantly higher height increment, diameter increment, photosynthetic rate, transpiration rate, and stomatal conductance than those at 30% and 100% RLIs. In addition, Cai et al. (2008) reported that photosynthetic rate and leaf nitrogen concentration of three *Bauhinia sp.* was increased with increacing light intensity from 5 to 25% RLI.

Additionally, some experiments have been conducted to investigate the optimum levels of fertilizer that should be applied for potted seedlings in order to produce healthy and high quality plant stocks in the nursery. For example, Gunatilleke et al. (1997) reported that total biomass, height, and leaf number of eight *Shorea* species growing in pots were significantly increased by application of Mg and P together in different levels compared to unfertilized seedlings. Saner et al. (2010) exhibited that application of 1.25 g NPK fertilizer three times of a period 13 months caused to a significant improvement in dry weight of *Vatica albiramis* seedlings planted in pots. Aminah et al. (2013) found that plant height and diameter increments of *N. heimii* seedlings received 1 and 2 g Blue NPK monthly during eleven months were significantly increased compared with the control. Shahanim et al. (2014) displayed that *N. heimii* seedlings treated with 10g of NPK Blue monthly for twelve months had significantly higher height increment, diameter increment, photosynthetic rate, transpiration rate, and stomatal conductance than those fertilized by 10 g of goat dung. Irino et al. (2004) revealed that photosynthetic rate of *Dryobalanops lanceolata* seedlings was significantly varied among fertilizer treatments as the highest photosynthetic rate was recorded in the seedlings that treated with 2 g NPK while its lowest value was detected at 10 g NPK.

On the other hand, a few empirical studies reported that shade tolerant tree species are able to survive and grow satisfactorily under full sunlight durring establishment stages if they are supported by a suitable level of nutrients (Amrhein et al., 2012; Nussbaum et al., 1995; Tripathi and Raghubanshi, 2013). While other researches revealed that sufficient sunlight is required in determining the plant response to fertilizer applications (Brown et al., 1999; Gunatilleke et al., 1997; Shahanim et al., 2014). In addition, light (Kenzo et al., 2008) and fertilizer (Barizan and Newbery, 2008) requirement are different among various species even in the same taxonomic group.

Therefore, there are still more studies should be performed to discover the optimal amount of light and fertilizer for different tropical shade tolerant tree species in the nursery stage to provide enough number of plant stocks with a high quality for the purpose of reforestation in the degraded secondary forest areas as usually performed in enrichment planting.

On the other hand, it is commonly assumed that shade tolerant tree species are unable to survive well under full sunlight in the early establishment stage while strong light is required for better growth (Suzuki et al., 2006). Based on shade tolerant theory, many of the shade tolerant species in Malaysia, such as *N. heimii* seedlings have been planted under heavy shade in many rehabilitation projects including the enrichment planting projects carried out by the Forestry Department of Peninsular Malaysia (Appanah and Weinland, 1993; Mohd Zaki et al., 2009). One such example is the planting of *N. heimii* in between rows of 3-year old *Acacia mangium* in the Multi-storey Forest Management in Chikus, Bidor, Perak. After eight years under the shade, *N. heimii* was exposed to sunlight by cutting down the adjacent *A. mangium*, and the trees recorded remarkable growth (Mohd Zaki et al., 2011). However, two questions below are still unanswered:

1. Would the species performed better if it was exposed to full sunlight earlier than eight years?

2. What would the appropriate shade periods of different shade tolerant species before exposing them to strong light?

These two important questions have to be answered comprehensively through measuring survival rate, growth, biomass, leaf morphology and physiology of *N. heimii, S. materialis* and *I. palembanica* before they are planted in more rehabilitation projects in the near future to overcome the impending problems of conservation and production.
For that reasons, these studies should be conducted to more understanding of ecophysiology and growth requirements of these three species.

1.2 Justification

These three shade tolerant species (*N. heimii*, *S. materialis* and *I. palembanica*) are the most common and commercial trees in Malaysia because they produce heavy hardwood timbers which are highly valued for their strength, durability and workability. Moreover, these three species have faced a serious risk of extinction as mentioned early. In addition, there were no exact report on the combination effect of different light intensities and fertilizer NPK ($15N:15P_2O_5:15K_2O$) levels and effect of shading periods on the growth and physiological properties especially of *S. materialies* and *I. palembanica* in controlled environment. Furthermore, the three species are considered as slow growing tree species. Therefore, more investigations are required in order to get more knowledge on growth requirements in terms of the adequate light condition, fertilizer levels and shading periods of the studied species.

1.3 Objectives of the Study

The main aim of the present study was to improve growth and physiological properties of *N. heimii, S. materialis* and *I. palembanica* so as to success their reforestation in Malaysia through better understanding of their ecophysiology and growth requirements. For this purpose, two specific objectives were identified in this study. These objectives are as follows:

1. To investigate the effects of different light intensities, fertilizer levels, and their interactions on the survival, growth performance and physiological traits of three shade tolerant species. In addition, to determine the correlation coefficient within and between growth and physiological variables of each the species overall treatment combinations.

2. To examine the effect of different shading periods on the survival, growth performance, plant biomass, morphology, and physiology of each the species. In addition, to identify which variables of leaf morphology and leaf physiology play a significant role in driving growth and biomass of the species.

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LIST OF PUBLICATIONS

Sherzad, O. H., Mohd Zaki, H., Hazandy, A. H., Mohamad Azani, A., & Noordin, W. D. (2015). Growth and Physiological Responses of *Shorea materialis* Ridl. Seedlings to Various Light Regimes and Fertilizer Levels under Nursery Condition. *The Malaysian Forester*, *78*(1 & 2), 133–150.

Sherzad, O. H., Mohd Zaki, H., Mohamad Azani, A., & Hazandy, A. H. Effect of different shade periods on *Neobalanocarpus heimii* biomass and leaf morphology. *Journal of Tropical Forest science* (In review).

Sherzad, O. H., Mohd Zaki, H., Hazandy, A. H., & Mohamad Azani, A. Survival, growth and physiological responses of *Neobalanocarpus heimii* seedlings to different shade periods (In process).

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