

**GROWTH RESPONSE OF OIL PALM SEEDLINGS AT  
PRE-NURSERY STAGE IN AN OXISOL AMENDED  
WITH OIL PALM MILL BY-PRODUCTS**

**ELSIE ALICIA BONG**

**DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF BACHELOR OF  
AGRICULTURAL SCIENCE WITH HONOURS**

**PERPUSTAKAAN  
UNIVERSITI MALAYSIA SABAH**

**CROP PRODUCTION PROGRAMME  
FACULTY OF SUSTAINABLE AGRICULTURE  
UNIVERSITI MALAYSIA SABAH  
2016**



**UMS**  
UNIVERSITI MALAYSIA SABAH

## UNIVERSITI MALAYSIA SABAH

## BORANG PENGESAHAN TESIS

JUDUL: Growth Response of Oil Palm Seedlings at Pre-Nursery Stage In An  
Oxisol Amended With Oil Palm Mill By-Products

IAZAH: Bachelor of Agricultural Science With Honours (Crop Production)

SAYA: ELSIE ALICIA BONG SESI PENGAJIAN: 2012 - 2016  
 (HURUF BESAR)

Mengaku membenarkan tesis \*(LPSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis adalah hak milik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓)

SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di AKTA RAHSIA RASMI 1972)

TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh:

PERPUSTAKAAN  
UNIVERSITI MALAYSIA SABAH

NURULAIN BINTI ISMAIL

LIBRARIAN  
UNIVERSITI MALAYSIA SABAH  
(TANDATANGAN PUSTAKAWAN)

Elsie  
(TANDATANGAN PENULIS)

Alamat Tetap: 428 G, Lrg 3,  
Taman Lee Ling, Jln Matang,  
93050 Kuching, Sarawak

M B Jalal

(NAMA PENYELIA)

TARIKH: 11/1/16

TARIKH: 11 Jan 2016

## Catatan:

\*Potong yang tidak berkenaan.

\*Jika tesis ini SULIT dan TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.

\*Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana Secara Penyelidikan atau disertai bagi pengajian secara kerja kursus dan Laporan Projek Sarjana Muda (LPSM).



## DECLARATION

I hereby declare that this dissertation is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that no part of this dissertation has been previously or concurrently submitted for a degree at this or any other university.



---

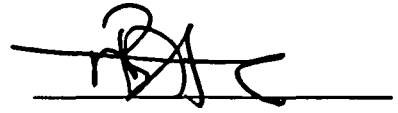
ELSIE ALICIA BONG

BR12110023

11<sup>TH</sup> JANUARY 2016

**VERIFIED BY**

1. Dr. Mohamadu Boyie Jalloh  
SUPERVISOR



**MOHAMADU BOYIE JALLOH, PhD**  
Professor Madye  
FAKULTI PERTANIAN LESTARI  
UMS CAWANGAN SANDAKAN

2. Prof. Dr. Mohammad Bin Mohd. Lassim  
CO-SUPERVISOR



**PROF. DR. MOHAMMAD BIN MOHD. LASSIM**  
PENYARAH  
FAKULTI PERTANIAN LESTARI  
UMS KAMPUS BANDARAN

## ACKNOWLEDGEMENT

First of all, I would like to take this opportunity to express my utmost gratitude to my supervisor, Dr. Mohamadu Boyie Jalloh, and co-supervisor, Prof. Dr. Mohammad Bin Mohd. Lassim for their guidance, advice and support given to me throughout this project. I am truly grateful for their efforts and patience in guiding me to complete my dissertation.

I would also like to thank my examiners, Prof. Dr. Mohammad Bin Mohd. Lassim and Madam Devina David for their helpful suggestions and advice during FYP I which enabled me to complete this dissertation.

Further, I would like to thank all the lecturers at the Faculty of Sustainable of Agriculture, Universiti Malaysia Sabah, for sharing of knowledge and valuable teaching throughout these four academic years, which has helped me a lot from the start until the end of this project.

I would also like to acknowledge and thank Mr. Mohan, Miss Siti and all their staff who had provided the raw materials, place, services and knowledge during the three months planting period of oil palm seedlings in IJMP Sijas Estate, Beluran.

My gratitude, also extends to the laboratory assistants who provided technical support making my laboratory analysis a smooth one. Of course, a lot of thank yous and gratitude to the alumni of Faculty of Sustainable of Agriculture, Universiti Malaysia Sabah, who have helped me in various ways while completing this project, by sharing their knowledge and experiences related to this project.

I wish to take this chance to also thank my family who has been constantly giving me moral and financial support in completing this project. Last but not least, I would like to thank all my friends who helped me in many ways giving me a helping hand during my hard times in completing this project.

## ABSTRACT

This study was carried out to evaluate the growth response of *Elaeis guineensis* seedlings in a tropical soil (Oxisol) amended with dried decanter cake, dried palm oil mill effluent (POME), and empty fruit bunch (EFB) biochar. In this experiment, a randomised complete block design (RCBD) was used and the duration was three months. The four treatments used were: (i) soil only (T1), (ii) soil and 10% dried decanter cake (T2), (iii) soil and 10% dried palm oil mill effluent (T3), and (iv) soil and 10% EFB biochar (T4). Each treatment was replicated six times. At the end of this experiment, plant height, plant diameter, shoot fresh weight, root fresh weight, root and shoot dry weight, soil total nitrogen, soil available phosphorus, soil cation exchange capacity (CEC), soil total organic carbon and organic matter, plant total nitrogen, and plant total phosphorus were measured. All the data collected were analysed using one-way analysis of variance (ANOVA) at 5% significance level. T4 resulted in the highest root dry weight of 0.54 g, followed by T1 (0.45 g), T2 (0.44 g), and T3 (0.35 g). For shoot dry weight, T4 also resulted in the highest weight of 1.44 g, followed by T2 (1.28 g), T3 (1.25 g), and T1 (1.21 g). However, plant total N was significantly higher for T1 with a value of 2.40%, compared to T3 (2.39%), T2 (2.40%) and T4 (0.90%). For plant P, T4 was significantly highest with a value of 13.33 mg kg<sup>-1</sup>, and the soil total nitrogen was significantly highest for T4 (0.51%) as well. The soil available P was significantly highest for T4 with a value of 4.46 mg kg<sup>-1</sup> and in soil CEC, T4 had 79.80% more CEC than T1. However, for total organic carbon and organic matter content, T1 was significantly higher with a value of 50.77%, compared to T4 (50.54%), T3 (50.04%), and T2 (49.03%). The results indicate that EFB biochar was better at improving the soil chemical properties. However, the oil palm seedlings showed better growth response to soil amended with dried POME. A longer term study is needed to observe the real potential of these soil amendments due to their slow effects and response from plants.

# ***PERTUMBUHAN PRE NURSERY KELAPA SAWIT (*Elaeis guineensis*) DALAM TANAH OXISOLYANG DIBAIKI DENGAN SISA-SISA KILANG KELAPA SAWIT***

## **ABSTRAK**

*Kajian ini dijalankan bagi mengenalpasti pertumbuhan pokok benih *Elaeis guineensis* dalam tanah tropika Oxisol yang telah dibaiki dengan kek decanter kering, kumbahan kilang kelapa sawit kering (POME), dan tanah buah kosong (EFB) biochar. Dalam experiment ini, rekabentuk blok rawakan lengkap (RCBD) telah digunakan dan tempoh masa experiment adalah tiga bulan. Rawatan yang telah digunakan adalah seperti berikut: (i) Tanah sahaja, (T1), (ii) Tanah dan 10% kek decanter kering (T2), (iii) Tanah dan 10% kumbahan kilang kelapa sawit kering (T3), dan (iv) Tanah dan 10% EFB biochar (T4). Setiap rawatan telah direplikakan sebanyak enam kali. Semasa berakhirnya experiment ini, ketinggian pokok, garis pusat pokok, jumlah berat bersih basah daun, jumlah berat bersih basah akar, jumlah berat kering daun dan akar, kandungan jumlah nitrogen tanah, kandungan phosphorus tersedia tanah, keupayaan pertukaran kation tanah (CEC), jumlah organik karbon tanah dan jumlah bahan organik, kandungan nitrogen dan phosphorus dalam pokok telah diukur. Semua data yang dianalisis dengan menggunakan satu arah ANOVA pada tahap 5% signifikasi. Bagi jumlah berat bersih kering daun, T4 (0.54 g) ada bacaan tertinggi, diikuti T1 (0.45 g), T2 (0.44 g) dan T3 (0.35 g). Dalam jumlah berat bersih kering daun, T4 (1.44 g) juga ada bacaan tertinggi, diikuti T2 (1.28 g), T3 (1.25 g) dan T1 (1.21 g). Namun, kandungan jumlah N pokok ada perbezaan signifikasi di mana T1 (2.40%) adalah lebih tinggi jika dibandingkan dengan T3 (2.39%), T2 (2.40%) dan T4 (0.90%). Kandungan jumlah P dalam pokok ada perbezaan signifikasi di mana T4 (13.33 mg kg<sup>-1</sup>) adalah tertinggi dan kandungan jumlah tanah N juga mempunyai perbezaan signifikasi di mana T4 (0.51 %) adalah tertinggi. Kandungan tersedia P juga mempunyai perbezaan signifikasi di mana T4 (4.45 mg kg<sup>-1</sup>) adalah tertinggi dan dalam tanah CEC, T4 ada 79.80% lebih banyak CEC daripada T1. Namun, bagi jumlah organik karbon tanah dan jumlah bahan organik, terdapat perbezaan signifikasi di mana T1 (50.77%) adalah lebih tinggi daripada T4 (50.54%), T3 (50.04%) dan T2 (49.03%). Keputusan ini menunjukkan keberkesanan EFB biochar dalam pembaikan tanah, manakala pokok benih telah menunjukkan kesan yang lebih bagus kepada rawatan POME kering dalam masa yang pendek. Namun, kesan positif pembaik tanah terhadap pertumbuhan pokok benih kelapa sawit tidak dapat diabaikan dan kajian jangka masa panjang adalah perlu untuk melihat potensi sebenar kerana mereka bertindak dalam kadar yang lambat.*

## TABLE OF CONTENTS

<b>Content</b>	<b>Page</b>
DECLARATION	ii
VERIFICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF SYMBOLS, UNITS AND ABBREVIATIONS	xi
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Introduction	1
1.2 Justification of Study	3
1.3 Objective	4
1.4 Hypothesis	4
<b>CHAPTER 2 LITERATURE REVIEW</b>	<b>5</b>
2.1 The Oil Palm	5
2.2 Soil Order Oxisol	7
2.3 EFB Biochar and Growth of Crop	8
2.4 POME and Growth of Crops	11
2.5 Decanter Cake and Growth of Crop	12
2.6 Germination of Oil Palm Seeds	13
2.7 Pre-nursery and Management	14
<b>CHAPTER 3 METHODOLOGY</b>	<b>17</b>
3.1 Location and Duration of Study	17
3.2 Materials and Methods	17
3.2.1 Materials	17
3.2.2 Methods	18
3.2.3 Experimental Design and Treatments	18
3.3 Crop Management	18
3.3.1 Sowing of Seeds	18
3.3.2 Irrigation and Fertilisation	19
3.4 Parameters of Study	19
3.4.1 Growth of Oil Palm Seedlings	19
3.4.2 Soil Properties	20
3.5 Statistical Analysis	20
<b>CHAPTER 4 RESULTS AND DISCUSSION</b>	<b>21</b>
4.1 Plant Parameters	21
4.1.1 Plant Height	21
4.1.2 Stem Diameter	23
4.1.3 Shoot Fresh Weight	24
4.1.4 Root Fresh Weight	25
4.1.5 Plant Root and Shoot Dry Weight	26
4.1.6 Plant Total Nitrogen	28
4.1.7 Plant Phosphorus	29
4.2 Soil Parameters	30





4.2.1	Soil Total Nitrogen	31
4.2.2	Soil Available Phosphorus	32
4.2.3	Soil Cation Exchange Capacity (CEC)	33
4.2.4	Soil Total Organic Carbon and Organic Matter	35
<b>CHAPTER 5 CONCLUSION AND RECOMMENDATIONS</b>		<b>37</b>
5.1	Conclusion	37
5.2	Recommendations	38
<b>REFERENCES</b>		<b>39</b>
<b>APPENDICES</b>		<b>45</b>

## LIST OF TABLES

<b>Table</b>	<b>Page</b>
2.1 Main characteristics of EFB	9
2.2 Characteristics of POME	9
3.1 Treatments of the experiment	18
4.1 Characteristics and chemical composition of each soil media mixture before planting	30
4.2 Total organic carbon content in different soil treatments	35

## LIST OF FIGURES

<b>Figure</b>	<b>Page</b>
2.1 Principal stage 0 of germination and emergence	14
2.2 Stained root with associated soil mycelium and spores of AMF	16
3.1 Correct sowing depth of germinated oil palm seed in each hole of pot tray	19
4.1 Mean plant height for the different treatments at 3 MAP	21
4.2 Mean stem diameter for the different treatments at 3 MAP	23
4.3 Mean shoot fresh weight for the different treatments at 3 MAP	24
4.4 Mean root fresh weight for the different treatments at 3 MAP	25
4.5a Mean plant root dry weight for the different treatments at 3 MAP	26
4.5b Mean plant shoot dry weight for the different treatments at 3 MAP	26
4.6 Mean plant Nitrogen for the different treatments at 3 MAP	28
4.7 Mean plant Phosphorus for the different treatments at 3 MAP	29
4.8 Mean soil total Nitrogen for the different treatments at 3 MAP	31
4.9 Mean soil available Phosphorus for the different treatments at 3 MAP	32
4.10 Mean soil CEC for the different treatments at 3 MAP	33

## **LIST OF SYMBOLS, UNITS AND ABBREVIATIONS**

AMF	Arbuscular Mycorrhizal Fungi
ANOVA	Analysis of Variance
AVROS	Algemene Vereniging van Rubberplanters ter Oostkust van Sumatra
BOD	Biochemical Oxygen Demand
CEC	Cation Exchange Capacity
COD	Chemical Oxygen Demand
EFB	Empty Fruit Bunch
FFB	Fresh Fruit Bunch
GHG	Greenhouse Gas
IJMP	IJM Plantations Berhad
MAP	Month after planting
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
OPT	Oil Palm Trunk
POME	Palm Oil Mill Effluent
SAS	Statistical Analysis System
SD	Standard Deviation

# CHAPTER 1

## INTRODUCTION

### 1.0 Introduction

One of the most important crop plants that changed the status of Malaysian agriculture and its economy is the oil palm. In 1870, oil palm (*Elaeis guineensis*) first came to Malaysia as an ornamental plant. The foundation for the palm oil industry in Malaysia happened with the first commercial planting in Tennamaran Estate in Selangor in 1917. The main reason for planting oil palm is due to its high oil yield per unit area, where two types of palm oil are produced from the same fruit: from the flesh or mesocarp and from the seed or kernel inside the hard-shelled mesocarp (Yusof, 2007). Oil palm is best grown in tropical areas where rain is plentiful throughout the year. In addition, this plant can grow in almost all types of soil. However, well drained, deep fertile loamy to loamy-clay soil are the most suitable for oil palm cultivation. In Malaysia, the crop's full potential has been exploited compared to in Africa where various challenges are being faced in the attempt towards domestication. The uses of palm oil produce include shortening, vanaspati, margarine, frying oils, as well as cheap raw materials (Gunstone, 2011).

With Malaysia's huge production of oil palm, there will also be abundant by-products and residues available. Three of the by-products are decanter cake, empty fruit bunch (EFB) and palm oil mill effluent (POME), which can be used as cheap organic fertilisers as an alternative to the excessive application of chemical fertilisers. For every 100 tons of fresh fruit bunch (FFB) being processed, about 20 tons of empty fruit bunch (EFB), 60 tons of palm oil mill effluent (POME) and 4 tons of decanter cake are produced (Ooi *et al.*, 2006). Further, the abundance of oil palm decanter cakes (OPDC) is a problem in oil palm mills and it is basically OPDC produced by the extraction of solids from the palm oil sludge (Utomo and Widjaja, 2004). Biochar is known as charred organic matter that is produced from various biomass



sources, and is a stable carbon compound that can be left in the soil for thousands of years. It has gained a lot of attention mainly because it improves soil fertility of degraded agriculture soil, as well as mitigates climate change through soil carbon sequestration thus reducing the greenhouse effect (Abdullah *et al.*, 2013).

EFB is one of the solid waste products (Okwute *et al.*, 2007) from the oil palm crop. Previously, EFB was used as fuel to produce steam at the mills. Due to its high content of nutrients, it was burnt to ash and used as fertilizer later on. However, to prevent air pollutions, burning of EFB is prohibited and now most EFB is used as soil mulching, boiler fuel and incineration, and the rest is left unused in the palm oil mills. (Astimar *et al.*, 2006). According to a report, EFB contains about 42% C, 0.8% N, 0.06% P, 2.4% K and 0.2% Mg (Prasertson *et al.*, 1996). Biochar can be produced through the pyrolysis of biomass of oil palm by-products, under zero or limited supply of oxygen with a temperature of below 700°C (Kong *et al.*, 2014). In producing EFB biochar, the same burning method can also be used.

On the other hand, POME is a viscous brown liquid with fine suspended solids and has a low pH of 3.5-4.5, high value of chemical oxygen demand (COD), biological demand (BOD), and suspended solids (Norazwina *et al.*, 2014). It also contains fair amounts of N, P, K, Mg and Ca. (Muhrizal *et al.*, 2006). During the extraction of crude palm oil, about 50% of the large quantity of water used in mills to extract oil will result in POME. In its untreated form, POME is very high strength waste. Hence, more than 85% of Malaysian palm oil mills have adopted the pond system for POME treatment (Ma *et al.*, 1993). During the extraction process, no chemical is added and therefore POME is regarded as non-toxic (Alimon, 2004). In the past, applying raw or digested POME as fertilizer in soil was considered harmful because the effluent could kill vegetation, causing water logging and jamming of percolation, which in the end causes anaerobic conditions (Mohammad *et al.*, 2012). However, this problem can be solved if POME is applied in small amounts at a time. According to a study by Wu *et al.* (2009), proper use of POME in the soil environment would actually directly improve soil fertility, where their results showed an enrichment of soils with regards to nitrogen, phosphorus, calcium and magnesium content after application of POME.

Decanter cake (DC) is a lignocellulosic biomass that can be found abundantly in oil palm mills. This solid waste is a brown-blackish paste which is produced after the extraction of crude oil. The production of Dried Decanter Cake (DDC) involves the processes of decanting, centrifuging and then drying within the machine system.

Before producing dehydrated POME, DC can be filter-pressed before being dried. This solid waste is considered valuable and a potential by-product that can be used as an alternative energy source and is usually a protein source for growing goats. DC usually consists of calcium (0.03%), phosphorus (0.003%), crude fiber (25.79%), and ether extract 7.12%) (Anwar, 2012)

In nature, Oxisols are acidic with low Cation Exchange Capacity (CEC), low exchangeable bases, and high Aluminium (Al) saturation. It is dominated by variable-charged minerals and the soil needs to be ameliorated before it can be utilized productively. The low fertility status is the reason why this kind of soils is not agriculturally productive, unless they are amended with lime and / or organic matter. Ultisols and Oxisols make up about 72% of the country's land surfaces (Ismail, 1992). In Sandakan, Sabah, the Meliau Estate contains an area of 1,942 ha of Oxisols but only about 809ha has been planted with oil palm to date (Paramanathan, 2002).

Oil palm seedlings are usually raised in polybags either at single or double stage (Turner *et al.*, 2003). In a double stage nursery, germinated oil palm seeds are planted in small polybags for three to four months and later transplanted into larger polybags for eight months prior to field planting. Chee *et al.* (1997) has reported the first commercial application where oil palm seedlings were grown in plastic pot trays in the first stage of pre-nursery seedlings. The pot tray system is almost similar to the double stage nursery with the main difference being the seedlings are grown in plastic trays with 25 holes. The advantages of using the pot tray system are that it uses lesser soil quantity, land area, water usage, and how low labour requirement (Mathews *et al.*, 2008).

The soil used for oil palm seedlings should be fairly rich and good planting media management is very important, as vigorous growth is needed to face the harsh conditions on the field for the production of quality seedlings (Khan *et al.*, 2006). Therefore, this experiment is conducted to observe the effect of using EFB mixed with POME biochar, dried POME, and dried decanter cake on the growth of prenursery oil palm seedlings in Oxisol soil by correcting its soil nutrient content.

### **1.1 Justification of Study**

Throughout Malaysia, about 70% of Oxisols can be found in the lowlands. Even with low pH, low Phosphorus (P), Calcium (Ca), and Magnesium (Mg), and high Al, it is still used for oil palm, rubber, cocoa, fruit and annual crop cultivation. However, tonnes of

soil amendment and fertilisers are needed to correct the soil in terms of nutrients, textures, and water holding capacity (Huang *et al.*, 1999). Since this type of soil has very low nutrient retention capacity and low moisture, hence oil palm trees being grown on this soil are prone to moisture stress and multiple nutrient deficiency problems (Paramananthan, 2013). In addition, it is expected that in the next three to four years Malaysia will run out of suitable land for new oil palm plantations, whereas Indonesia will have another 10 to 12 years to expand the crop's acreage. With limited land and regulatory restrictions on developing new plantations while having increasing demand, other options should be explored to overcome the land problem, for example treating the problematic soils (Hanim, 2012).

With the increasing global demand for biodiesel, edible oil, and oleo-chemicals derived from palm oil, Malaysia needs to increase its oil palm production by further extending the acreage for higher yield, which will directly increase the income of our country. In addition, with the abundance of readily available EFB and POME biomass, DDC and dried POME, using them as alternatives can reduce the cost of buying inorganic fertilisers to improve the soil. In addition, very few researches have been done on the effect of EFB-POME biochar, DDC and dried POME on the growth of oil palm seedlings. Hence, if these soil amendments can be shown to improve soil nutrient conditions, it can have some impact to the oil palm industry.

## 1.2 Objective

Objectives of this study were to:

- (i) Evaluate the growth of *Elaeis guineensis* seedlings in an Oxisol amended with EFB biochar, DDC, and dried POME.
- (ii) Evaluate the effects of EFB biochar, DDC, and dried POME on plant and soil nutrient content.

## 1.3 Hypothesis

$H_0$  : There was no significant effect of EFB-POME biochar, DDC, and dried POME on the growth of *Elaeis guineensis* seedlings in an Oxisol, soil and plant nutrient content, and their growth comparisons in different soil amendments.

$H_A$  : There was a significant effect of EFB-POME biochar, DDC, and dried POME on the growth of *Elaeis guineensis* seedlings in an Oxisol, soil and plant nutrient content, and their growth comparisons in different soil amendments.



## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 The Oil Palm

The oil palm, or *Elaeis guineensis*, *Elaeis* comes from the Ancient Greek word "Elaion", which means olive because of its oil-rich fruits, while *guineensis* refers to its assumed place of origin in the region of Guinea on the Western coast of Africa. This elegant palm originated from the humid inter-tropical Africa and it belongs to the family of Aracacea (Palmae) and subfamily of cocoidae, which also includes the coconut and the pinang palm (Balick *et al.*, 1990).

Oil palm is a monoecious crop as it bears both male and female flowers on the same tree. Each tree produces compact bunches that weigh between 10 and 25 kilograms with 1000 to 3000 fruitlets per bunch. Each fruitlet is elongated and almost spherical in shape. In most cases, the fruitlet is dark purple, almost black and the colour turns to orange red when they ripen. Each fruitlet consists of a hard kernel (seed) enclosed in a shell (endocarp) which is surrounded by a fleshy mesocarp. Oil palm trees may reach a height of up to sixty feet and more. The trunks of young and mature trees are enclosed in fronds which give them a rather rough appearance. The older trees have smoother trunks apart from the scars left by the fronds which have withered and fallen off (MPOC, 2014).

The determination of the future success of plantations and later ventures in the life cycle is the quality of planting materials. With the establishment of the first oil palm plantation, "Plant Introduction" of oil palm breeding was introduced. Plant introduction is a form of breeding and this breeding method is often overlooked and least recognised. An important feature in this breeding method is the existence of three fruit forms – *dura*, *pisifera* and *tenera* – mainly distinguished by their shell thickness



(Ahmad, 2009). Fruits may be shell-less or have shells of up to 8 mm in thickness. The internal fruit form is of genetic character and can be described as follows:

- (i) *Dura*: Shell 2-8 mm thick, low to medium mesocarp content of 35-55% but in the *Dura* of the Far East, this may be as high as 65%. No fibre ring.
- (ii) *Pisifera*: Shell-less.
- (iii) *Tenera*: Shell 0.5-4 mm thick, medium to high mesocarp content of 60-95%, fibre ring, hybrid of shell-less pisifera and the common thick shelled *Dura* form.

The term macrocarya, which refers to *dura* palms with thicker shells, is found in the Congo and West Africa, different from the less thick shelled Deli *Dura* of the Far East, which has largely gone out of use (Ng, 1972).

According to MPOB (2015), the oil palm planted area in 2014 reached 5.39 million hectares, an increase of 3.1% as against the 5.23 million hectares recorded in the previous year. This was mainly due to the increase in new planted areas in Sarawak, which recorded an increase of 8.8% or 102,493 hectares. Sabah is still the largest oil palm planted state, with 1.51 million hectares or 28% of total oil palm planted area, followed by Sarawak with 1.26 million hectares or 23%, while Peninsular Malaysia accounts for 2.62 million hectares or 49%.

IJM Plantations Berhad (IJMP) is one of the few Sabah-based organizations that have established an oil palm breeding programme. In 1997, IJMP signed a collaboration agreement with MPOB and in the following years started receiving crosses of advanced Deli *dura* (D) and AVROS (Av) *tenera* (T) families for establishing a seed garden to produce commercial DxP seeds (Seng *et al.*, 2011). AVROS (*Algemene Vereniging van Rubberplanters ter Oostkust van Sumatra*) oil palm *pisiferas* in Malaysia started with the Department of Agriculture Malaysia and Harrisons and Crosfield (now Sime Darby) importing the oil palm *tenera* x *pisifera* (TxP) seeds from Indonesia and planting them at Klanang Baru Estate in 1957 (Fife, 2007). In 1965, progenies of this material were planted in Trial 0.79 at Federal Station, Serdang. In 1981 and 1982, the *tenera* x *tenera* (TxT) and TxP were planted at the Malaysian Palm Oil Board (MPOB) in Kluang. Since then, the AVROS *pisiferas* progenies have acted as the basic male parent materials for MPOB research and commercial seed production, as *pisifera* palms are predominantly sterile female. The AVROS *pisifera* progenies show a high mesocarp-to-fruit and oil to bunch ratios but they are tall (Rao, *et al.*, 1999). On

the other hand, the original palms introduced in Java (Bogor) in 1848 were of the *dura* type, and their offspring is generally referred to as the *Deli Dura*. *Deli* refers to Deli district in Sumatera, where the famous *Deli dura* was established in 1881. The rather uniform high yielding *Deli* population has led to the theory of a common progenitor for the four Bogor palm types and it is used as the female parent in breeding programmes. Even though the fruit is *dura* (thick-shelled) in form, the spikelets of the bunches end in short spikes instead of long spines. The fruits are larger and contain a much higher proportion of mesocarp (around 60%) than the African *dura* (Nair, 2010).

## 2.2 Soil Order Oxisol

Oxisols (Subgroup: Typic hapludox) (Sumner, 2000) are formed on basic or ultrabasic rocks that are highly weatherable, with pH ranging from pH 4 to 5 in the B horizons. The mineralogy of the clay fraction of Oxisols developed from basalt, andesite and serpentinite in Malaysia is dominated by kaolinite, gibbsite, goethite and hematite (Shamshuddin *et al.*, 2008). The areas where the soils are found and are subject to extreme weather conditions such as high temperature and high rainfall throughout the year, which cause leaching of cations and accumulation of sesquioxides. This kind of soil has low levels of nitrogen (N), phosphorus (P), and potassium (K), high levels of metals (e.g. nickel, cobalt), high levels of magnesium (Mg) with low calcium (Ca), and low moisture, as well as minimal organic content. It also has high aluminium (Al) saturation which results in low productivity. Hence, these situations pose challenges for plant growth and survival (Shamshuddin *et al.*, 2011). As for biological properties, activities of the beneficial microorganisms are detrimentally affected by soil acidity, which affects the decomposition of organic matter, nutrient mineralization, and immobilization, uptake, and utilization by plants, and eventually crop yields. (Baligar, 2015). According to Sahibin *et al.* (2011), ultrabasic igneous rocks outcrop in many areas in Sabah, for example around Telupid and Ranau. He also stated that this soil that occurs widely in Sabah is not suitable for agricultural purposes due to their high content of toxic heavy metals.

Basalt is a soil amendment. According to a finding by Shamshuddin *et al.* (2011), basalt application improved the chemical fertility of the oxisols where there is an increase in pH, Ca, Mg, K and P as well as cation exchange capacity. The increase in pH lowered Al in the soil solution as it was precipitated as Al-hydroxides. The pH increase is caused by hydrolysis of the silicate released by basalt. A study done by

Shamshuddin *et al.* (2008) has shown that the basalt application can increase soil pH, which would result in an increase of negative charges in the soil. In addition, with the increase in organic matter contents, the soil pH also increases. In another finding by Shamshuddin *et al.* (2014), the application of EFB biochar improved soil fertility by increasing soil pH, where the  $Al^{3+}$  activities in the soil solution decreased exponentially with increasing rate of biochar application. This can be due to the biochar fixing some of the Al by chelation. In his finding, Ultisol was used instead of Oxisol. However, the study can be used as a reference as a Ultisols and Oxisols in Malaysia have the same clay mineralogical composition (Shamshuddin *et al.*, 2011).

Oil palm is now grown on various soil types and some of them may require specific attention, especially in fertilisation. As IJMP's mills' waste management, EFB is systematically applied as organic mulch in the estates where it aids both soil and water conservation. When the EFB mulch decomposes, plant nutrients are returned to the soil. Rotary driers that are installed in the mills produce dried decanter cakes and this is used as a soil amendment to improve the Oxisol soils in the Meliau estate (IJMP, 2005).

### **2.3 EFB Biochar and Growth of Crop**

A lot of researches have been done on converting oil palm biomass into value-added products, but none except biochar has come close to being labelled as carbon negative products. Producing biochar from oil palm biomass does not only potentially lead a healthier environmental, societal and economic growth for the oil palm industry specifically, but it also enhances sustainability in a worldwide context (Sieng *et al.*, 2014). Application of biochar to low fertility soils has drawn significant attention globally due to its unique potential to improve soil nutrient retention capacity, water holding capacity and it acts as a stable carbon sink to mitigate climate change, as well as reduce greenhouse gas (GHG) emissions (Atkinson *et al.*, 2010). Biochar is a carbonaceous material that is obtained from the pyrolysis of biomass under zero or limited supply of oxygen, at relatively low temperatures, usually below 700 °C (Duku *et al.*, 2011).

Since direct burning of biomass will release many pollutants into the air, using them in other forms of energy products is more beneficial. Pyrolysis is one potential technique to reduce these environmental concerns, where oil palm residues are converted into bio-oil and biochar and it is an environmentally friendly method because

no waste is produced using this method. Pyrolysis is the thermal decomposition of organic material at elevated temperatures in an inert environment (Faisal *et al.*, 2013). EFB is ligno-cellulose residue comprising 46% cellulose and 16.5% lignin. Due to the high C:N ratio of about 45 to 70, nitrogen fertilization seems necessary in order to reach the optimum initial C:N ratio of 30. Therefore, Salétes *et al.* (2004) stated that adding POME into the EFB biochar may supply sufficient nitrogen (Tables 2.1 and 2.2). Furthermore, POME contains high organic acids and is suitable to be used as a carbon source (Tindaon *et al.*, 2012).

Table 2.1 Main characteristics of EFB

Characteristics	EFB
Proximate Analysis (wt%)	
Volatiles	81.9
Fixed Carbon	12.6
Ash	3.1
Moisture	2.4
Ultimate Analysis (wt%)	
Carbon	53.78
Hydrogen	4.37
Nitrogen	0.35
Oxygen*	41.50
H/C	0.98
O/C	0.58
Calorific value (MJ kg <sup>-1</sup> )	17.08

\*By difference

Source: Mohamad *et al.*, 2011

Table 2.2 Characteristics of POME

Characters	Mean	Range
pH	4.2	4.4-5.2
BOD	25,000	10,250-43,750
COD	51,000	15,000-100,000
Total solids	40,000	11,500—79,000
Suspended Solids	18,000	5,000-54,000
Volatile Solids	34,000	9,000-72,000
Oil and Grease	6,000	130-18,000
Ammoniacal Nitrogen	35	4-80
Total Nitrogen	750	180-1,400

\*Units in mg/l except pH.

Source: MPOB, 2015

EFB has a moisture content of 12% after the extraction of fruits from fresh fruit bunches (FFB). It is placed for drying by natural convection in an open place. As the

EFB has a moisture content of about 9%, it is transported from the mill to the biochar plant using trucks (Soni *et al.*, 2013). First, the oven is heated with hot air produced in a burner using diesel fuel. The temperature used for the slow pyrolysis is between 350°C and 450°C. The slow pyrolysis process needs ample use of diesel fuel for heat generation. In the first and second operating hours, no further diesel is required because the heat production is supported by the syngas obtained as a by-product from the pyrolysis process. The syngas produced during slow pyrolysis is used to generate additional heat for drying and slow pyrolysis. Excess energy is released through a chimney. Biochar, syngas and bio-oil are the products obtained from the slow pyrolysis of palm oil EFB. The biochar produced is composed of carbon (C), nitrogen (N), ash and water (Soni *et al.*, 2015).

A research was conducted by Tan *et al.* (2012) to determine the characteristics (pH, total C, total N, nutrient content, cation exchange capacity and surface morphology) of EFB biochar and its potential use as soil amendment, as well as the effect of EFB biochar soil amendment on soil nutrient leaching in a field container experiment. At the end of this research, they have found out that the characterisation study showed that EFB biochar exhibits beneficial characteristics. In the field container experiment, treatments with EFB biochar amendment showed significantly lower nutrient leached compared to the control. As a new soil amendment, biochar has potential in controlling the fate of trace elements in the soil system. From a study conducted by Norazlina *et al.* (2014) on rice husk biochar and EFB biochar, it was shown that both have the potential to be as good sorbents for Arsenic (As) and Cadmium (Cd). Hence, it can be suggested that the application of this EFB biochar can possibly reduce the trace elements availability in contaminated soil.

A study by Azni *et al.* (2014) to determine the effects of EFB biochar on N fertilizer recovery, crop uptake, and N leaching. From the results obtained, EFB biochar demonstrated the ability to increase water holding capacity and reduce leaching. The biochar acts like a reserve for water and therefore holds more soluble plant nutrients, especially N which resulted in greater maize biomass that were treated with EFB biochar than in the control. Even though maize was used as the crop in this experiment, it could have the same effect on oil palm seedlings.

## 2.4 POME and Growth of Crops

POME contributes a large proportion of the agricultural waste in Malaysia and if not treated properly, it can cause environmental pollution. POME is often disposed in disposal ponds which results in the leaching of contaminants that pollute groundwater and soil, as well as the release of methane gas into the atmosphere. Palm oil processing mills produce an oily wastewater, which is later combined with the wastes from steriliser condensate and cooling water, called POME and it contains various suspended components. As compared to municipal sewage, POME contains 100 times more Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Even so, POME is a non-toxic waste because no chemical is added during the oil extraction process, but is harmful to the environment due to its large oxygen depleting capability in aquatic systems. The presence of different sugars such as glucose, galactose, manose, arabinose and xylose mean that it contains high organic matter. Since POME is non-toxic, microorganisms can obtain nutrients from it. The primary treatment for POME is via anaerobic digestion (Tindaon *et al.*, 2012). Currently, after being treated, POME is being utilised in agriculture as organic fertiliser.

Application of POME to soil has been shown to increase the growth of oil palm and other crops. However, if the application of raw POME is high, it can adversely affect the growth of plants. Direct application of POME into the soil was observed to reduce the growth of oil palm seedlings and the production of oil palm fresh fruit bunch. This inhibitory effect of raw POME on plant growth has been linked to the presence of lipid and some volatile substances, which indirectly affect the proper growth of plant roots (Zakaria and Hassan, 1993).

In a study done by Ratziah *et al.* (1997), on the effect of decomposed and raw POME on plant growth, the results showed that the shoot and root dry weights of tomato and spinach in decomposed POME was significantly increased. Further, in general the soil N, P and K increased in both decomposed and non-decomposed POME, but was better in decomposed POME. In addition, the bioassay results also showed that in raw POME, the tomato radicle was inhibited due to the high amount of lipids, but the inhibition was reduced in decomposed POME. Hence, this study showed that decomposed POME is more suitable to be used as organic fertiliser.

On the other hand, based on a study done by Embrandiri *et al.* (2013a), the percentage of seed germination of kidney beans (*Phaseolus vulgaris*) was the most

minimum with 100% POME. This may be due to the existence of excess amounts of ammonia in the effluent, causing the depletion of the tricarboxylic acid cycle, which reduces the respiration rate and subsequently germination. However, the root and shoot length of the kidney bean seedling was the longest at 25% POME, and it decreased from 50% POME onwards. The authors of this study concluded that since the higher concentration of effluent was toxic to plant growth, it was recommended that POME may be used only after treatment and dilution.

## 2.5 Decanter Cake and Growth of Crop

One of the major wastes in the crude palm oil industry is the decanter cake and it is normally disposed off in landfills or reused as fertiliser. However, decanter cakes have real potential to be used as a solid fuel, as it acts like charcoal or wood briquette that are common as sources of fuel. It may be used as solid fuel because of its calorific value due to the oil residue existing in the decanter cakes. Decanter cake is formed when the decanter used as a separator to remove the fine solids and water after homogenous oil mesh from the digester is pushed through a screw press. Hence, at this stage, the decanter cake is seen as one of the major wastes which is reused as fertiliser or as an animal nutrition source due to the presence of C, N, P, K and Mg (Mohd *et al.*, 2009). It also contains 12.63% crude protein, 7.12% ether extract, 25.79% crude fibre, 0.03% calcium, and 0.003% phosphorus respectively (Wan and Alimon, 2012). Aisueni and Omoti (1999) reported that the oil palm industry is one of the best sources of agricultural wastes that can be converted to organic fertilisers. However, it should be noted that the rate of application should be determined prior to its land application as plants vary in their nutrient requirements.

From a study done by Embrandiri *et al.* (2012) on the effect of palm oil waste on plant growth characteristics, it was shown that soil mixed with decanter cake caused a reduction in soil pH from 7.93 to 6.64, and the C:N ratio was the highest with 30% decanter cake amendment. At 10% decanter cake amendment, the lady's finger, tomato and brinjal had similar germination patterns but they all decreased when the amendment was increased. This may be due to osmotic pressure caused by the rise in dosage of nutrients. Therefore, this can prove that decanter is best applied at about 10% for the better germination of plants.

In another study done by Embrandiri *et al.* (2013b) on the growth of lady's finger at different ratios of decanter cake amendment, the phenol content and ascorbic



## REFERENCES

- Abdullah, N. and Sulaiman, F. 2013. The Oil Palm Wastes in Malaysia. <http://cdn.intechopen.com/pdfs/wm/44387.pdf>. Accessed on 17 March 2015. Verified on 24 March 2015
- Abolfath, M., Teh, C.B.S., Goh, K.J., Ahmad, H.M.H. and Che, F.I. 2012. Evaluation of Four Soil Conservation Practices in a Non-Terraced Oil Palm Plantation. *Agronomy Journal* **104(6)**: 1727-1740
- Abu, B.R., Siti, Z.D., Kulaseharan, S. and Jamaluddin, N. 2011. Effects of ten year application of empty fruit bunches in an oil palm plantation on soil chemical properties. *Nutrient Cycling in Agroecosystems* **89**: 341–349
- Adilah, S., Nur, S.M.A. and Nurhayati, A. 2014. Slow Pyrolysis of Oil Palm Empty Fruit Bunches for Biochar Production and Characterisation. *Journal of Physical Science* **25(2)**: 97–112
- Ahmad, K. D. 2009. Role of Oil Palm Breeding in Wealth Creation and Quality of Life. In: *Proceedings of the 8th Malaysia Congress on Genetics*. 4-6 August 2009. Genting Highlands, Malaysia
- Aisueni, N.O. and Omoti, U. 1999. The making of compost from empty oil palm bunch refuses. In: *Books of Abstracts, Soil Science Society of Nigeria Conference*. 21–25 November 1999. Benin
- Alimon, A.R. 2004. The nutritive value of palm kernel cake for animal feed. *Palm Oil Developments*. *Palm Oil Developments* **40**: 12–16
- Anwar, A.G. 2012. Utilization Of Palm Oil Decanter Cake As Protein And Energy Sources For Small Ruminants. In: *Proceedings of the 33rd MSAP Annual Conference*. 4-7 June 2012. Langkawi, Malaysia.
- Asiah, A., Mohd, R.I., Mohd, K.Y., Marziah, M. and Shaharudin, M. 2004. Physical and Chemical Properties of Coconut Coir Dust and Oil Palm Empty Fruit Bunch and the Growth of Hybrid Heat Tolerant Cauliflower Plant. *Pertanika Journal of Tropical Agricultural Science* **27(2)**: 121 – 133
- Astimar, A.A and Wahid, M.B. 2006. Supply Outlook of Oil Palm Biomass in Malaysia. In: *Proceedings of the Seminar on Ecomat Research and Promotion*. 24-25 July 2006. Beijing, China
- Atkinson, C.J., Fitzgerald, J.D. and Hipps, N.A. 2010. Potential Mechanisms for Achieving Agricultural Benefits from Biochar Application to Temperate Soils: A Review. *Plant and Soil* **337**: 1-18
- Azni, I., Lee, S.C.K., Rosenani, A.B., Che, F.I. and Khairuddin, A.R. 2014. Pot Experiment on N-Fertilizer Leaching and Crop Uptake. *Biochar in Agriculture* **3**: 2
- Baligar, V. C. 2015. Chapter 7 Ameliorating Soil Acidity of Tropical Oxisols by Liming For Sustainable Crop Production. *Advances in Agronomy* **99**: 346-379
- Balick, M.J. and Beck, H.T. 1990. *Useful Palms of The World*. United States of America: Columbia University Press
- Beinroth, F.H., Eswaran, H., Palmieri, F. and Reich, P.F. 1996. Properties, classification and management of oxisols. *World Soil Resources, Natural Resources Conservation Service*
- Blal, B. and Gianinazzi-Pearson, V. 1990. Interest of Endomycorrhizae for The Production of Micropropagated Oil Palm Clones. *Agriculture, Ecosystems and Environment* **29**: 39–43
- Bouhila, K., and Sanaa, M. 2011. Effects of organic amendments on soil physico-chemical and biological properties. *Journal of Materials and Environmental* **2(1)**: 485-490

- Chee, K.H., Chiu, S.B. and Chan, S.M. 1997. Pre-nursery seedlings grown on pot trays. *The Planter* **73(855)**: 295-299
- Cherdchai, P., Rodriguez, A., Sanders, I.R. and Jeffries, P. 2010. The role of mycorrhizas in more sustainable oil palm cultivation. *Agriculture, Ecosystems and Environment* **135(3)**: 187-193
- Corley, R.H.V. and Tinker, P.B. 2003. *The Oil Palm*. USA: Blackwell Science Ltd.
- Duku, M.H., Sai, G. and Hagan, E.B. 2011. Biochar Production Potential in Ghana – A Review. *Renewable and Sustainable Energy Reviews* **15**: 3539–3551
- Embrandiri, A., Rupani, P.F., Quaik, S., Mahammad, H.I. and Singh, R.P. 2012. Environmental Sustainability in the Palm Oil Industry; Palm Waste as Nutrient Supplement and Effects on Plant Growth Characteristics. In: *International Conference on Environmental, Biomedical and Biotechnology IPCBEE*. 4–5 August 2012. Singapore
- Embrandiri, A., Singh, R.P., Mahamad, H. I. and Singh, P. 2013a. Effect of different Palm Oil Mill Effluent (POME) concentrations on Seed Germination, Seedling Growth and Physiological response of Kidney bean (*Phaseolus vulgaris*). *Journal of Environmental Science and Sustainability* **1(3)**: 97-102
- Embrandiri, A., Rajeev P.S. and Mahamad, H.I. 2013b. Biochemical, morphological, and yield responses of lady's finger plants to varying ratios of palm oil mill waste (decanter cake) application as a bio-fertilizer. *International Journal Of Recycling of Organic Waste in Agriculture* **2**: 7
- Enders, A. and Lehmann, J. 2012. Comparison of Wet-Digestion and Dry-Ashing Methods for Total Elemental Analysis of Biochar. *Communications in Soil Science and Plant Analysis* **43**: 1042–1052
- Faisal, A., Wan, M.A.W.D. and Sahu, J.N. 2013. Utilization of Oil Palm Tree Residues to Produce Bio-oil and Bio-char via Pyrolysis. *Energy Conversion and Management* **76**: 1073–1082
- Fife, B. 2007. *The Oil Palm Miracle*. Colorado Springs: Picadilly Books
- Gehring, C. 2003. The role of biological nitrogen fixation in secondary and primary forests of Central Amazonia. *Acta Amazonica* **38(1)**: 3-5
- Goh, K.J., Ng, P.H.C. and Lee, C.T. 2009. Fertilizer Management and Productivity of Oil Palm in Malaysia. In: *Proceedings of the 6<sup>th</sup> International Planters Conference on Plantation Agriculture and Environment*. 22-24 February 2009. Kuala Lumpur, Malaysia
- Gunstone, F. D. 2011. *Vegetable Oils in Food Technology: Composition, Properties and Uses*. 2<sup>nd</sup> Edition. West Sussex: Blackwell Publishing Ltd
- Hamdan, A.B., Ahmad, M.T. and Mohd, D.T. 1998. Empty fruit bunch mulching and nitrogen fertilizer amendment: The resultant effect on oil palm performance and soil properties. *PORIM Bulletin* **37**: 1–14
- Hanim, A. 2012. Malaysia's oil palm land fast depleting. <http://www.thestar.com.my/business/business-news/2013/08/05/diesel-shortage-hits-palm-oil-sector-millions-may-be-lost-in-income-and-refineries-shut-down-due-to/>. *The Star Online*, 24 May, 1. Accessed on 17 March 2015. Verified on 24 March 2015
- Haron, K., Mohammed, A.T., Halim, R.M. and Din, A.K. 2008. Palm-based bio-fertilizer from decanter cake and boiler ash of palm oil mill. *Malaysian Palm Oil Board (MPOB): Information Series* **412**: 1-4
- Hormaza, P., Fuquen, E.M. and Romero, H.M. 2012. Phenology of the oil palm interspecific hybrid *Elaeis oleifera* × *Elaeis guineensis*. *Scientia Agricola* **69(4)**: 275-280
- Huang, P.M and Iskandar, I.K. 1999. *Soils and Groundwater Pollution and Remediation: Asia, Africa, and Oceania*. United States of America: CRC Press

- Huda, A., Hamdan, J, Ahmed, H. and Rosenani, A.B. 2014. Biochar from Empty Fruit Bunches, Wood, and Rice Husks: Effects on Soil Physical Properties and Growth of Sweet Corn on Acidic Soil. *Journal of Agricultural Science* **7(1)**: 192-200
- IJMP. 2005. Annual Report 2005. IJMP
- IJMP. 2014. Annual Report 2014. IJMP
- Ismail, H. 1992. *The Effects of Dolomitic Limestone and gypsum on Chemical Properties of an Ultisol and Oxisol in Malaysia and On the Growth of Corn (Zea mays L.)*. Master of Science Dissertation. Universiti Pertanian Malaysia
- Izham, A., Yahya, A. and Zamani, O. 2000. The use of Different Media for the Production of Wild Durian (*Durio lowianus*) Rootstocks. *Malaysian Journal of Soil Science* **4**: 1-7
- Jien, S.H. and Wang, C.S. 2013. Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena* **110**: 225-233
- Jones, D.L., Rousk, J., Edwards-Jones, G., DeLuca, T.H. and Murphy, D.V. 2012. Biochar-mediated changes in soil quality and plant growth in a three year field trial. *Soil Biology and Biochemistry* **45**: 113-124
- Leco Corporation. 2013. 628 Series Carbon/Hydrogen/Nitrogen Determinator. <http://www.leco.com/products/analytical-sciences/carbon-hydrogen-nitrogen-protein-sulfur-oxygen-analyzers/628-series>. Accessed on 10 October 2015. Verified on 10 October 2015.
- Lehmann, J. 2007. Bio-energy in the black. *Frontiers in Ecology and the Environment* **5**: 381-387
- Lim, K.C. and Zaharah, A.R. 2002. The effects of oil palm empty fruit bunches on oil palm nutrition and yield, and soil chemical properties. *Journal of Oil Palm Research* **14**: 1-9
- Khan, M.M., Khan, M.A., Abbas, M., Jaskani, M.J., Ali, M.A. and Abbas, H. 2006. Evaluation of potting media for the production of rough lemon nursery stock. *Pakistan Journal of Botany* **38(3)**: 623-629
- Kong, S.H., Soh, K.L., Bachman, R.T., Sahibin, A.R. and Jumat, S. 2014. Biochar From Oil Palm Biomass: A review of Its Potential and Challenges. *Renewable and Sustainable Energy Reviews* **39**: 729-739
- Ma, A.N., Cheah, S.C. and Chow, M.C. 1993. Current status of palm oil processing wastes management. Waste Management in Malaysia. In: B. G. Yeoh *et al.* (Eds), *Current status and Prospects for Bioremediation* (pp. 111-136). Kuala Lumpur: Ministry of Science, Technology and the Environment
- Mallarino, A. 2000. Soil Testing and Available Phosphorus. Iowa State University: *Integrated Crop Management* **484(22)**: 164-166
- Markus, J. and Banks, K. 1999. A Practical Guide to Germinating Palm Seeds. *Journal of the International Palm Society* **43(2)**: 56-59
- Mathews, J., Chong, K.M., Yong, K.K. and Ip, W.M. 2008. Raising pre-nursery oil palm seedlings in plastics pot tray: An 101 group experience. *The Planter* **84(986)**: 285-297
- Mettler-Toledo. 2007. pH meter FE20 / FG2 Operating Manual. [http://woodall.ece.ucdavis.edu/pdf/mettler\\_toledo\\_FE20\\_manual.pdf](http://woodall.ece.ucdavis.edu/pdf/mettler_toledo_FE20_manual.pdf). Accessed on 11 November 2015. Verified on 25 November 2015.
- Mohamad, A.S., Loh, S.K., Nasrin, A.B. and Choo, Y.M. 2001. Production and Characterization of Bio-Char from the Pyrolysis of Empty Fruit Bunches. *American Journal of Applied Sciences* **8(10)**: 984-988
- Mohammad, N., Alam, M.Z., Kabbashi, N.A. and Ahsan, A. 2012. Effective Composting of Oil Palm Industrial Waste by Filamentous Fungi: A review. *Resources, Conservation and Recycling* **58**: 69-78

- Mohd, H.M.H., Dewayanto, N. and Mohd, R.N. 2009. Solid fuel from decanter cake: a preliminary study. In: *3rd Malaysian Technical Universities Conference and Exhibition on Engineering and Technology (MUCEET 2009)*. 20-22 June 2009. Kuantan, Pahang
- MPOB. 2015. Overview of The Malaysian Oil Palm Industry 2014. Economics & Industry Development Division
- MPOC. 2014. The Oil Palm Tree. [http://www.mpoc.org.my/The\\_Oil\\_Palm\\_Tree.aspx](http://www.mpoc.org.my/The_Oil_Palm_Tree.aspx). Accessed on 1 April 2015. Verified on 4 April 2015
- Muhrizal, S., Shamshuddin, J., Fauziah, I. and Husni, M.A.H. 2006. Changes in Iron-poor Acid Sulfate Soil Upon Submergence. *Geoderma* **131**: 110-122
- Mutezo, W.T. 2013. Early crop growth and yield responses of maize (*Zea mays*) to biochar applied on soil. *Natural Resources, Agricultural Development and Food Security* **13(3)**: 50
- Nair, K. P. P. 2010. *The Agronomy and Economy of Important Tree Crops of the Developing World*. USA: Elsevier Inc.
- Ng, S. K. 1972. *The Oil Palm, its Culture, Manuring and Fertilisation*. Paris: International Potash Institute
- Nigussie, A., Kissi, E., Misganaw, M. and Ambaw, G. 2012. Effect of Biochar Application on Soil Properties and Nutrient Uptake of Lettuces (*Lactuca sativa*) Grown in Chromium Polluted Soils. *American-Eurasian Journal of Agriculture and Environmental Science* **12(13)**: 369-376
- Norazlina, A.S., Che, F.I. and Rosenani, A.B. 2014. Characterisation of Oil Palm Empty fruit Bunch and Rice Husk Biochars and Their potential to Absorb Arsenic and Cadmium. *American Journal of Agricultural and Biological Sciences* **9(3)**: 450-456
- Norazwina, Z., Sakinah, A. and Hakim, L. 2014. Optimization of Biological pH Treatment for Acidic Palm Oil Mill Effluent. In: *International Conference on Innovative Trends in Multidisciplinary Academic Research*. 20-21 October 2014. Turkey. 211-219
- Okwute, L.O. and Isu, N.R. 2007. The environmental impact of palm oil mill effluent (POME) on some physico-chemical parameters and total aerobic bioload of soil at a *dump site in Anyigba, Kogi State, Nigeria*. *African Journal of Agricultural Research* **2(12)**: 656-662
- Ooi, L.H., Lee, K.H. and Chan, K.S. 2006. Turning POME and EFB into Organic Fertilizer Without Waste and Discharge. In: *International Oil Palm Conference*. 19-23 June 2006. Bali, Indonesia
- Osaigbovo, A. U. and Orhue, E. R. 2011. Effect of palm oil mill effluent on some soil chemical properties and growth of maize (*Zea mays* L.). *Nigerian Journal of Agriculture, Food and Environment* **7(3)**: 51-54
- Palanivell, P., Susilawati, K., Ahmed, O.H. and Nik, M.A.H. 2012. Effects of crude humin and compost produced from selected waste on *Zea mays* growth, nutrient uptake and nutrient use efficiency. *African Journal of Biotechnology* **12(13)**: 1500-1507
- Paramanathan, S. 2002. Soils of Meliau Estate IJM Plantations Sendirian Berhad Labuk and Sugut District Sandakan Sabah. *IJM/Desa Talisai Group Estates* 16-19
- Paramanathan, S. 2013. Managing Marginal Soils for Sustainable Growth of Oil Palms in the Tropics. *Journal of Oil Palm & The Environment* **4**: 1-16
- Potash & Phosphate Institute. 1994. Effective phosphate management: Understanding behaviour of phosphorus relative to environment and recent technology

- Prendergast-Miller, M.T., Duvall, M. and Sohi, S.P. 2011. Localisation of nitrate in the rhizosphere of biochar-amended soils. *Soil Biology and Biochemistry* **43**: 2243–2246
- Prasertsan, S. and Sajjakulnukit, B. 1996 . Biomass Residues from Palm Oil Mills in Thailand: An Overview on Quantity and Potential Usage. *Biomass and Bioenergy* **11(5)**: 387-95
- Radziah, O., Azizah, H. and Zaharah, A.R. 1997. The Phytotoxic Effects of Palm Oil Dry Solids on Plant Growth. *Pertanika Journal of Tropical Agricultural Science* **20(2/3)**: 91-99
- Rao, V., Law, I.H., Zuraini, S. and Chia, C.C. 1999. Ekona and AVROS- a tale of two Pisiferas. In: *Proceedings of the MPOB International Palm Oil Conference (PIPOC'99)*. 16 February 1999. Bangi Selangor, Malaysia. 90–102
- Robertson, S. 2011. Direct Estimation of Organic Matter by Loss on Ignition: Methods. *San Francisco University Soil Science Lab* 1-11
- Rondon, M. A., Lehmann, J., Ramirez, J. and Hurtado, M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. *Biology and Fertility of Soils* **43**: 699-708
- Rosenani, A.B. and Hoe, S.F. 1996. Decomposition of oil palm empty fruit bunches in the field and mineralization of nitrogen. *Progress in Nitrogen Cycling Studies of the series Developments in Planand Soil Sciences* **68**: 127-132
- Rosenani, A.B., Azni, I., Tinia I.M.G., Mohd, A.M.S., Lee, S.C.K. 2014. Pot Experiment on N-Fertilizer Leaching and Crop Uptake. *Biochar in Agriculture: Perspectives for Germany and Malaysia-2nd Public Newsletter*
- Sahibin, A.R., Mohamed, M.T. and Baba, M. 2011. Heavy Metals Composition of Some Soils Developed from Basic and Ultrabasic Rocks in Malaysia. <http://borneoscience.ums.edu.my/wp-content/uploads/2011/05/heavy-metals-composition-of-some-soils-developed-from-basic-and-ultrabasic-rocks-in-malaysia1.pdf>. Accessed on 2 April 2015. Verified on 6 April 2015.
- Salétes, S., Siregar, F.A., Caliman, J.P. and Liwang, T. 2004. Ligno-Cellulose Composting: Case Study on Monitoring Oil Palm Residuals. *Compost Science & Utilization* **12**: 372-382
- Seng, S.Y., Donough, C.R. and Rajanaidu, N. 2011. Performance of MPOB Nigeria Prospection Materials in Sabah. In: *International Seminar on Breeding for Sustainability in Oil Palm*. 18 November 2011. Kuala Lumpur, Malaysia. 1-17
- Shamshuddin, J and Anda, M. 2008. Charge properties of soils in Malaysia dominated by kaolinite, gibbsite, goethite and hematite. *Geological Society of Malaysia* **54**: 27-31
- Shamshuddin, J., Fauziah, C.I., Anda, M., Kapok, J. and Shazana, M.A.R.S. 2011. Using Ground Basalt and/or Organic Fertilizer to Enhance Productivity of Acid Soils in Malaysia for Crop Production. *Malaysian Journal of Soil Science* **15**: 127-146
- Shamshuddin, J., Rabileh, M.A., Panhwar, Q.A., Rosenani, A.B., and Anuar, A.R. 2014. Effects of Biochar and/or Dolomitic Limestone Application on the Properties of Ultisol Cropped to Maize under Glasshouse Conditions. *Canadian Journal of Soil Science* **95(1)**: 37-47
- Sieng, H.K., Soh, K.L., Bachmann, R.T., Sahibin, A.R. and Jumat, s. 2014. Biochar From Oil Palm Biomass: A Review of Its Potential and Challenges. *Renewable and Sustainable Energy Reviews* **39**: 729-739
- Sikora, F.J. and Kissel, D.E. 2014. Soil pH. *Southern Cooperative Series Bulletin* **419**: 48-53
- Singh, R.P., Embrandiri, A., Mahamad, H.I. and Singh, P. 2013. Effect of different Palm Oil Mill Effluent (POME) concentrations on Seed Germination, Seedling Growth

- and Physiological response of Kidney bean (*Phaseolus vulgaris*). *Journal of Environmental Science and Sustainability* **1(3)**: 97-102
- Soni, H., Grundman, P., Lek, H.L., Hansen, A., Amran, S. and Meyer-Aurich, A. 2013. Energy Balances, Greenhouse Gas Emissions and Economics of Biochar Production from Palm Oil Empty Fruit Bunches. *Resources, Conservation and Recycling* **77**: 108-115
- Soni, S.H., Grundman, P. and Siahaan, D. 2015. Role of Biogas and Biochar Palm Oil Residues for Reduction of Greenhouse Gas Emissions in the Biodiesel Production. *Energy Procedia* **65**: 344 – 351
- Sumner, M. E. 2000. *Handbook of Soil Science*. United States of America: CRC Press
- Tan, W.L., Rosenani, A.B., Ahmad, S.H. and Ishak, C.F. 2012. Oil palm empty fruit bunch biochar : characterization and potential usage as soil amendment for its nutrient retention capacity in soil. In: *The 4th IBI Biochar Congress*. 16-20 Sep 2012. Beijing, China. 475-484
- Tanawut, N., Wiriya, D., Suteera, P. and Poonsuk, P. 2012. Effect of inoculum size on production of compost and enzymes from palm oil mill biogas sludge mixed with shredded palm empty fruit bunches and decanter cake. *Songklanakarin Journal of Science and Technology* **36 (3)**: 275-281
- Tindaon, F., Tampubolon, B., Pandiangan, S. and Siahaan, D. 2012. Biochar or Compost in Palm Oil Industry: An Introduction to Research and Development. In: *Seminar and Workshop Creating a High Quality of Educational Atmosphere for Young Generation for Independency and Creativity Development*. 3-4 November 2012. Banda Aceh, Indonesia. 93-100
- Turner, P.D. and Gillbanks, R.A. 2003. Nursery techniques. *The Incorporated Society of Planters* **2**: 173-254
- Utomo, B. N. & Widjaja, E. 2004. Limbah padat pengolahan minyak sawit sebagai sumber nutrisi ternak ruminansia. *Jurnal Libang Pertanian* **23**: 22-28
- Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S., and Cowie, A. 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Journal of Plant and Soil Science*: **327**: 235–246.
- Wan, A., Wan, K.R., Rosenani, A.B., Aminuddin, H. and Rozita, A. 2011. Effects of Mulching and Fertiliser on Nutrient Dynamics of Sand Tailings Grown with *Acacia* Hybrid Seedlings. *Journal of Tropical Forest Science* **23(4)**: 440–452
- Wan, Z.W.M. and Alimon, A.R. 2012. Recent advance in the utilisation of oil palm products as animal feed. In: *International Conference on Livestock Production and Veterinary Technology (ICARD)*. 01-04 October. Bogor, Indonesia. 1-14
- Wu, T.Y, Muhammad, A.W., Jahim, J.M. and Anuar, N. 2009. A Holistic Approach to Managing Palmoil Mill Effluent (POME): Biotechnological Advances in the Sustainable Reuse of POME. *Biotechnology Advances* **27**: 40-52
- Yusof, B. 2007. Palm oil Production through Sustainable Plantations. *European Journal of Lipid Science and Technology*. **109**: 289-295
- Zaharah, A.R., and Lim, K.C. 2000. Oil palm empty fruit bunch as a source of nutrients and soil ameliorant in oil palm plantations. *The Malaysian Journal of Soil Science* **4**: 51–66.
- Zakaria, Z.Z. and Hassan, A.H. 1993. Standard glossary and terminology of palm oil mill effluent (POME). Palm oil Research Institute of Malaysia.