EFFECTS OF OIL PALM DECANTER CAKE ON GROWTH OF SELECTED VEGETABLES

ASHA EMBRANDIRI

UNIVERSITI SAINS MALAYSIA

2016

EFFECTS OF OIL PALM DECANTER CAKE ON GROWTH OF SELECTED VEGETABLES

by

ASHA EMBRANDIRI

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

JANUARY 2016

DEDICATION

To My Family

ACKNOWLEDGEMENTS

My gratitude goes to my supervisor Associate Professor Mahamad Hakimi Ibrahim for his guidance throughout the research. I am grateful to Dr Rajeev Pratap Singh of Banaras University, Varanasi, India for his mentoring and support. To Professor Sultan Ahmed Ismail of Ecoscience Research Foundation, Chennai, I am thankful for his advice and guidance. Finally, I would like to appreciate Professor. Ir Dr. Mohd Omar Ab Kadir, School of Industrial Technology, for dedicating his time, providing suggestions and his timely guidance. I am grateful for the effort spent by Dr Mrs Chitralekha Ramachandran of Stella Maris College, Chennai and Dr Sivakumar of Karpaga Vinayaga College of Engineering and Technology, Chennai, India in going through the thesis, editing and advising.

I would like to thank all the members of my family, (Mr and Mrs Embrandiri), sister (Dr Jishalakshmi, Mr Sandeep and Varunshankar) and brother (Mr Manoj Embrandiri and Shanu) for everything they have done for me.

My sincere appreciation also goes to all my USM friends who have directly or indirectly been involved in my struggles. I am thankful to all my friends, the world over who have been there for me.

Finally, I would like to acknowledge the USM PRGS (1001/PTEKIND/844080) grant for the financial assistance, the 100/PTEKIND/811254 RUI grant and also the Scanning Electron Microscopy unit and plant house staff of the School of Biological Sciences, USM.

Asha Embrandiri

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LIST OF ABBREVIATIONS

BCF	Bioconcentration Factor
DC	Decanter Cake
EC	Electro-conductivity
EF	Enrichment Factor
EFB	Empty Fruit Bunch
FFB	Fresh Fruit Bunch
HI	Harvest Index
LAI	Leaf Area Index
LAR	Leaf Area Ratio
LWR	Leaf Weight Ratio
OC	Organic Carbon
PKC	Palm Kernel Cake
PPF	Palm Press Fibre
POME	Palm Oil Mill Effluent
POFA	Palm Oil Fuel Ash
POMW	Palm Oil Mill Wastes
RSR	Root Shoot Ratio
RTB	Root Total Biomass
SLA	Specific Leaf Area
SLW	Specific Leaf Weight

SVI	Seedling Vigour Index
TF	Translocation Factor
TI	Tolerance Index
$\mu M\ g^{-1}$	micro Molar per gram
h	Hours

KESAN-KESAN KEK DEKANTER KELAPA SAWIT KE ATAS TUMBESARAN TANAMAN SAYURAN TERPILIH

ABSTRAK

Kek Dekanter (DC) merupakan salah satu sisa yang terhasil semasa pemprosesan minyak sawit. Kajian lepas telah menunjukkan kandungan nutrien yang tinggi dalam DC berpotensi untuk dijadikan sebagai sumber bekalan nutrien untuk pertumbuhan tanaman. Walau bagaimanapun disebabkan oleh sifatnya yang berasid, kegunaannya sebagai nutrien untuk tanaman perlu dikaji sepenuhnya. Dalam kajian ini, DC digunakan sebagai pengubahsuai tanah dalam pelbagai nisbah untuk menilai kesan komposisi DC dalam pertumbuhan tanaman kacang bendi, tomato dan terung. Sifat-sifat tertentu tanah, ciri-ciri pertumbuhan tanaman, kandungan biokimia, hasil tanaman, corak pengumpulan nutrien dan mikrograf mikroskop imbasan elektron (SEM) telah dikaji atas tanaman ujian yang didedahkan kepada pengubahsuaian tanah dengan komposisi DC berbeza (10, 20 dan 30%) berserta kawalan. Keputusan analisis tanah menunjukkan pH dan ketumpatan pukal tanah masing-masing berkurang sebanyak 44.5% dan 41.8%. Manakala OC, EC dan nisbah C:N menunjukkan peningkatan sebanyak 96.5%, 51.6% dan 76% masing-masing bagi pengubahsuaian dengan DC yang sama. Kajian terhadap pertumbuhan tanaman terung pada pengubahsuaian DC sebanyak 30% menunjukkan peratusan pembenihan yang tinggi (50%) berbanding tanaman dengan pengubahsuaian DC 10%. Tanaman terung menunjukkan respon (peningkatan) yang positif terhadap pertambahan dalam pengubahsuaian DC bagi panjang pucuk (80%), panjang akar (72%), hasil (89%),

biojisim (89%) dan luas permukaan daun (85%). Terdapat penyusutan dalam kandungan karotenoid dalam kesemua tanaman kajian manakala kandungan fenolik didapati tinggi dalam kesemua tanaman kajian (3 mg g^{-1} – 13 mg g^{-1}). Kepekatan kesemua logam dalam daun, pucuk dan buah pada tanaman kacang bendi, tomato dan terung yang ditanam pada nisbah kek dekanter yang berbeza tidak menunjukkan perbezaan yang ketara ($p>0.05$) dari tanaman-tanaman yang sama dalam tanah yang tidak terubahsuai (kawalan). Nilai-nilai faktor pengkayaan (enrichment factors) dalam kajian ini kesemuanya di bawah 3, dan menunjukkan bahawa pengkayaan ion-ion logam adalah amat sedikit. Ketiga-tiga tanaman kajian tidak memindahkan ion logam berlebihan dari tanah ataupun dari pengubahsuai kepada bahagian buah sebagaimana yang ditunjukkan oleh faktor bio-kepekatan (BCF). Ketiga-tiga tanaman kajian menunjukkan faktor translokasi (TF) yang tinggi daripada tanaman kawalan kecuali kandungan natrium dalam kacang bendi. Nilai-nilai tersebut kesemuanya berada di bawah kadar piawaian yang dibenarkan untuk sayuran. Kajian SEM pada epidemis daun tanaman kajian menunjukkan bahawa kadar pembukaan sel-sel pengawal berkurangan apabila rawatan kek dekanter ditingkatkan, kecuali untuk tanaman kacang bendi. Kesimpulannya, kek dekanter sebagai pengubahsuai tanah boleh dijadikan sebagai sumber pengubahsuai tanah untuk tanaman kacang bendi (pada 10%DC), tomato (pada 10%DC) dan terung (pada 30%DC).

EFFECTS OF OIL PALM DECANTER CAKE ON GROWTH OF SELECTED VEGETABLES

ABSTRACT

Decanter cake (DC) is one of the several wastes produced during the processing of oil palm. Research has shown that the high nutrient composition of decanter cake makes it a potential source of nutrients for plant growth. However due to its acidic nature, its use as plant nutrients has not been fully explored. This studies the addition of various ratios of DC to soil in order to evaluate the effects on lady's finger, tomato and brinjal plants. Selected soil properties, plant growth characteristics, biochemical contents, yield, nutrient accumulation patterns and scanning electron micrographs (SEM) were measured on the test plants subjected to different ratios of decanter cake (10, 20 and 30%) with controls. Results of the soil analyses revealed that soil pH and bulk densities decreased by 44.5% and 41.8% respectively as compared to the control soils. For Organic Carbon, Electro-conductivity and C: N ratio there was a 96.5%, 51.6% and 76% increase respectively with respect to the control as well. Growth studies indicate that at 30% DC ratios, brinjal plants had high germination percentage (50%) compared to plants grown at 10% DC ratios. Brinjal plants had positive response (increments) to the addition of DC ratios with respect to shoot length (80%), root length (72%), yield (89%), biomass (89%) and leaf area (85%). There was reduction in carotenoid contents in all three plants while total phenolic contents were high in all three plants (3 mg g^{-1} – 13 mg g^{-1}). Concentrations of all the analysed elements in leaf, shoot and fruit parts of lady's finger, tomato and brinjal grown at different ratios of decanter cake were not significantly different ($p>0.05$) from the plants grown in un-amended soil (control). Enrichment factor (EF) values in this study were all below 3 indicating low uptake of metal ions from soil to plants. The test plants did not transfer excess heavy metal ions from the soil or ratios to the fruit portion in all the three plants as evidenced by bioconcentration factor (BCF). Likewise all three plants had higher translocation factor (TF) values than control plants except for sodium in lady’s finger plants. None of the values of accumulation or metal concentrations exceeded the permissible standards for vegetables. SEM studies of the leaf epidermis of the test plants revealed that with increasing decanter cake treatments stomatal opening reduced, in all but the lady’s finger plants. In summary, specific ratios of decanter cake in soil could serve as a source of nutrients for the growth of lady’s finger (at 10%DC), tomato (at 10%DC) and brinjal (at 30%DC) plants.

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND TO THE STUDY

The Malaysian palm oil industry is a major revenue earner (around USD 7 biliion per annum in GDP) and is ranked as one of the largest producers in the world (Ng *et al*., 2012). Zwart, (2013) stated that CPO production reached 18.91 million metric tons in 2011. However, growth of the industry is synonymous with a massive production of agro-industrial waste (Liew et al., 2015). Wastes such as palm oil mill effluent (POME), palm kernel cake (PKC), decanter cake (DC), empty fruit bunches (EFB), palm kernel shell (PKS), palm press fibre (PPF) are some of the major by-products of the palm mill whose management poses a big challenge for the palm oil producing nations (Singh et al., 2012).

Land filling and incineration were the foremost cheapest options put forward by scientists to reduce the large volumes of solid wastes and aeration ponds for the POME (Rupani *et al*., 2012). In more recent times, composting and vermi-composting have gained grounds as better options for the management of these wastes because of their better NPK value. Both processes cut down the amount of waste which makes it easier for land application (Thambirajah *et al.*, 1995, Yusri *et al.*, 1995, Danmanhuri 1998). Efforts are being made to come up with cleaner production technologies to achieve 'zero waste' target in the oil palm sector. Despite all these attempts, the volume of waste produced still supercedes the re-use and most of the waste is left unattended to or lying in the plantations (Singh *et al*., 2012). Only 10% of the palm biomass is commercially exploited (KeTTHA, 2011).

Ng *et al*., (2012) reported a number of on-going experiments utilising oil palm biomass by-products in various industries such as bio-fuels, lumber for wood, feed for animals, shells as activated carbon for water purification etc. Palm waste has also been suggested as a good bio-fertiliser, potting material and soil conditioning agent (KeTTHA, 2011). Likewise, there are many studies reporting the use of organic wastes from agriculture for plant growth experiments. The amendments of soil with organic wastes in agriculture has led to improved soil structure and better crop performance by the recycling of nutrients such as N and P (Singh and Agrawal, 2007, 2008). Silva *et al* (2010) also suggested that agricultural wastes such as olive mill wastes, tannery, oil seed cakes, palm mill wastes,etc could also be used as an additive to soils. Olive waste extract at 10%, 30% and 50% amendment ratios improved seed emergence of lettuce with reduced biomass (Kelepsei and Tzortzakis., 2009). Also, combinations of poultry manure and NPK resulted in significant differences in height and yield of spinach (Ndaeyo *et al.*, 2013). Another example is the use of palm boiler ash for the growth of eggplant, okra and pepper (Adjei-Nsiah and Obeng. 2013).

However, only a few investigations have been reported with regards to using decanter cake for the growth of vegetables. Therefore this work contributes to knowledge on the employment of decanter cake for the growth of lady’s finger, tomato and brinjal plants.

1.1 PROBLEM STATEMENT

In Malaysia, the oil palm industry has been regarded as one of the best sources for organic fertilizer due to its vast production (Aisueni and Omoti,1999). As with any production process, there is bound to be huge amounts of wastes produced. On going research with respect to the utilization of the wastes of the palm mills is already in motion with most of the other waste forms. Empty fruit bunch (EFB), palm press fibre (PPF), fresh fruit bunch (FFB), palm effluents (POME) have been used in different sectors including agriculture (Singh *et al*., 2010) with the exception of decanter cake (DC). There are several publications in this regard, however, to date there has been little/no evidence reporting the utilization of decanter cake alone for the enhancement of plant growth with regards to vegetables with the exception of Haron and Mohammed, (2008) who incorporated DC with inorganic fertilizers. This could probably be due to the acidic nature of the decanter cake as reported in previous studies (Singh.,2012, Razak *et al*., 2012, Sahad *et al*., 2014). Acidic soils are known to restrict root access to water and nutrients. Plants therefore show the tendency to exhibit deficiency symptoms despite adequate fertiliser application (Bolland *et al*., 2004).

The dosage ratio is however an issue of concern as excess amounts of nutrients will lead to problems such as leaching and ground water contamination, inhibition in plant growth, yield and subsequent death of plants (Yussuff *et al*., 2007). A study is therefore required to investigate the composition of decanter cake and its combinations with soil in comparison to other organic wastes in order to identify its effects on the test plants as indicators of growth and yield.

1.2 OBJECTIVES

The overall objective of this study was to evaluate the effects of decanter cake on the growth of lady's finger (*Abelmoschus esculentus*), tomato (*Lycopersicum esculentum*) and brinjal (*Solanum melongena)* as bio-indicators. The focus of the study was the utilisation of the waste rather than the production of an ideal fertilizer and the various responses of the test plants were analysed in comparison to other soil amendments.

The specific objectives of this research are:

1. To determine the effect of different ratios of DC: soil application on selected soil properties, plant growth characteristics, biochemical contents and yield of the selected plants.

2. To determine the nutrients accumulation pattern in selected plants under different treatments in plant parts: leaves, shoot and roots and scanning electron microscopic (SEM) studies

3. To compare the responses of decanter cake treatments in the selected plants based on shoot length, root length, leaf area, yield and biomass.

1.3 SCOPE AND LIMITATIONS OF THE STUDY

This study focuses on the feasibility of utilizing palm decanter cake as soil amendment for the growth of selected vegetable plants as a means of reducing environmental pollution and at the same time possibly playing a vital role in enhancing plant growth and soil properties. It does not focus on the production of an ideal fertilizer but rather on the possibility of being used as an amendment. Germination percentage was calculated at 4 days after sowing (DAS) to observe the responses of seeds to the nutrients present in decanter cake at the different ratios of mixing. Since this is not a phytoremediation study, uptake factors were calculated with the aim to measure the movement of metals from one part of plant to another. Lab scale experiments involved 3kg of soil in all the pots selected based on literature (Ekutudo *et al*., 2011and Fujimura *et al.*, 2012). All data were collected during similar conditions and timings. Focus of the study is on the nutrients and not heavy metals. SEM was carried out as both quantitative and qualitative tests with stomata cell area and photographs presented as representative indicators of presence of excess nutrients.

The three plants chosen for the experiments (lady's finger, tomato and brinjal) were selected because they are annual crops, easily available and they represent a large part of Malaysian diet. They serve as indicators of the plant growth and nutrient uptake.

1.4 CONTRIBUTIONS

This study provides novel research on the possibility of utilization of decanter cake via:

1. The response of lady's finger, tomato and brinjal seeds to the nutrient composition of decanter cake.
2. The responses of lady's finger, tomato and brinjal to growth, yield and biomass under the different ratios of decanter cake.
3. The Scanning Electron Microscopic studies on lady's finger, tomato and brinjal plants subjected to decanter cake ratios in soil.

It contributes to the knowledge bank on residue use in the palm oil industry and can act as a platform for further research towards technical, environmental, economic and social feasibility; as well as applicability of palm waste especially decanter cake in the palm oil plantation itself and on agriculture as a whole.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

Decanter Cake is one of the several waste residues obtained at the extraction phase of palm oil processing. This chapter deals with the review of palm oil production in the world, production processes and wastes produced at each phase. It also takes a look at the application of several other wastes as soil amendments and effects on test plants. A review about the factors and parameters being determined in this study is also presented and how they have been reported. A brief description of the test plants has been discussed as well as effects of pot size and volume on growth of plants and the use of Scanning Electron Microscopy to observe stomatal opening and measurement of area in order to relate to effects of organic wastes on plant leaf structure.

2.1 Palm oil production in Malaysia

Oil palm was introduced to Malaysia from Nigeria by the British colonialists in 1917. The Malaysian palm oil industry is a major revenue earner (around USD 7 biliion per annum in GDP) and is ranked as one of the largest producers in the world. However, growth of the industry is synonymous with a massive production of agro-industrial waste (Liew et al., 2015). According to Ng *et al*, (2012), 88.74 Mt of fresh fruit bunch (FFB) of oil palm was processed in 2011. Singh *et al.*, (2010) stated that *Elaeis guineesis Jacq*, has the highest production rate of the *Elaeis* genus with 10-35 tonnes of fresh fruit bunches produced from a hectare of oil palm per year.

Oil palm is a perennial tree crop with an average planting cycle of 25 years for efficient productivity. A stand of the tree covers about 0.0068 ha of land and each tree could yield about 150 kg of fresh bunches per year (Yusoff, 2004) and with proper care can produce effectively for over 20 years. Oil palm grows in the tropical plains with a uniform rainfall distribution (1,800–5,000 mm $year^{-1}$). Oil Palm can adapt in wide range of soils, but susceptible to high pH and stagnant water (Hartley, 1988). Globally, the rapid demand for edible oils in the recent past has resulted in the substantial increment of land area for oil crop cultivation, primarily oil palm and soybean (Yacob, 2008). As compared to soybean; an annual crop highly influenced by weather related changes, the oil palm is more stable as it can be harvested all year long with very low weather related risks. Oil palm are efficient producers of high-quality, versatile oils.

Total oil palm acreage in the world reached more than 16 M ha in 2011 (Zwart, 2013). In Malaysia alone, a total land area of 4.98 Mha was attained as of 2011 (MPOB, 2011), which covers approximately 73% of the agricultural land. Zwart, (2013) also stated that CPO production in 2011 reached 18.91 million metric tons (MMT). At present there are over 5 million ha of oil palm plantations in Malaysia replacing other agricultural crops like cocoa, rubber and coconut which in recent times have lost their market values (Zwart, 2013). Figure 2.1 shows the trend of some of the commercial crops in the past decade. Oil palm plantation in Malaysia had risen from 2.03 million hectares to 5 million hectares from 1990 to 2011, an increase of 146%. Meanhile the production of rubber, cocoa and coconut had declined in the recent years (MPOB 2012).

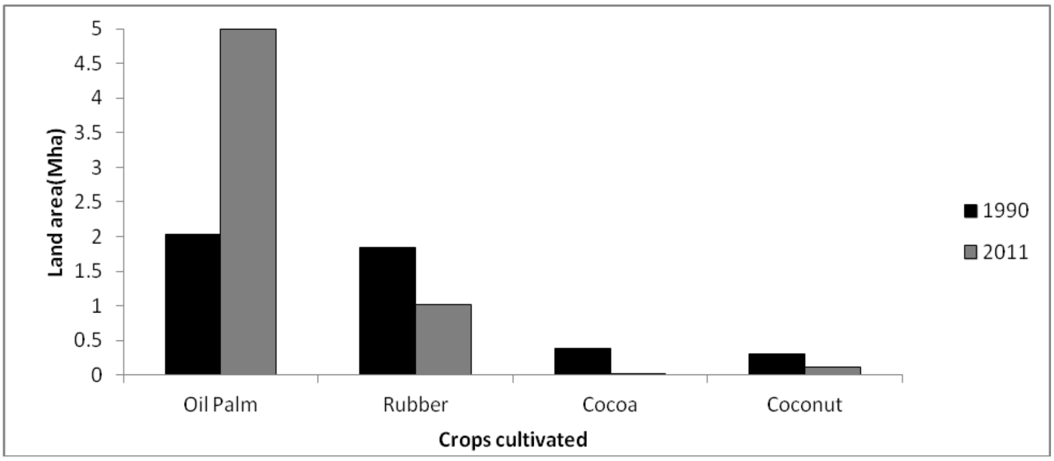

Figure 2.1: Changes in land use of selected crops in Malaysia (million hectares) Source: MPOB 2012.

Palm oil has a wide range of uses such as cooking oil, as ingredient in margarines and also used in most confectionaries. It is also used as base for most liquid detergents, soaps and shampoos and for lipstick, wax and other cosmetics in its dense form (Aisueni and Omoti (1999), Abdullah M. (2008), Rupani *et al*. 2012). Due to increasing demand for palm oil and its production, enormous quantities of wastes are generated every year. There is therefore an urgent need for sustainable management of oil palm production which if left un-attended will lead to several environmental problems. Research is on-going on the use of by-products as bio-fuels for the future (Singh *et al.* 2012). Composting and vermicomposting are other options for the management of these wastes because they are organic in composition. Owing to the rises in crude oil prices globally, palm oil is much sought after as an alternative for fuel (Abdullah and Sulaiman, 2013). It could be regarded as the "*Crop for the future*" because of its numerous uses. With this increase in demand, environmental management in the oil palm sector has become a pertinent issue today. The mills are most often located in the plantations and the prevailing practice is collecting the waste and dumping in the plantations itself in the most unscientific manner as excess nutrients may be harmful to both the growing plants and the ecology on the whole (Singh *et al*., 2011).

2.2 Palm oil processing

Fresh fruit bunches (FFB) are crushed to produce CPO (crude palm oil) along with other by-products. Oil palm is processed for two types of oils; the red palm oil from the fibrous mesocarp (40-50% of the FFB) and lauric oil/kernel oil obtained from the kernel [Dashiny (2009), Abdullah and Sulaiman, (2013)]. Kittikun *et al.*, (2000)] reported that kernel oil yield was about 40–50%. Potential yield oil from both mesocarp and kernel accounts for about 17 t ha^{-1} $year^{-1}$ (Corley 1983). According to Pleanjai *et al.*, (2004), about 1 tonne of crude palm oil (CPO) is produced from 5.8 tonnes of FFB. Fibre, shell, decanter cake and empty fruit bunch (EFB) account for 30, 6, 3 and 28.5% of the FFB, respectively (Pleanjai *et al.*, 2004). A schematic process flow of palm oil milling process is shown in Figure 2.2 and consists of the following steps: Sterilization, Stripping, Digestion, Crude Palm oil extraction, Nut/fiber separation and Nut cracking.

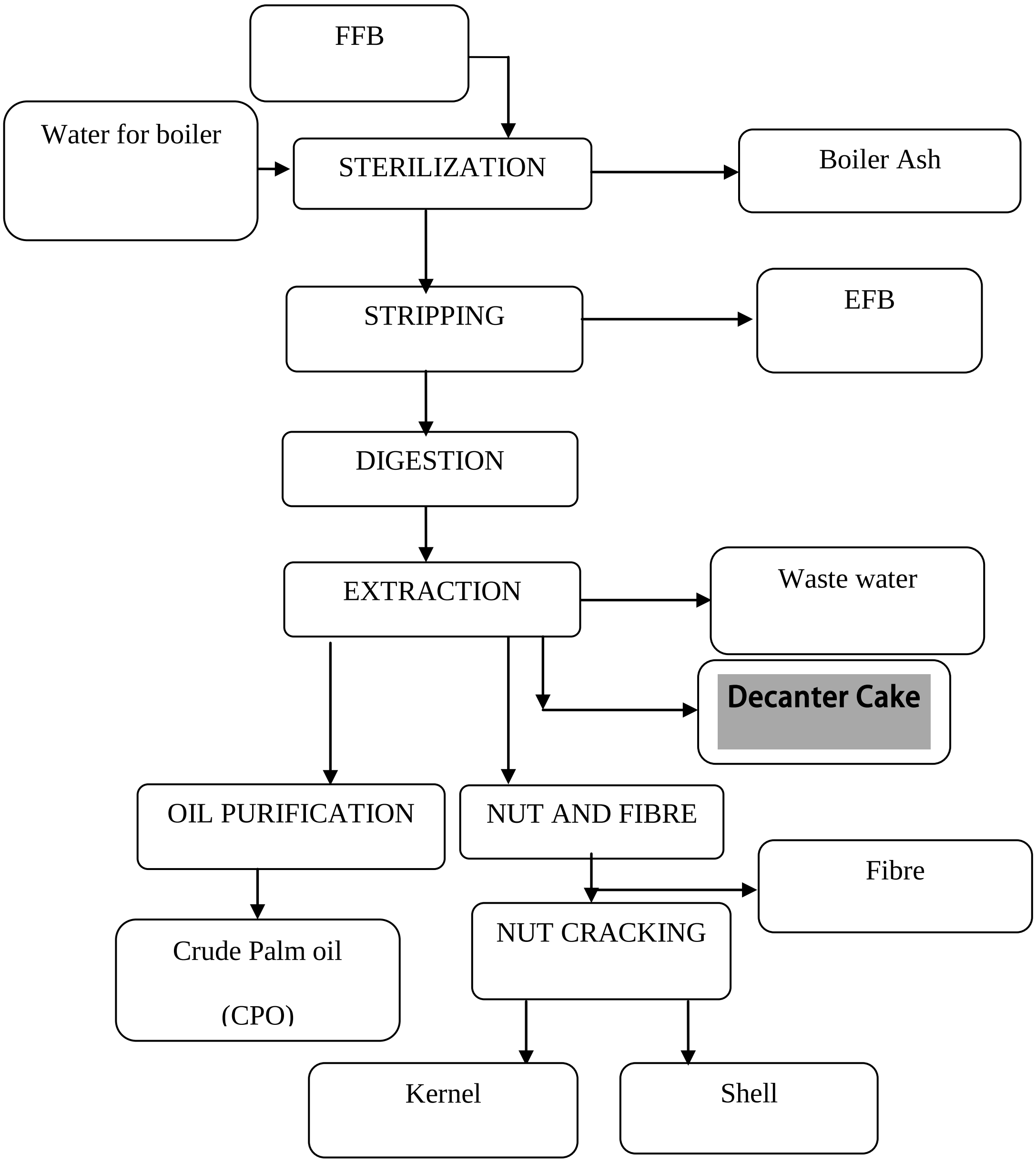

Figure 2.2: Stages in production of palm oil and the types of waste produced. Modified from (Dashiny, 2009)

2.2.1 Sterilization

This is the first stage in the extraction of crude palm oil. The FFB bunches are sterilized batch wise in an autoclave for about 2 h per batch at about 120-130^{0}C. This deactivates the hydrolytic enzymes responsible for the breakdown of oil to free fatty acids and to loosen the fruits from the bunches. The steam condensate generated from the sterilizer results as one of the major sources of wastewater (Thani *et al.*, 1999).

2.2.2 Stripping (threshing)

Stripping takes place after sterilization of FFB. The fruits are stripped by a rotary drum-stripper collected in a bucket conveyor and discharged into a digester. This stage results in the production of empty fruit bunches.

2.2.3 Digestion

Digestion involves the mashing up of the steamed and stripped fruits under steam conditions in a digester by its rotating arms (Singh *et al*., 2011) This results in the breakdown of the oil-bearing cells. Twin screw presses are used to squeeze out the oil from the digested mash of fruits under high pressure. To improve the flow of the oils hot water is added. No particular waste is produced in this step.

2.2.4. Crude palm oil extraction

This phase involves removing fine solids and water while the homogenous oil mash from the digester is passed through a screw press followed by a vibrating screen, a hydro-cyclone and decanter. Centrifugal and vacuum driers are used to further purify the oil before sending to a storage tank. The storage temperature is maintained at 60^{0}C with steam coil heating. Oil separation and purification is then done by passing through a clarification system (Singh *et al*., 2012). The mixture of various proportion of palm oil (35-45%), water (45-55%) and fibrous materials constitutes the crude palm oil (CPO) from the screw press. This is then pumped to a horizontal or vertical clarification tank to skim the oil from top of the clarification tank. It is then passed through a high speed centrifuge and a vacuum dryer before being sent to storage tanks. The main wastes produced in this step are wastewater and decanter cake (Singh *et al*., 2012).

2.2.5. Nut/fiber separation

The composition of the press cake discharged from the screw press is moisture, oily fiber and the cakes which are then conveyed to a depericarper for the nuts and the fiber separation.(Thani *et al.*, 1999) The fiber is usually sent to the boiler house to be used as boiler fuel. The next step is sending the nuts to a rotating drum to remove the remaining fibers.

2.2.6 Nut cracking

Cracking of the nuts take place in a centrifugal cracker or hydrocyclone. Through clay suspension the kernels and shells are separated after the cracking process. The last source of waste water stream comes out from this process (Chow and Ho., 2000). The separated shells from the kernels are sent to other mills as fuel and the kernels are sent to a silo dryer for further processing to kernel oil.

2.3 Palm oil mill wastes and applications.

Empty fruit bunch (EFB) are the residues left after the processing of fresh fruit bunch (FFB) at the mill which are suitable material for recycling. In 2014, approximately 19.8 million tonnes of EFB was predicted to be generated in Malaysia (Ishak *et al*., 2014). Studies have involved the composting of EFB with organic manure in order to add value and reduce mass. This has proved to be more effective on the soil when compared to using EFB alone (Prasertsan and Prasertsan, 1996). The use of EFB for the cultivation of mushrooms is due to its cellulose (45-50%), hemicellulose and lignin contents (Deraman 1993). A closer look at the properties of EFB, shows that it could be used for coir fibre, fibre board and tiles just as coconut is used in India.

Palm Press Fibre (PPF) or mesocarp fibre is produced after pressing fruit or mesocarp to obtain oil. On an average, for every tonne of FFB processed, 120 kg of fibre is produced (Astimer *et al*., 2002). Pressed fibre is a good combustible material because of the oil content whereas the shells can be used as fuel to generate steam and energy required for operation of mill, but now not in use because of pollution concerns. PPF ash contains 1.7- 6.6% P, 17- 25% K, 7% Ca which indicate that PPF is a good source of minerals to plants. Palm fibres are versatile and stable and can be processed into various dimensional grades to suit specific applications such as mattress cushions, erosion control, soil stabilization/compaction, landscaping and horticulture, ceramic and brick manufacturing, thermoplastic filler, flat board manufacturing, paper production, acoustics control, compost, fertilizer, animal feed, etc. (MPOB 2012)

Palm kernel shell (PKS) is the most difficult waste to decompose. It is another by-product that can be used for mulch purposes (Hamza *et al*., 2015). 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 the possibility of 20.3% fixed carbon which is similar to coconut shell. Activated carbon can be used for decolourisation of dark coloured effluent of the mills Ortiz *et al*. (1992).

Palm kernel cake (PKC), sometimes referred to as palm kernel expeller (PKE) is of a grayish white colour. Saw *et al*., (2008) stated that PKC is regarded as the most useful by-product among the various by-products produced in the palm oil industry. It is an outcome of a mechanical extraction process to produce kernel oil. It is rich in carbohydrate (48%) and protein (19%) and suitable as feedstock (Kolade *et al*., 2005).

Oil extraction, washing and cleaning processes in the mills is the main source of POME thus contains fats, oil and grease. It is said to be the main source of environmental pollution (Schuchardt, 2008). About 3 tonnes of POME is produced for every tonne of oil extracted in an oil mill. 24.9 million tonnes of crude palm oil had been produced in 2012, resulting in 5547.4 million tonnes of POME (Global Green Synergy, 2012). It contains high percentages of carotene, an antioxidant which protects the cells against the effects of free radicals (Abdullah M, 2008). Carotenes possess anti-cancer properties, enhance immunities, prevent blindness and skin disorders. Pharmaceutical industries are therefore very keen on the extraction of carotene from the mill effluent. Adsorption chromatography is adopted to recover the carotenes present in the oil. The pollution potential of the effluent is also reduced when oil and grease is removed.

Palm Oil Fuel Ash **(**POFA) is produced when the solid wastes of the mill are used as fuel to generate electricity. It is an agricultural solid waste that is being produced abundantly in Malaysia and Thailand. Utilization of POFA as a source of siliceous material for the synthesis of adsorbent for flue gas desulfurization has been studied (Schuchardt, 2008). It is very unmanageable due to its minute particles and most times it is disposed off in landfills resulting environmental and health hazards. Table 2.1 summarizes the various palm oil mill residues and reported use in the industries and for agriculture.

2.3.1 Decanter Cake (DC)

Oil palm decanter cake is a brown-blackish paste (Appendix II) obtained in the extraction phase of processing for palm oil (Seephueak *et al*, 2011)(Figure 2.2). Most of the solid in the final effluent is decanted in a decanter and passed to a filter press before being dried in a rotary dryer (Devendra *et al.*, 1981). Haron and Mohammed (2008) reported that a mill with 90 t hr^{-1} FFB processing capacity will produce about 160-200 tonnes of DC per hour. Afdal *et al*., (2012) reported that decanter cake consists of 12.63% crude protein, 7.12% ether extract, 25.79% crude fibre, 0.03% calcium and 0.003% phospohorus respectively. The fatty acids (FA) components of DC are usually palmitic, oleic, linoleic, stearic and myristic acids (Afdal *et al.*, 2012). Table 2.1 indicates the various palm wastes produced in the mill and its different uses.

Table 2.1 Table presenting the various palm oil mill residues, their uses in industries and agriculture.

No.	Type of palm waste residue	Uses
1	Fronds, trunks and leaves	-Used as mulching material in the fields which helps in moisture retention. -Roofing material and processed as furniture.
2	Empty fruit bunch(EFB)	-Generating steam for the mills and ash residues used as fertilizer.(Lim, 2000) - As raw material for products such as paneling, composites, fine chemicals, pulp and paper as well as compost and bio-fertilizer [RamLi *et al*., 2002] - Main substrate for the cultivation of (oyster mushroom (Tabi *et al*., 2008)
3	Palm press fibre (PPF)	-substrate for animal feed in addition to soymeal, fishmeal. Potting material for ornamental plants to improve foliar growth(Yusoff, 2004) -Used for making fibre boards.(RamLi *et al*., 2002) -Polymeric composites for building materials referred to as AGROLUMBER for products like wall panels, sub-floors, doors and furniture parts. (MPOB, 2009)
4	Decanter cake (DC)	-Used in combination with inorganic fertilizer to improve soil quality on palm plantations (Haron and Mohammed, 2008) -Utilization of oil palm decanter cake for cellulase and polyoses production (Razak *et al* ., 2012) Feed for goats (Gafar *et al*., 2013) Production of natural polymer composite (Adam *et al.*, 2014)
5	Palm kernel cake (PKC)	-Suitable as feedstock because it has 48% carbohydrate and 19% protein (Kolade *et al*., 2005).
6	Palm kernel shells (PKS)	-Used mainly for fuel. (Paepatung *et al*., 2006) -Converted into activated carbon for water purification purposes(Ortiz *et al*., 1992)
7	(POME)	-Mainly used for Irrigation purposes -Carotenes are extracted from POME by pharmaceutical industries(Wood and Lim., 1989)

Reports show that most decanter cake is used as fertilizer and soil cover materials (mulch) in oil palm plantation area or biogas production (Chavalparit *et al.*, 2006; Paepatung *et al.*, 2009), while its utilization in animal feed is minimal. Bamikole and

Babayemi (2008) reported that the sludge has good potential as feed and could be directly used in ruminant feeding as an energy source. Anwar *et al.*, (2012) stated that DC is a valuable and potential by-product that can be utilized as an alternative energy and protein source for rearing goats.

Decanter cake composition has been studied by a number of researchers however with respect to plant growth studies, literature remains limited. Haron *et al*., (2008) reported that DC is made up of 2.42% Nitrogen, 0.51% Phosphorus, 1.24% Potassium, 0.54% Magnessium and 1.68% Calcium. In another study by Sahad *et al*., (2014), elemental composition of DC revealed 43.73% of Carbon, 2.93% of N, 0.41% of P, 2.73% of K, 0.62% Mg and 2.1% Ca.

2.4 Effects of application of organic wastes on soil and plants

The safe disposal of organic wastes is an environmental concern worldwide (Singh 2008). Managing solid waste is a huge task for industries as a large area of land is needed to dispose these wastes. It would also result in ground and surface water contamination, pathogens and odour problems (Singh 2008, Rupani *et al*., 2012). Most frequently adopted disposal options are landfilling, indiscriminate dumping at sea, soil application and incineration (Sanchez Monedero *et al.*, 2004; Singh and Agrawal, 2008). The application of agricultural wastes have various effects on soil physico chemical properties and biological properties. The role of bacteria and fungi in the breakdown of organic wastes have been reviewed in 2.4.1. The effects of organic wastes on soil properties and on growth characteristics and indices are in 2.4.2 and 2.4.3 respectively. The choice of test plants and the nutrient contents and uptake of metals by plants is at 2.4.4 and 2.4.5 respectively.

2.4.1 Role of bacteria and fungi in breakdown of soil organic matter.

Soil organic matter is degraded aerobically via activities of successive group of microorganisms. This is often referred to as composting. It is an environmentally sound way to minimize organic wastes and simultaneously producing organic fertiliser or soil conditioner (Gajdos, 1992). Soil itself is a highly complex system in which organisms, such as algae, bacteria, fungi, protozoans, insects, mites and worms, are linked by complex ecological interactions (Neeraj 2011). The diversity of soil bacteria and fungal communities is influenced by agricultural management (Zaccardelli *et al.*, 2013). Soil microorganisms play vital roles in the transformation of organic matter into soil nutrients and processes such as the decarboxylation of manures cannot take place without the presence of microorganisms (Neeraj 2011). Brady and Weil (2002) also mentioned that soil porosity, aggregation and structure as well as the decomposition of organic matter and mineralization are controlled by the biological compositions of soil. Microbes are able to retrive nitrogen from the soil more easily than the plants. This would mean that when there is insufficient N for the soil organisms, the plants will most likely be deficient in N (Neher *et al.*, 2013). The addition of soil amendments or fertilizers will augment the quantity of N (as well as other nutrients) accessible to plants via improved microbial activity thus leading to increased microbial density. Adding organic matter could also intensify earthworm activity, which in turn can also improve soil aggregation.

Bacteria are important in agricultural soils because they contribute to the carbon cycle by fixation (photosynthesis) and decomposition (Rebollido *et al* 2008). Some bacteria are important decomposers and others such as actinomycetes are particularly effective at breaking down tough substances such as cellulose (which makes up the cell walls of plants) and chitin (which makes up the cell walls of fungi). Land management influences the structure of bacterial communities as it affects nutrient levels (Bot and Benites, 2005). Bacteria species commonly found in organic soils are *Staphylococcus aureus, E. Coli, Psuedomonas spp, Bacillus spp* and a host of others.

Soil fungi are involved in processes related to the recycling of nutrients, plant growth and health (Christensen, 1989; Pierzynski *et al.*, 2000). These include decomposition of organic matter with release of soluble nutrients (Pierzynski *et al.*, 2000; Frey *et al.*,2003), solubilization of nutrients from minerals (Asea *et al.*, 1988), translocation of elements and nutrients within the soil profile and from soil to plants (Christensen 1989), uptake of nutrients and incorporation into the fungal biomass (Frey *et al.*, 2003), creation of secondary soil structure (Pierzynski *et al.*, 2000; Frey *et al.*, 2003), and production and suppression of disease in plants (Weller *et al.*, 1988; Englehard 1989). Therefore, factors that affect populations and activities of fungi in soil may significantly affect soil productivity and environmental quality. Fungi utilise many carbon sources, mainly ligno-cellulosic polymers and can survive in extreme conditions. (Miller 1996). Fungi affect soil fertility, suppress plant diseases and promote mushroom growth (Straatsma and Samson 1993). They also degrade complex polymers such as polyaromatic compounds or plastics and are applied to bio remediate soils contaminated with a wide range of pollutants (Kastner and Mahro 1996, Eggen and Sveum 1999, Minussi *et al* 2001). Fungal species common to composting materials belong mostly to the *Aspergillus, Cladosporium and*

Penicillium, genera, due to their thermo-tolerance or ability to degrade a wide range of organic waste (Miller 1996).

Florian and Hafeel (2004) in their review noted that a high proportion of both fungi and bacteria are decomposers in the soil which degrade plant residues differently and have various functions in the recycling of nutrients. This is partly due to their different choice of habitats within the soil and the different types of organic matter they consume (Florian and Hafeel 2004). Fungi are generally much more efficient at assimilating and storing nutrients than bacteria (Blagodatskaya and Kuzyakov 2013) because they are composed of polymers of chitin and melanin, making them very resistant to degradation. Bacterial membranes, on the other hand , are phospholipids, which are energy-rich. They degrade easily and quickly and function as a food source for a wide range of microorganisms (Blagodatskaya and Kuzyakov 2013). Bacteria and fungi play prominent roles in the mineralisation processes of nutrients in the soil (Neher *et al*., 2013). Fungi needs greater amount of carbon to grow and reproduce whereas bacteria requires more nitrogen both of which are obtained from the soil organic matter.

2.4.2 Effects of organic wastes on soil properties

Recently, a number of research has been focussed on using organics as soil amendments. Organic substrates (i.e the physical and chemical properties) have been said to be accountable for providing nutrients and support. (Akca and NamLi 2015). Organic wastes in general are reported to improve soil physical, chemical, and biological properties; including soil structure, nutrient availability, and water and nutrient retention and increases plant growth (Glaser *et al*., 2002; Lehmann and Rondon 2005, Akca and NamLi 2015). This would depend on the plants ofcourse as each plant has varying nutrient requirements. In a recent study, a mixture of green waste compost, sedge peat, and furfural residue (1:1:1 v/v) significantly reduced Na content but improved EC and the contents of available N, P, and K (Wang et al., 2014). Table 2.3 summarizes various findings with respect to the use of organic wastes as soil amendments.

2.4.3 Plants for growth experiments

The choice of plants for any growth experiment is mostly dependent on the aim of the experiment. Several studies have utlized a wide range of plants based on rooting, fruiting, flowering, girth, leaf size, short term or long term crops etc. Table 2.2 describes a number of experiments carried out on various plants. Plants like tomato, lady's finger and brinjal are one of the most common pot based vegetable crops used for plant growth studies (Adjei-Nsiah and Obeng., 2013). They are short term crops that grow, flower and fruit in one cycle. Thus is easy to observe and monitor within this period. Using crops like maize would not be suitable due to its fibrous root system and unsuitable for pot size experiments(Mollier and Pellerin,1998). The physiology of the three plants used in this study are described in the subsequent sections.

2.4.3.1 Lady's finger (*Abelmoschus esculentus* L.)

Lady's finger is a fruit vegetable. It is also known as okra in some countries. It is an annual crop and a very common vegetable in Malaysian dishes. It tolerates a wide range of soils types. Plants are upright, green and have many branches. Leaves are green coloured, palmate shaped and have alternate arrangements. Petiole is green or reddish. Flowers are large, yellow petals with dark red color in the middle. NPK requirements are 10-10-10. Plants can attain maximum height of 1.0 - 2.0 m and maturity at 50-55 days after sowing. Fruits are green, angular shaped and hairy and estimated yield is 10,000 - 15,000 kg/ha. (Ministry of Agriculture, Penang Malaysia, 2013).

2.4.3.2 Tomato (*Solanum lycopersicum*)

Tomato is typically served as part of a salad or main course of a meal and is considered a vegetable for most culinary uses. The plants typically grow to 1–3 meters (3–10 ft) in height and have a weak stem that often sprawls over the ground and vines over other plants. An average common tomato weighs 102–105 g. The leaves are 10–25 centimetres (4–10 in) long, odd pinnate, with five to 9 leaflets on petioles. Tomato plants attain maturity in about 45-60days after pollination (Ministry of Agriculture, Penang Malaysia, 2013). Tomato requires the standard NPK fertilizer in the ratio 10: 10:10 or 5:10:10.

Table 2.2 Studies on the effect of different waste amendment ratios on growth and yield of plants

Type of Waste And Amendment	**Plants**	**Effect on growth & Yield of Plants**	**References**
Flyash @5-10% w/w in pots	Broad bean	Increase in pH and EC, lower application of FA enhanced seed germination and seedling growth.	Singh *et al.* (1997)
SewageSludge@0,25,100w/w	Cucumber	Emergence percentage was highest in the 100w/w ratio.	Onder *et al.* (2000)
Tannery sludge+straw+ cattle manure @0,25, 50,75 100 %	Capsicum	Significant increase in leaf number, fruits, stem length and chlorophyll content. Also led to higher length and chlorophyll content.	Silva *et al.* (2000)
Sewage Sludge @ 0, 10, 20, 30, 40,50t/ha dry weight	Maize	Increase in germination with increasing amendment rate. Maximum root and shoot lengths at 20t ha^{-1}.	Qasim *et al.* (2001)
Olive mill wastes@10,30 and 50% amendment ratio	Lettuce	Improved seed emergence but reduced fresh weight	Kelepsei and Tzortzakis(2009)