GROWTH RESPONSE OF PRE-NURSERY OIL PALM SEEDLINGS IN AN ULTISOL AMENDED WITH OIL PALM MILL BY-PRODUCTS

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ABSTRACT

This study was conducted to evaluate the effect of oil palm mill by-products on growth of oil palm seedlings in a sandy soil. There were 3 treatments including the control, each replicated 6 times in randomized complete block design (RCBD). The treatments were: (i) dried decanter cake (T1); (ii) empty fruit bunch with palm oil mill effluent biochar (T2); and (iii) palm oil mill effluent (T3). T1 was the control as it is the standard practice of IJM Plantations Berhad (IJMP) where this experiment was conducted. Plant height, stem girth, dry weight of shoots and roots, total nitrogen of leaves and roots, total leaf phosphorus, soil pH, soil organic matter content, soil total nitrogen, soil available phosphorus and cation exchange capacity were recorded and all data analyzed using one way analysis of variance (ANOVA) at 5% significance level. T2 resulted in significantly higher plant height (22.99 cm) compared to T1 (19.17 cm) and T3 (21.95 cm) at 3 months after planting. There were no significant differences in stem girth where the highest mean stem girth was for T2 (4.51 mm), followed by T3 (4.34 mm) and T1 resulted in the lowest stem girth (4.24 mm). There were no significant effects on the dry weight of shoots and roots. The highest mean shoot dry weight was for T2 (1.47 g), followed by T3 (0.98 g) and T1 resulted in the lowest dry weight of shoots (0.93 g). The highest mean dry weight of roots was for T1 and T2 (0.42 g) and T3 resulted in the lowest dry weight of roots (0.34 g). T1 resulted in higher leaf total nitrogen, which was 1.99% as compared to T2 (1.72%) and T3 (1.87%). Root total nitrogen was significantly higher in T1 (2.11%) compared to T2 (0.03%) and T3 (1.12%). T1 resulted in significantly higher total P of leaves (13.32 mg kg^{-1}) compared to T2 (9.38 mg kg^{-1}) and T3 (10.38 mg kg^{-1}). Soil pH was significantly higher in T2 (6.61) compared to T1 and T3 (5.35). There were significant differences in effects between T1, T2 and T3 on soil organic matter and total organic carbon. T2 resulted in the highest soil organic matter (1.88%) compared to T1 (1.32%) and T3 (0.84%). T2 resulted in higher soil total nitrogen (0.13%) compared to T1 (0.12%) and T3 (0.08%). Soil available phosphorus was significantly higher for T1 (373.64 mg kg^{-1}) compared to T2 (225.41 mg kg^{-1}) and T3 (224.22 mg kg^{-1}). There was no significant difference between T1, T2 and T3 for soil cation exchange capacity. T1 decreased the soil cation exchange capacity at 3 months after planting by 70.73% whereas T2 and T3 increased the soil cation exchange capacity by 59.09% and 46.15% respectively. The results indicate that the sandy soil treated with EFB-POME biochar improved the growth rate of the pre-nursery oil palm seedlings. However, sandy soil amended with POME enhanced the soil fertility.

KESAN BERBAGAI HASIL SAMPINGAN SISA KELAPA SAWIT TERHADAP PERTUMBUHAN ANAK BENIH KELAPA SAWIT (Elaeis guineensis) DI TANAH BERPASIR

ABSTRAK

Kajian ini telah dijalankan untuk menilai kesan berbagai hasil sampingan sisa kelapa sawit terhadap pertumbuhan anak benih kelapa sawit di tanah berpasir. Tiga rawatan hasil sampingan sisa kelapa sawit yang berbeza mempunyai enam replikasi dan disusun menggunakan reka bentuk blok rawak lengkap (RCBD). Rawatan-rawatan yang digunakan ialah (i) kek decanter kering (T1) (ii) buah tandan kosong dengan Palm Oil Mill Effluent biochar (T2) dan (iii) Palm Oil Mill Effluent (T3). Rawatan T1 digunakan kawalan kerana ianya merupakan amalan biasa yang digunakan oleh IJM Plantations Berhad untuk penanaman anak benih kelapa sawit. Ketinggian pokok, ukuran keliling batang, berat kering pucuk dan akar, jumlah nitrogen dalam daun dan akar, jumlah fosforus dalam daun, pH tanah, bahan organik dalam tanah, jumlah nitrogen dalam tanah, kandungan fosforus dalam tanah dan pertukaran kapasiti kation dalam tanah telah direkodkan dan dianalisis dengan menggunakan ANOVA satu hala pada aras signifikan sebanyak 5%. Pada bulan ketiga, hasil ketinggian pokok menunjukkan kesan perbezaan seerti. Rawatan T2 mempunyai ketinggian pokok yang paling tinggi (22.99 cm) berbanding dengan rawatan T1 (19.17 cm) dan rawatan T3 (21.95 cm). Pada bulan ketiga. Tiada kesan perbezaan seerti ditunjukkan untuk ukuran keliling batang. Hasil ukuran keliling batang yang tertinggi ialah T2 (4.51 mm), diikuti oleh rawatan T3 (4.34 mm) dan rawatan T1 (4.24 mm). Tiada kesan perbezaan seerti ditunjukkan untuk berat kering pucuk dan akar. Hasil tertinggi untuk berat kering pucuk ialah rawatan T2 (1.47 g), diikuti oleh rawatan T2 (0.98 g) dan rawatan T1 (0.93 g). Manakala untuk berat kering akar pula, rawatan T1 dan T2 dengan hasil 0.42 g lebih berat berbanding dengan rawatan T3 (0.34 g). Tiada kesan perbezaan seerti ditunjukkan untuk jumlah nitrogen dalam daun. Rawatan T1 (1.99%) mempunyai jumlah nitrogen daun yang tertinggi berbanding dengan rawatan T2 (1.72%) dan rawatan T3 (1.87%). Terdapat kesan perbezaan seerti ditunjukkan untuk jumlah nitrogen akar. Jumlah nitrogen dalam akar yang tertinggi ialah rawatan T1 (2.11%) diikuti dengan rawatan T2 (0.03%) dan rawatan T3 (1.12%). Rawatan T1 (13.32 mg kg^{-1}) mencatatkan jumlah fosforus dalam daun yang tertinggi berbanding dengan rawatan T2 (9.38 mg kg^{-1}) dan rawatan T3 (10.38 mg kg^{-1}). pH tanah yang paling tinggi terdapat dalam rawatan T2 (6.61) diikuti dengan rawatan T1 dan rawatan T3 (5.35). Rawatan T2 menghasilkan bahan organik tanah yang paling tinggi (1.88%), berbanding dengan T1 (1.32%) dan rawatan T3 (0.84%). Rawatan T2 (0.13%) menghasilkan jumlah nitrogen tanah yang tertinggi, berbanding dengan rawatan T1 (0.12%) dan rawatan T3 (0.08%). Kandungan fosforus yang dalam tanah yang tertinggi ialah rawatan T1 (373.64 mg kg^{-1}) diikuti dengan rawatan T2 (225.41 mg kg^{-1}) dan rawatan T3 (224.22 mg kg^{-1}). Tiada kesan perbezaan seerti menunjukkan di antara rawatan T1, T2 dan T3 untuk pertukaran kapasiti kation dalam tanah. Rawatan T1 menurun pertukaran kapasiti kation dalam tanah dengan 70.73% dalam masa 3 bulan, manakala rawatan T2 dan T3 menunjukkan peningkatan masing-masing pertukaran kapasiti kation dalam tanah masing-masing sebanyak 59.09% dan 46.15%. Keputusan menunjukkan tanah berpasir yang dirawat dengan EFB-POME biochar boleh meningkatkan kadar pertumbuhan terbaik untuk anak benih kelapa sawit pra-nurseri. Walau bagaimanapun, tanah berpasir dengan rawatan POME boleh meningkatkan kesuburan tanah.

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LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

ANOVA	One way analysis of variance
BRIS	Beach Ridges Interspersed with Swales
CEC	Cation Exchange Capacity
DC	Decanter Cake
DxP	Dura x Pisifera
EFB	Empty Fruit Bunch
et al.	and other
FAO	Food and Agriculture Organization of the United
FELCRA	Federal Land Consolidation Rehabilitation Agency
FELDA	Federal Land Development Agency
FFB	Fresh Fruit Bunch
GB	Genetic Block
IJMP	IJM Plantation
KCl	Potassium chloride
MARDI	Malaysian Agricultural Research and Development Institute
mg	Milligram
MPOB	Malaysian Palm Oil Board
MPOC	Malaysia Palm Oil Council
OM	Organic matter
OPF	Oil Palm Fronds
OPT	Oil Palm Trunks
PKC	Palm Kernel Cake
PKS	Palm Kernel Shell
POME	Palm Oil Mill Effluent
PPF	Palm Presses Fibres
RCBD	Randomize Completely Block Design
RISDA	Rubber Industry Smallholders Development Authority
SPAD	Sarawak Plantation Agriculture Development
SPSS	Statistical Package for Social Science
USDA	United States Department of Agriculture
NRCS	Natural Resources Conservation Service
t	Tonnes
wt	Weight

CHAPTER 1

INTRODUCTION

1.1 Introduction

Traditionally the oil palm (*Elaeis guineensis*) was grown in semi-wild groves in tropical Africa. It was first introduced to Malaysia for planting in the Botanical Gardens in Singapore in 1870 (Abdullah and Sulaiman, 2013). Oil palm is a tropical crop, and it is planted in 43 countries over a total land area of 16.4 million hectares (FAO, 2014).

The Malaysian oil palm industry is very important to the Malaysian economy. In 2014, the total exports of oil palm products, consisting of palm oil, palm kernel oil, palm kernel cake, oleochemicals, biodiesel and others was 25,072,103 tonnes (RM 63,618.87 million) (MPOB, 2013). The main problem in the oil palm tree cultivation and its related industries is the substantial amount of biomass wastes. The wastes such as empty fruit bunches (EFB), palm kernel shell (PKS), mesocarp fiber (MF), palm oil mill effluent (POME), oil palm trunks (OPT), oil palm leaves (OPL) and oil palm fronds (OPF) are generated after harvesting, palm oil processing or during replantation. The regular practice to convert these wastes into useful products is through simple mechanical processes like shredding, chipping and palletizing for size reduction. Approximately 75% of the wastes in the form of OPT and OPF are left rotting in the plantation for mulching and nutrient recycling purposes (Awalludin *et al.*, 2015). The availability of the oil palm biomass is high and these can be utilized as recycled crop residue in the oil palm plantation.

The one important factor in achieving success in the nursery is the availability of sufficient nutrients in the growing medium. The polybag soil in the nursery must be thoroughly moist with no dry patches at all times, to allow unimpeded growth and to prevent any dehydration of the seedlings. The production of high quality oil palm seedlings is dependent on good nursery management and practices (Halimah *et al.*, 2012).

An oil palm nursery is raised either in single or double stages. The single stage nursery system involves planting of germinated seeds directly into soil-filled large polybags (46 cmx 41 cm layflat) and nurtured in the same large polybags until the plants have grown sufficiently and are ready for transplanting to the field (usually around 10 to 12 months). The double stage nursery system however involves planting of germinated seeds into soil-filled small polybags (23 cm x 15 cm layflat) for the first three to four months (pre-nursery stage) and the small seedlings are then transplanted to large polybags, where the seedlings are nurtured for another seven to nine months (main nursery stage) before transplanting to the field (Mathews *et al.*, 2010).

The amount of fertile soil in Malaysia is greatly reduced as time goes by. Most people intend to buy land for planting purposes but unfortunately, the land is infertile. Previous studies showed sandy soils are weakly structured, nutrient deficient, have low water retention capacity, limited ability to support plant growth and a relatively high soil temperature (Mohd *et al.,* 2009). Thus, the idea of mixing soil amendment can be used to overcome this issue. Sandy soils mixed with soil amendments may allow the planting of oil palm seedlings. When used as a soil amendment, biochar has been reported to boost soil fertility and improve soil quality by raising the soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity (CEC), and retaining nutrients in soil (Lehmann *et al.*, 2006). The addition of biochar to soils has been shown to enhance soil fertility (Glaser *et al.*, 2002; Chan *et al.*, 2007; Laird *et al.*, 2010).

Decanter cake amendments of up to 10% may be a probable substitute for inorganic fertilizers with respect to lady's finger (*Abelmoschus esculentus*) plants due to high nutrient content, yield and biomass, as well as morphological characteristics. However, there were observable negative effects after 10% decanter cake amendment ratios (Embrandiri *et al.*, 2013).

1.2 Justification

Sandy soils are the native soil in the IJM Plantation nursery at Sugut. The purpose of this study is to improve the soil properties of sandy soils added with soil amendment which may act as a planting medium for oil palm seedlings. It may act as an alternative soil media for the oil palm plantation nursery. Further, the use of biochar in Malaysian soils has not been studied extensively. There are knowledge gaps as no research has been done before on sandy soils use as a planting medium in the oil palm plantation nursery.

The palm oil industry generates an abundance of oil palm biomass such as mesocarp fiber, shell, empty fruit bunch (EFB), frond, trunk and palm oil mill effluent (POME) (Mohamad *et al.*, 2011). Therefore, sustainable biochar production and its use as a soil amendment has been suggested as a way of reducing waste, improving soil quality, and enhancing crop growth. In the oil palm plantation, recycling crop residues such as empty fruit bunches (EFB) and palm oil mill effluent (POME) can increase soil nutrients (Garuba *et al.*, 2012).

1.3 Objectives

This study were conducted:

a) To evaluate the effects of different oil palm mill by-products on growth responses of oil palm seedlings in a sandy soil.
b) To evaluate the effects of different oil palm mill by-products on oil palm seedlings and soil nutrient content.

1.4 Hypothesis

H_0: There is no significant effect of different oil palm mill by-products on the growth of oil palm seedlings, soil and plant nutrient content.

H_A: There is a significant effect of different oil palm mill by-products on the growth of oil palm seedlings, soil and plant nutrient content.

CHAPTER 2

LITERATURE REVIEW

2.1 Oil Palm Cultivation in Malaysia

Oil palm, *Elaeis guineensis*, which belongs to the Palmae family, is the most productive oil producing plant in the world. Two types of oil are produced from oil palm, one is the palm oil from the fibrous mesocarp and another is lauric oil produced from the palm kernel (Rupani *et al.*, 2010). In Malaysia, palm oil production has recorded a rocketing growth over the years, from about 4 million tonnes in 1985 to about 6 million tonnes in 1990 and to 19.6 million tonnes in 2014 (MPOB, 2015). Oil palm (*Elaeis guineensis*) supplies around 30% of the world's vegetable oil (USDA-FAS, 2013). MPOB (2014) reported that the land area committed to oil palm plantations in 2012 accounted for around 5076929 hectares. The Federal Land Development Agency (FELDA), Rubber Industry Smallholders Development Authority (RISDA), Federal Land Consolidation Rehabilitation Agency (FELCRA), private estates, state agencies and independent small holders are the main palm trees ownership forms in Malaysia.

Palm trees usually have a vertical trunk and feathery leaves and every year around 20–40 new leaves, known as palm frond, grown. Bunches of palm fruit develop between the trunk and base of the new fronds. Generally, 5–6 years after planting the first crop of fresh fruits can be harvested and each tree can provide palm fruits for 25–30 years (Areerat, 2006).

2.2 Oil Palm Seeds

An oil palm breeding program was started by using selected genetic materials from MPOB to produce DxP seeds in the future with mother palms and pollen. The first Genetic Block (GB) was planted in 2001 at Sijas Plantation near Beluran with specially selected advanced generation Deli-D and Av-P families from MPOB.

Seed production started in Sijas Estate, Sabah, in 2006 using elite Deli-D mother palms from the Genetic Blocks. These elite Sijas Deli D mother palms were crossed with the proven AVROS pisifera pollen from MPOB to produce IJM DxP Sijas Excellence. IJM DxP Sijas Excellence emphasizes on excellent fruit characteristics and production efficiency. Excellent fruit characteristics which is big fruits with thick mesocarp and high oil content, ensures high oil yield (IJMP, 2005).

Oil palm dura x pisifera (DxP) hybrid seeds are largely based on Deli dura selections at various research centres such as the Malaysian Palm Oil Board (MPOB), Chemara, Banting, Dami, Socfindo and Dabou. The basic information for this hybrid seed is shown in Table 2.1. The main sources of pisiferas are AVROS, NIFOR (Calabar), Ekona, Yangambi and La Me. Oil palm DxP seed production in Malaysia increased marginally from 50 million in 1995 to 65 million in 2007 and 88 million in 2008. The number of seed producers in Malaysia has remained constant over the years (Kushairi *et al.*, 2010), as shown in Table 2.2.

Table 2.1 Basic Information on Oil Palm Dura x Pisifera (DxP)

Origin	Origin West Africa
Average height increment (present palms)	~ 60 cm/year
Trunk diameter	~ 60 cm
No. of fronds produced per year	~ 24
Average length of frond	3 – 4 m
Leaf colour	Green
Colour of ripe fruit	Usually yellowish red (there are also other colours)
Nursery period	12 - 18 months
1st harvesting	~ 30 months after field planting
Harvesting cycle	2 - 3 weeks
No. of bunches produced per palm	10 - 15 per year
Average weight of bunch	10 - 20 kg
No. of fruits per bunch	1000 - 3000
Shape of bunch	Round or oval
Fruit size (l x b)	5 cm x 2 cm
Fruit weight	~ 10 g
Kernel content	3-8% per fruitlet
Oil extraction rate	20%
Palm oil yield	~ 4 tonnes/ha/year
Planting density	136 - 160 palms/ha
Economic lifespan	20 - 30 years

Source: MPOC, 1995

Table 2.2 Average oil palm DxP seed production capacity in Malaysia, 1995-2008

Company	Million seeds/year
Federal Land Development Authority (Felda)	17
Sime Darby (including Guthrie, Golden Hope)	30
United Plantations Berhad	10
Industrial Oxygen Incorporated (IOI)	6
Highlands Research Unit (HRU)	8
Borneo Samudera	5
Sasaran Ehsan Utama (SEU)	2
Rubber Industry Smallholders Development Authority (RISDA)	1
IJMP, Sabah	1
SPAD, Sarawak	1
Malaysian Palm Oil Board (MPOB)	0.5
Total	81.5

Source: Kushairi *et al.*, 2010

2.3 Oil Palm Pre-Nursery

The age of oil palm seedlings in pre-nursery stage is below 4 months (120 days). Currently at pre-nursery stage the plastic pot tray system has replaced the conventional small polybag system, as shown in Figure 2.1. Raising pre-nursery oil palm seedlings using the pot tray system commercially was first reported by Chee *et al.* (1997). The advantages of introducing the pot tray system includes less land area needed, reduction in soil quantity, reduction in water usage in irrigation and low labour requirements (Mathews *et al.,* 2008). In a tray of 25 seedlings drawn out of a bed it is easier to observe the abnormal seedlings and runts within the population (25 seedlings) (Mathews *et al.*, 2010).

Figure 2.1 Pre-nursery oil palm seedlings using pot trays

2.4 Palm Solid Residue Generation in Malaysia

Malaysia also produces large quantities of palm oil biomass such as empty fruit bunch (EFB), palm oil mill effluent (POME), palm kernel cake (PKC), decanter cake and palm shells. The waste products from oil palm processing consists of oil palm trunks (OPT), oil palm fronds (OPF), EFB, palm pressed fibres (PPF) and palm kernel shells, less fibrous material such as palm kernel cake and liquid discharge POME (Singh *et al.*, 2010).

According to Prasertsan and Prasertsan (1996), during processing in the palm oil mill more than 70% (by weight) of the processed fresh fruit bunch (FFB) was left over as oil palm waste. According to Pleanjai *et al.* (2004), fiber, shell, decanter cake and EFB accounts for 30, 6, 3 and 28.5% of the FFB respectively. The diverse applications of palm biomass are being developed and investigated to convert the previous 'waste' into 'value-added products'. For instance, EFB and POME have been successfully converted into cattle feed, cow flooring and fertilizer in a pilot study carried out by the Malaysian Agricultural Research and Development Institute (MARDI) (MARDI, 2011). Palm biomass is usually left on plantation grounds for mulching as organic fertilizer or landfilled as waste.

2.5 Characteristics of Palm Oil Mill Wastes and its Applications

2.5.1 Palm Oil Mill Effluent (POME)

POME is the effluent from the final stages of palm oil production in the mill. It is a colloidal suspension containing 95-96% water, 0.6-0.7% oil and 45% total solids including 2-4% suspended solids (Yeong *et al.*, 2008). POME contains high concentrations of protein, nitrogenous compounds, carbohydrate, lipids and minerals that could be converted into useful material using the microbial process (Habib *et al.*, 1997; Agamuthu and Tan, 1985). The characteristics of POME is shown in Table 2.3. Wu *et al.* (2009) reported that biologically treated POME can be employed as liquid fertilizer. It is estimated that 1 t of FFB processed will generate 0.67 t of POME (Ng *et al.*, 2011). On average about 4.9 - 12.1 percent of the total nitrogen content of the POME applied was utilized by the oil palm seedlings over a period of 40 weeks (Hashim and Zaharah, 1994).

Table 2.3 Characteristic of POME

Characteristics of POME		
Parameter *	Mean	Range
pH	4.2	3.4-5.2
Biological Oxygen Demand	25000	10250-43750
Chemical Oxygen Demand	51000	15000 - 100000
Total Solids	40000	11500 - 79000
Suspended Solids	18000	5000 - 54000
Total Volatile Solids	34000	9000 - 72000
Oil and Grease	4000	-
Ammoniacal nitrogen	35	4 - 80
Total Nitrogen	750	180 - 1400
Phosphorus	180	-
Potassium	2270	-
Magnesium	615	-
Calcium	439	-
Boron	7.6	-
Iron	46.5	-
Manganese	2.0	-
Copper	0.89	-
Zinc	2.3	-

*Units in mg/L except pH

Source: Lam and Lee, 2011

2.5.2 Empty Fruit Bunches (EFB)

The ash produced from EFB was used as fertilizer or soil conditioner (Yusoff, 2004). Most of the EFB in Malaysia is used in soil mulching as an organic nutrient to reduce the input of inorganic fertilizers. The ash is the solid residue of EFB that remains after combustion. It consists mostly of metal oxides such as potassium oxide (2.4%), magnesium oxide (0.23%), silica (0.19%), phosphorus pentoxide (0.18%) and calcium oxide (0.13%) (Yahya *et al.*, 2010). The EFB ash can enhance the release of nitrogen from soil organic matter. EFB ash is very hygroscopic and can be used as source of P, K, Mg and Ca in oil palm cultivation. The highest number of leaves, palm height and leaf area were obtained in the application of EFB ash to oil palm seedlings (Garuba *et al.*, 2012). The analysis of EFB generated from Malaysian palm oil mills is shown in Table 2.4.

Table 2.4 Analysis of EFB generated from Malaysian palm oil mills

Proximate analysis (wt %)	EFB from Malaysian palm oil mills
Moisture	8.75
Volatile matter	79.65
Fix carbon	8.60
Ash	3.00
Ultimate analysis	
C	48.79
H	7.33
O	40.18
N	0
S	0.68
Others	0.02
Ash	3.00
Lower heating value MJ/kg	18.96

Source: Hamzah, 2008

2.5.3 Oil palm Mesocarp Fiber (OPMF)

Oil palm mesocarp fiber (OPMF), also known as palm pressed fiber (PPF) is the biomass residue obtained after pressing the palm fruits for palm oil extraction (Ariffin *et al.*, 2013). On average, for every tonne of FFB processed, 120 kg of fibre is produced (Astimar *et al.*, 2002). Pressed fibre is a good combustible material because of the oil content. However, the shell material is no longer used as fuel to generate steam and the energy required for the operation of the mill because of pollution concerns. They can also be used to improve foliar nutrient levels and vegetative growth (Yusoff, 2004). This by-product (the fibre) is acceptable for ruminants at low levels of addition to their diet. PPF ash contains 1.7–6.6% P, 17–25% K, 7% Ca, which indicate that PPF is a good source of minerals for plants. Oil palm fibre (OPF) is a non-hazardous biodegradable material extracted from oil palm's EFB (Embrandiri *et al.*, 2012).

2.5.4 Palm Kernel Shell (PKS)

Palm kernel shell (PKS) has been used as mulch because it is hard to decompose. According to Ortiz *et al.* (1992), approximately 5 tonnes of shell are obtained from 66 tonnes of FFB. PKS is used for activated carbon production. It has up to 20.3% fixed carbon which is similar to the coconut shell. Activated carbon can be used for decolourisation of the dark coloured effluent of the mills.

2.5.5 Decanter Cake (DC)

Decanter cake (DC) is a solid waste produced from the three phase separation step of the crude palm oil process. The production rate of DC amounts to about 4 – 5 weight % of the fresh fruit bunch processed. Fresh decanter cake contains about 70 weight % moisture, while the dry matter contains oils, fiber and inorganic components. The most common utilization of the decanter cake is as fertilizer and animal nutrition sources due to the presence of C, N, P, K and Mg (Chavalparit *et al.,* 2006). The chemical composition of DC is as shown in Table 2.5. DC is another waste product used as either fertilizer or animal food (Southworth, 1985). Haron and Mohammed (2008) reported that a mill with 90 t hr^{-1} FFB processing capacity will produce about 160–200 tonnes of DC. Application of DC integrated with inorganic fertilizer can boost the efficiency of nutrient uptake by crops and enhances the nutrient retention in the soil to improve soil quality (Haron and Mohammed, 2008).

Table 2.5 Chemical composition (%) and pH value of decanter cake

Chemical composition (%) and pH value of decanter cake					
N	P_2O_5	K_2O	CaO	MgO	pH
2.42	0.51	1.24	1.68	0.54	4.8

Source: MPOB, 2008

2.6 Soils in Malaysia

The soils of Malaysia can be broadly divided into 2 groups: (a) the sedentary soils formed in the interior on a wide range of rock types, and (b) the soils of the coastal alluvial plains (Nieuwolt *et al.,* 1982). The sedentary soils are developed on igneous, sedimentary and metamorphic rocks, and are strongly weathered with mostly kaolinitic clay minerals. The problematic soils in Malaysia, namely, peat, acid sulphate and sandy soil (bris soils) fall under the coastal alluvial soils which is under the categories Gleysols, Cambisols and Podzols (Entisols, Inceptisols, Spodosols). The sandy soils spread along the East Coast of the Peninsula and the coastal area of Sabah, cover an area of just under 200,000 ha with 155,400 ha in Peninsular Malaysia and 40,400 ha in Sabah. Bris soils contain 82-99% sand particles, mainly quartz, and have a low CEC of 9.53 meq/100 g with pH 4.3-4.4 (Theeba, 2014).

2.6.1 Ultisol

Ultisols, a prominent soil order within the tropics are subject to low productivity and soil degradation and exhibit characteristics that make its management important. These characteristics include low water holding capacity, poor surface soil stability and relatively high bulk density (Babalola and Obi, 1981). They are also coarse-textured with low organic matter content (Igwe *et al.,* 1995; Mbagwu *et al.,* 1995). Prasetyo and Suryadikarta (2006) reported that soil fertility of Ultisols is generally accumulated in the thin upper layer or a layer containing low organic material. Essential macroelements such as P and K which are often in deficit, low soil pH and high Al saturation are the characteristics of Ultisol that limits plant growth (Budianta, 2001). Due to the low soil fertility of the Ultisol, it requires an effort to improve the fertility of Ultisols through increasing soil pH and nutrient supply, and decreasing Al toxicity by adding EFB (Dedik *et al.,* 2010).

2.6.2 Sandy soil

BRIS (Beach ridges interspersed with swales) soil is commonly known as problematic soils in Malaysia. BRIS soils can be found between 0.2–8.0 km from the sea beach which covers about 155 400 hectares in Peninsular Malaysia and about 40 000 hectares in the state of Sabah (Toriman *et al.,* 2009). The BRIS Soils in Malaysia are not well utilized for crop production due to their inherent poor fertility. Sandy soils are lacking in organic and inorganic colloids (Roslan *et al.,* 2011). Previous studies showed it to be too sandy, weakly structured, nutrient deficient, having low water retention capacity, limited ability to support plant growth and having a relatively high soil temperature (Mohd *et al.*, 2009). BRIS soil originates from sediment sand from the sea that accumulated from the erosion of layers of steep cliffs by the sea during the monsoon seasons and has a coarse sand component (Nossin, 1964). BRIS soils in the coastal region of Malay Peninsula are known to be successful in growing tobacco, with the combination of waste products like chicken manures and palm oil extracts can also improve on the development of the soil quality (Usman *et al.,* 2013).

2.7 Biochar

Biochar is a product of thermal decomposition processes such as the slow pyrolysis process for organic materials, e.g., biomass, in the total absence or limited supply of oxygen (O_2) and at a relatively low temperature (< 700°C) (Sohi *et al.*, 2010; Lehmann and Joseph, 2009). The application of biochar to soil improves soil productivity, reduces the emission of N_2O from soil, increases water holding capacity and has the potential to become a long-term carbon sink due to its high chemical stability, high carbon content and potential to reside in the soil for a long time (Lehmann and Joseph, 2009; CSIRO, 2010; Koide *et al.,* 2011). The types and properties of biochar and soil determine the effectiveness of the use of biochar for soil treatment. The properties, composition and yield percentage of biochar depends on many factors. The initial state and type of biomass feedstock used (chemical composition, ash composition and size), pre-treatment process (drying, washing or crushing) and pyrolysis parameters (temperature, heating rate and residence hour) are among the major factors that influence the characteristics of the biochar produced (Pilon and Lavoie, 2011; Yang *et al.*, 2006).

2.7.1 Biochar derived Biomass in Malaysia

Pyrolysis of palm oil biomass converts it into a volatile fraction consisting of gases, vapors and tar components and a carbon rich solid residue (char) fraction (Dewayanto, 2010). The abundant agricultural residues can be pyrolyzed to produce biochar. Biochar can be produced in a large reactor or by using a simple or small kiln (Rebitanim *et al.*, 2012). In the Institute of Advanced Technology (ITMA) University Putra Malaysia, biochar from various agricultural residues such as bamboo, wood and palm kernel are produced daily. Conversion of the biomass also depends on the biomass moisture content, for example EFB which has 50% moisture content will result in 25% conversion by weight (Rebitanim *et al.*, 2012).

2.7.2 Biochar and Soil Fertility

Modern research has demonstrated that the porous structure coupled with a large surface area of many biochars can promote plant growth by improving soil physical and chemical characteristics, such as nutrient retention, pH and cation exchange capacity (CEC) (Kong *et al.*, 2014). The effect of biochar as soil amendment is highly dependent on soil fertility and fertilizer management (Galinato *et al.,* 2011). Mukherjee and Zimmerman (2013) concluded that biochar should be chosen carefully for each given amendment project and suggested the use of higher temperature or aged biochar in sandy soils because they have a lower tendency to release sudden pulses of nutrients. Sika and Hardie (2014) observed that application of 2.5 and 10% pine wood slow pyrolysis biochar (450 °C) to sandy soil led to over liming raising some concerns regarding the practical use of biochar in improving nitrogen fertilizer-use efficiency of plants. Zheng *et al.* (2013), on the other hand, suggested that addition of up to 5% slow pyrolysis giant reed grass biochar to soil (29% sand content) could reduce N leaching and increase N retention and bioavailability in agricultural soils and thus potentially decrease the N fertilizer demand for maize crop growth.

REFERENCES

Abdullah, N. and Sulaiman, F. 2013. The Oil Palm Wastes in Malaysia. *INTECH*

Abdulrazzaq, H., Jol, H., Husni, A. and Abu-Bakr, R. 2014. Characterization and Stabilization of Biochars Obtained from Empty Fruit Bunch, Wood, and Rice Husk. *BioResources* **9(2)**: 2888-2898.

Adeptu, J. A. and Anyaduba, E. T. 1983. Predicting the phosphorus fertilization of tropical soil critical solution P requirement of cowpea P, sorption capacity and free iron content of soils. *Journal Tropical Agriculture Science* **21(1)**: 21-70

Agamuthu, P. and Tan, E. L. 1985. Digestion of dried palm oil mill effluent by Cellulomonas species. *Microbios letters* **30**: 109-113

Alfred, O., Jan, M., Vegard, M., Gerard, C. and Trond, B. 2015. In situ effects of biochar On aggregation, water retention and porosity in light-textured tropical soils. *Soil and Tillage Research* **155**: 35-44

Areerat, K. 2006. *Appropriate technology evaluation for oil palm by-products utilization in Krabi province.* Mahidol University

Ariffin, H., Nishida, H., Andou, Yoshito, Mohd, A. H. and Shirai, Y. 2013. Modification of Oil Palm Mesocarp Fiber Characteristics Using Superheated Steam Treatment. *Molecules* **18**: 9132-9146

Astimar, A. A., Das, K., Husin, M. and Mokhtar, A. 2002. Effects of physical and chemical pretreatments on xylose and glucose production from oil palm press fibre. *Journal of Oil Palm Research* **14(2)**: 10-17

Awalludin, M. F., Sulaiman, O. and Hashim, R. 2015. An overview of the oil palm industry In Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. *Renewable and Sustainable Energy Reviews* **50**: 1469-1484

Babalola, O. and Obi, M. E. 1981. Physical properties of acid sands in relation to land use. In: Udo, E. J. and Sobulo, R. A. Acid sands of Southern Nigeria. *Soil Science Society of Nigeria Special Publication Monography* **1**: 27-55

Belder, P., Spiertz, J. H. J., Bouman, B. A. M., Lu, G. and Tuong, T. P. 2005. Nitrogen Economy and water productivity of lowland rice under water - saving irrigation. *Field Crops Research* **93(2-3)**: 165-185

Bellido, L. L., Bllido, R. J. and Redondo, R. 2005. Nitrogen efficiency in wheat under Rainfed Mediterranean conditions as affected by split nitrogen application. *Field Crops Research* **94(1)**: 86-97

Bieleski, R. L. 1973. Phosphate pools, phosphate transport, and phosphate availability. *Annual Review of Plant Physiology* **24**: 225-252

Bruce, H. 2002. *Organic Matter by Loss on Ignition.* University of Marine

Bruun, E. W., Petersen, C. T., Hansen, E., Holm, J. K. and Hauggaard-Nielsen, H. 2014. Biochar amendment to coarse sandy subsoil improves root growth and increases water retention. *Soil Use Management* **30**: 109-118

Budianta, D. 2001. Response of soybean on the application of lime and green manure Derived from velvet bean planted in an Ultisol. *Journal of Tropical Soils* **7(13)**: 1-9

Chan, K. Y., Zwieten, L. V., Meszaros, I., Downie, A. and Joseph, S. 2007. Agronomic values of green waste biochar as a soil amendment. *Australian Journal of Soil Research* **45**: 629-634

Chee, K. H., Chiu, S. B. and Chan, S. M. 1997. Prenursery seedlings grown on pot trays. *The Planter* **73(855)**: 295-299

Chavalparit, O., Rulkens, W. H., Mol, A. P. J. & Khaodhair, S. 2006. Options for environmental sustainability of the crude palm oil industry in Thailand through enhancement of industrial ecosystems. *Environment, Development and Sustainability* **8**: 271-287

Chris, O. N., Chidinma, P. and Sola, O. 2012. Plant nutrient recovery following Palm Oil Mill Effluent Soil amendment in a maize (*Zea mays*) grown screen house experiment. *International Journal of Agricultureand Rural Development* **15(2)**: 1109-1118

Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2010. Biochar. www.csiro.au/files/files/pnzp.pdf. Accessed on 7th April 2015. Verified on 16th May 2015

Daniel, P. S., Robert, J. R. and Ayling, S. M. 1998. Phosphorus Uptake by Plants: From Soil to Cell. *Plant Physiology* **116(2)**: 447-453

David, A. 2014. *International Turf Management.* New York: Reed Educational and Professional Publishing Ltd

Dedik, B., Ali, Y. A. W. and Wahana, L. 2010. Changes in Some Soil Chemical Properties of Utisol Applied by Mulch from Empty Fruit Bunches in an Oil Palm Plantation. *Journal of Tropical Soils* **15(2)**: 111-118

Desai, R. M., Bhatia, C. R. 1978. Nitrogen uptake and nitrogen harvest index in durum wheat. *Euphytica* **27**: 561-566

Dewayanto, N. 2010. *Waste to valuable by product: utilization of carbonised decanter cake from palm oil milling plant as an effective adsorbent for heavy metal ions in aqueous solution.* Universiti Malaysia Pahang

Donald, S. R. and Quirine, K. 2011. *Recommended Methods for Determining Soil Cation Exchange Capacity.* Northeastern United States

Edwin, C. R., Meine, V. N., Didik, S. and Cadish. 2005. Nitrogen use efficiency of monoculture and hedgerow intercropping in the humid tropics. *Plant and Soil* **268**: 61-74

Embrandiri, A., Singh, R. P. and Ibrahim, M. H. 2013. 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**: 1-6

Embrandiri, A., Singh, R., Ibrahim, H. M. and Ramli, A. A. 2012. Land application of biomass residue generated from palm oil processing: its potential benefits and threats. *Environmentalist* **32**: 111-117

Erica, F. 2011. *Application of Low-Temperature Produced Biochar on Plant Growth in Californian Alfisol Soil.* University of California

Eschbach, J. M., Massimino, D. and Mendoza, A. M. R. 1982. Effet d'une carence en chlore surla germination, la croissance et la photosynthèse du cocotier. *Oléagineux* **37(3)**: 115-125

Evans, J. R. 1983. Nitrogen and photosynyhesis in the flag leaf of wheat (*Triticum aestivum* L.). *Plant Physiology* **72**: 297-302

Evans, H. J. 1989. Photosynthesis and nitrogen relationshipin leaves of C3 plants. *Oecologia* **20**: 9-19

FAO, 2014. FAOSTAT online statistical service. http://faostat.fao.org. Accessed on 21 March 2015. Verified on 13th April 2015

FAO. 2005. The Importance of Soil Organic Matter. In: *Food and Agriculture Organization of the United Nation.* Via delle Terme di Caracalla, Italy

Field, C. and Mooney, H. A. 1986. *The photosynthesis – nitrogen relationship in wild plants. In: On the economy of plant form (GIVNISH T. J., Ed.).* Cambridge, University Press

Furihata, T., Suzuki, M. and Sakurai, H. 1992. Kinetic characterization of two phosphate uptake systems with different affinities in suspension-cultured Catharanthus roseus protoplasts. *Plant and Cell Physiology* **33**: 1151-1157

Galinato, S. P., Yoder, J. K. and Granatstein, D. 2011. The economic value of biochar in crop production and carbon sequestration. *Energy Policy* **39**: 6344-6350

Garuba, N., Sulaiman-Ilobu, B. B., Ederion, O., Imogie, A., Imoisi, B. O., Uwumarongie-Ilori, E. G. and Ugbah, M. 2012. *Greener Journal of Agricultural Sciences* **2(2)**: 26-30

Glaser, B., Haumaier, L., Guggenberger, G. and Zech, W., 2001. The Terra Preta phenomenon-a model for sustainable agriculture in the humid tropics. *Naturwissenschaften* **88**: 37-41

Glaser B., Lehmann J., Zech W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with biochar-a review. *Biology and Fertility of Soils* **35**: 219-230

Goh, K. J, Chew, P. S. and Teoh, K. C. 2004. Vegetative growth, resource optimisation and N productivity of oil palm (*Elaeis guineensis* Jacq.) as influenced by soil and fertilization. http://www.regional.org.au/au/asa/2004/poster/2/3/438_gohkj.htm. Accessed on 4th August 2015. Verified on 9th September 2015

Habib, M. A. B., Yusoff, F. M., Phang, S. M., Ang, K. J. and Mohamed, S. 1997. Nutritional values of chironomid larvae grown in palm oil mill effluent and alga culture. *Aquaculture* **158**: 95-105

Halimah, M., Ismail, B. S., Salmijah, S., Tan, Y. A. and Choo, Y. M. 2012. A Gate-to-gate Case Study of the Life Cycle Assessment of an Oil Palm Seedling. *Tropical Life Sciences Research* **23(1)**: 15-23

Hamzah, M. M. B. 2008. The production of ecofiber from palm oil empty fruit bunch, In: Universiti Malaysia Pahang. http://umpir.ump. edu.my/521. Accessed on 8th April 2015. Verified on 20th May 2015

Haron, K. and Mohammed, A. T. 2008. Efficient use of inorganic andorganic fertilisers for oil palm and potential utilisation of decanter cake and boiler ash for biofertiliser production. In: *Proceedings of the 2008 national seminar on biofertiliser, biogasand effluent treatment in the oil palm industry*. Malaysia

Hashim, T. M. and Zaharah, A. R. 1994. Nitrogen contribution by palm oil mill effluent to young oil palm (*Elaeis guineensis* Jacq.) as measured by 15N Isotope Dilution Technique. *Journal Tropical Agriculture Science* **17(2)**: 81-87

Havlin, J. L., Beaton, J. D., Tisdale, S. L. and Nelson, W. L. 2015. *Soil fertility and fertilizers: An introduction to nutrient management* 7th edition. New Jersey (USA): Pearson Education

Hazelton, P. A. and Murphy, B. W. 2007. *Interpreting Soil Test Results: What Do All The Numbers Mean?*. Melbourne. CSIRO Publishing

Helena, S. 2009. *Extraction methods in soil phosphorus characterisation*. Department of applied chemistry and microbiology. University of Helsinki

Igwe, C. A., Akamigbo, F. O. R. and Mbagwu, J. S. C. 1995. Physical properties of soils of southeastern nigeria and the role of some aggregating agents on their stability. *Soil Science Society of Nigeria.* **160**: 431-441

IJM Plantations Berhad. 2005. http://www.ijm.com/plantation/index.html. Accessed on 9th April 2015. Verified on 17th May 2015

Julia, G. and Melony, W. 2009. Nutrient Management. University of Georgia. http://soilquality.org/practices/nutrient_management.html. Accessed on 3rd June 2015. Verified on 17th July 2015

Kittikun, A. H., Prasertsan, P., Srisuwan, G. and Krause, A. 2000. Environmental Management for palm oil mill material flow analysis of integrated biosystems. http://www.globetree.org/jackyfoo/ic-mfa/kittikun/index.html. Accessed on 11th April 2015. Verified on 17th May 2015

Koide, R. T., Petprakob, K. & Peoples, M. 2011. Quantitative analysis of biochar in field soil. *Soil Biology and Biochemistry* **43(7)**: 1563-1568

Kong, S. H., Loh, S. K., Bachmann, R. T., Rahim, S. A. and Salimon, J. 2014. Biochar from oil palm biomass: A review of its potential and challenges. *Renewable and Sustainable Energy Reviews* **39**: 729-739

Kushairi, A., Tarmizi, A. H., Zamzuri, I., Ong-Abdullah, M., Samsul Kamal, R., Ooi, S. E. and Rajanaidu, N. 2010. Production, Performance and Advances in Oil Palm Tissue Culture. Malaysian Palm Oil Board

Laird, D., Fleming, P., Wand, B., Horton, R. and Karlen, D. 2010. Biochar impacts on nutrient leaching from Midwestern agricultural soil. *Geoderma* **158(3)**: 436-442

Lam, M. K. and Lee, K. T. 2011. Renewable and sustainable bioenergies production from palm oil mill effluent (POME): Win–win strategies toward better environmental protection. *Biotechnology Advances* **29**: 124-141

Lee, J. W., Hawkins, B., Li, X., Day, D. M., 2013. *Biochar fertilizer for soil amendment and carbon sequestration.* In book: Advanced Biofuels and Bioproducts, 57-68

Lehmann, J., Liang, B., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J. O., Thies, J., Luizao, F. J., Peterson, J. and Neves, E. G. 2006. Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal* **70**: 1719-1730

Lehmann, J. and Joseph, S. 2009. *Biochar for environmental management: An introduction. In Lehmann, J. & Joseph, S. (Eds.). Biochar for environmental management-science and technology.* London: Earthscan

Lehmann, J., Thies, J. E., Cheng, C. H., Burton, S. D. and Engelhard, S. D. 2006. Oxidation of black carbon by biotic and abiotic processes. *Organic Geochemistry* **37**: 1477-1488

López-Cano, I., Cayuela, M. L., Roig, A. and Sánchez-Monedero, M. A. 2011. *Effect of biochar on the N mineralization dynamics of an agricultural soil amended with sheep manure.* CEBAS-CSIC, Campus Universitario de Espinardo.

Malaysians Palm Oil Board, 2008. Palm-based Biofertilizer from Decanter Cake and Broiler Ash of Palm Oil Mill. MPOB Information Series. http://bepi.mpob.gov.my/index.php/statistics/production/125-production-2014/659-production-of-crude-oil-palm-2014.html. Accessed on 10th April 2015. Verified on 7th June 2015

Malaysians Palm Oil Board, 2013. Malaysian oil palm statistics. Summary of the Malaysian Oil Palm Industry 2014,http://bepi.mpob.gov.my/index.php/summary/710-summary-2014.html. Accessed on 24th March 2015. Verified on 16th April 2015

Malaysians Palm Oil Board, 2014. http://www.mpob.gov.my/palm-info/environment/520-achievements. Accessed on 7th May 2015. Verified on 7th June 2015

Malaysians Palm Oil Board, 2015. http://bepi.mpob.gov.my/index.php/statistics/production/125-production-2014/659-production-of-crude-oil-palm-2014.html. Accessed on 8th April 2015 Verified on 7th May 2015

Malaysian Palm Oil Council. 1995. Malaysian Palm Oil. In Palm Oil Information Series. http://www.mpoc.org.my/. Accessed on 19th April 2015. Verified on 9th May 2015

Manna, M. C., Swarup, A., Wanjari, R. H., Ravankar, H. N., Mishra, B., Saha, M. N., Singh, Y. V., Sahi, D. K. and Sarap, P. A. 2005. Long term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub- humid and semi-arid tropical India. *Field Crops Research* **93(2-3)**: 264-280

MARDI, 2011. http://www.mardi.my/. Accessed on 6th May 2015. Verified on 9th June 2015

Masulili, A., Utomo, W. H., and Syechfani, M. 2010. Rice husk biochar for rice based cropping system in acid soil 1. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. *Journal of Agricultural Science* **2(1)**: 39-47

Mathews, J., Chong, K. M., Yong K. K. and IP, W.M. 2008. Raising pre-nursery oil palm seedlings in plastics pot tray: a 101 group experience. *The Planter* **84(986)**: 285-297

Mathews, J., Tan, T. H., Ng, S. K., Chong, K. M., Yong K. K. and IP, W.M. 2010. Managing Oil Palm nursery: IOI's Experience. *The Planter* **86(1016)**: 771-785

Mbagwu, J. S. C., Unamba-Oparah, I. and Nevoh, G. O. 1995. Physico-chemical properties and productivity of two tropical soils amended with dehydrated swine waste. *Bioresources Technology* **49**: 163-171

Mohamad, A. S., Loh, S. K., Nasrin, A. B. and Choo, Y. M. 2011. Production and Characterization of Bio-Char from the Pyrolysis of Empty Fruit Bunches. *American Journal of Applied Sciences* **8(10)**: 984-988

Mohd, E. H. T., Mazlin, B. M., Muhammad, B. G. and Nor Azlina A. A. 2009. Analysis of the Physical Characteristics of Bris Soil in Coastal Kuala Kemaman, Terengganu. *Research Journal of Earth Sciences* **1(1)**: 1-6

Mohd Hashim, T. 1990. *Utilisation of palm oil mill effluent as nitrogen source for oil palm (Elaeis guineensis* Jacq.*)*. Graduate Theses and Dissertation. University of Agriculture, Malaysia

Mukherjee, A. and Zimmerman, A. R. 2013. Organic carbon and nutrient release from a range of laboratory-produced biochars and biochar–soil mixtures. *Geoderma* **193-194**: 122-130

Ndor, E., Amana, S. M. and Asadu, C. L. A. 2014. Effect of Biochar on Soil Properties and Organic Carbon Sink in Degraded Soil of Southern Guinea Savanna Zone, Nigeria. *International Journal of Plant & Soil Science* **4(3)**: 252-258

Ng, F. Y., Yew, F. K., Basiron, Y. and Sundram, K. 2011. A renewable future driven with Malaysian palm oil-based green technology. *Journal of Oil Palm and the Environment* **2**: 1-7

Nieuwolt, S., Zaki, M. G., and Gopinathan, B. 1982. *Agro-ecological regions in Peninsular Malaysia*. MARDI: Serdang, Malaysia

Nossin, J. J. 1964. Beach Ridges of the East Coast of Malaya. *Tropical Geography Journal* **18**: 111-117

Ortiz, R. A., Villalobos, E. and Fernandez, O. 1992. Mulch and fertiliser effects on soil nutrient content, water conservation and oil palm growth. *Agricultural Service Deparment Oil Palm Papers* **6**: 1-11

O'Toole, A., Knoth de Zarruk, K., Steffens, M. and Rasse, D.P. 2012. Characterization, stability, and plant effects of kiln-produced wheat straw biochar. *Journal of Environmental Quality* **42(2)**: 429-436

Oviasogie, P. O. and Uzoekwe, S. A. 2011. Concentration of Available phosphorus in Soil Amended with Rock Phosphate and Palm Oil Mill Effluent. *Ethiopian Journal of Environmental Studies and Management* **(4)1**: 64-67

Pilon, G. and Lavoie, J. M. 2011. Characterization of switchgrass char produced in torrefaction and pyrolysis conditions. *Journal of Biological Resources* **6(4)**: 4824-4839

Pleanjai Somporn, H., Gheewala Shabbir and Garivait Savitri, 2004. Environmental Evaluation of Biodiesel Production from Palm Oil in a Life Cycle Perspective.In: *The Joint International Conference on Sustainable Energy and Environment (SEE)*. Hua Hin, Thailand

Prasertsan, S. and Prasertsan, P. 1996. Biomass residues from palm oil mills in Thailand: an overview on quantity and potential usage. *Biomass Bioenergy* **11(5)**: 87-395

Prasetyo, B. H. and Suryadikarta, D. A. 2006. Karakteristik, Potensi, dan Teknologi Pengelolaan Tanah Ultisol untuk Pengembangan Pertanian Lahan Kering di Indonesia. *Jurnal Litbang Pertanian* **25(2)**: 39-47

Prioul, J. L., Brangeon, J. and Reyss, A. 1980. Interaction between external and internal conditions in the development of photosynthetic features in a grass leaf I. *Plant Physiology* **66**: 762-769

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

Rebitanim, N. Z., Ghani, W. A. W. Ab. K., Rebitanim, N. A. and Salleh, M. A. M. 2012. Potential applications of waste from energy generation particularly biochar in Malaysia. *Renewable and Sustainable Energy Reviews* **21**: 694-702

Reid, J. and Goss, M., 1981. Effect of living roots of different plant species on the aggregate stability of two arable soils. *Journal of Soil Science* **32**: 521–541

Roslan, I., Shamshuddin, J., Fauziah, C. I. and Anuar, A. R. 2011. Fertility and Suitability of the Spodosols Formed on Sandy Beach Ridges Interspersed with Swales in the Kelantan - Terengganu Plains of Malaysia for Kenaf Production. *Malaysia Journal of Soil Science* **15**: 1-24

Rupani, P. F., Singh, R. P., Ibrahim, M. H. and Esa, N. 2010. Review of Current Palm Oil Mill Effluent (POME) Treatment Methods: Vermicomposting as a Sustainable Practice. *World Applied Sciences Journal* **11(1)**: 70-81

Sharifuddin, H. A. H., Shahbuddin, M. F. and Zaharah, A. R. n.d. Effect of Organic Amendments and EM on Production of Food Crops in Malaysia. University of Agriculture, Serdang, Malaysia

Sika, M. P. and Hardie, A. G. 2014. Effect of pine wood biochar on ammonium nitrate leaching and availability in a South African sandy soil. *European Journal of Soil Science* **65**: 113-119

Singh, R. P. and Agrawal, M. 2010a. Effect of different sewage sludge applications on growth and yield of Vigna radiata L. field crop: metal uptake by plants. *Ecological Engineering* **36**: 969-972

Singh, R. P. and Agrawal, M. 2010b. Variations in heavy metal accumulation, growth and yield of rice plants grown at different sewage sludge amendment rates. *Ecotoxicology and Environmental Safety* **73**: 632–641

Singh, R. P. and Agrawal, M. 2010c. Biochemical and physiological responses of rice (*Oryza sativa* L.) grown on different sewage sludge amendment rates. *Bulletins of Environmental Contamination and Toxicology* **84**: 606–612

Singh, R. P., Ibrahim, M. H. and Esa, N. 2010. Composting of waste from palm oil mill: A sustainable waste management practice. *Reviews in Environmental Science and Biotechnology* **9(4)**: 331-344

Southworth, A. 1985. Palm oil and palm kernels. *Journal American Oil Chemists' Society* **62(2)**: 250-254

Sohi, S. P., Krull, E., Lopez-Capel, E. and Bol, R. 2010. A review of biochar and its use and function in soil. *Advances in Agronomy* **105(1)**: 47-82

Stevenson, F. J. and Cole, M. A. 1999. *Cycles of Soils: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients (second edition)*. London: John Wiley & Sons
Toriman, M. E. H., Mokhtar, M. B., Gasim, M. B. and Aziz, N. A. A. 2009. Analysis of the physical characteristics in Coastal Kuala Kemaman, Terengganu. *Research Journal of Earth Science* **1**: 1–6
Theeba, M. 2014. Biochar on acidic agricultural lands in South- East Asia: Sequestering carbon and improving crop yield. MARDI Research Report
Ullrich-Eberius, C., Novacky, A. and van Bel, A. 1984. Phosphate uptake in Lemna gibba G1: energetics and kinetics. *International Journal of Plant Biology* **161**:46–52
USDA-FAS. 2013. Oilseeds World Markets and Trade
USDA Natural Resources Conservation Service. 2011. Carbon to Nitrogen Ratios in Cropping Systems
Usman, M. I., Edi Armanto, H. M. and Adzem, M. A. 2013. Performances of BRIS Soils Genesis and Classification in Terengganu, Malaysia. *Journal of Biology Agriculture and Healthcare* **3(20)**: 86-92
Van Zwieten, L., Kimber, S., Morris, S., Chan, K., Downie, A., Rust, J., Joseph, S., Cowie, A. 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil* **327**: 235–246
Vos, J., Van der Putten, P. E. L. and Birch, C. J. 2005. Effect of nitrogen supply on leaf appearance, leaf growth leaf nitrogen economy and Photosynthetic capacity in maize (*Zea mays* L.). *Field Crop Research* **93(1)**: 64-73
Warncke, D. D. and Barber, S. A. 1973. Ammonium and nitrate uptake by com (*Zea mays* L.) as influenced by nitrogen concentration and ammonium/nitrate ratio. *Agronomy Journal* **65**: 950-953
Wu, T. Y., Mohammad, A. W., Jahim, J. M. and Anuar, N. 2009. A holistic approach to managing palm oil effluent (POME): biotechnological advances in the sustainable reuse of POME. *Biotechnology Advances* **27**: 40-52
Wu, Y., Xu, G. and Shao, H. B. 2014. Furfural and its biochar improve the general properties of a saline soil. *Solid Earth* **5**: 665-671
Yahya, A., Sye, C. P., Ishola, T. A. and Suryanto, H. 2010. Effect of adding palm oil mill decanter cake slurry with regular turning operation on the composting process and quality of compost from oil palm empty fruit bunches. *Bioresource Technology* **101(22)**: 8736-8741
Yang, H. Yan, R. and Zheng, C. G. 2006. Mechanism of palm oil waste pyrolysis in a packed bed. *Energy Fuels* **20(3)**: 1321-1328
Yeong, W.T., Mohammad, A. W., Md Jahim, J. and Anuar, N. 2008. Palm Oil Mill Effluent (POME) treatment and bioresource recovery using ultrafiltration membrane: effect of pressure one membrane fouling. *Biochemical Engineering Journal* **35(3)**: 309-317
Yusoff, S. 2004. Renewable energy from palm oil: innovation on effective utilization of waste. *Journal of Cleaner Production* **14(1)**: 87-93
Zahari Abu Bakar and Kho, B. L. 1983. Nutrient enrichment of POME under anaerobic conditions. In: *Proceedings of Seminar on Fertilizers in Malaysian Agriculture*. Kuala Lumpur
Zainab, H., Ainatul, A. A., Othman, H. and Lee, B. B. 2013. Characterization of Physicochemical Properties of Biochar from Different Agricultural Residues. *Advances in Environmental Biology* **7(12)**: 3752-3757
Zheng, H., Wang, Z., Deng, X., Herbert, S. and Xing, B. 2013. Impacts of adding biochar on nitrogen retention and bioavailability in agricultural soil. *Geoderma* **206**:32-39