APPLICATION OF OIL PALM EMPTY FRUIT BUNCH (OPEFB) – TREATED PALM OIL MILL EFFLUENT (POME) SLUDGE PELLET ON SOIL EROSION AND ITS IMPLICATION ON SIMULATED EXPERIMENT

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by

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Yazan Khalaf Ali Almanasir

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LIST OF SYMBOLS

cm	Centimeter
ft	Feet
gpm	Global precipitation measurement
g	Gram
kg	Kilogram
ha	Hectare
L	Liter
Mpa	Megapascal
m	Meter
µm	Micrometer
mBar	Millibar
mg	Milligram
mL	Milliliter
mm	Millimeter
NTU	Nephelometric turbidity units
psi	Pound-force per square inch
ft^2	Square feet
tons	Tonnes
w/w	Weight by weight
SDGs	Sustainable Development Goals

LIST OF ABBREVIATIONS

C	Carbon
Ca	Calcium
CPO	Crude palm oil
DO	Dissolved oxygen
FFB	Fresh fruit bunch
-OH	Hydroxyl group
K	Potassium
Mg	Magnesium
N	Nitrogen
OPA	Oil palm ash
OPEFB	Palm oil empty fruit bunch
P	Phosphorus
PO_4^{-3}	Phosphate
USM	Universiti Sains Malaysia
H_2O	Water
PO	Palm Oil
EMS	Environmental management systems
WHO	World Health Organization
BOD	Biological oxygen demand
COD	Chemical oxygen demand
LCC	Leguminous cover crops
DOE	Department of environment
CH_4	Methane
TDS	Total dissolved solids
EC	Electrical conductivity
PCA	Principal component analysis
GNI	Gross national income
GDP	Gross domestic product

OPT	Oil palm trunks
OPF	Oil palm fronds
MET	Malaysian meteorological department

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ABSTRAK

Sisa efluen kilang kelapa sawit (POME) dan tandan kosong kelapa sawit (OPEFB) adalah merupakan dua sisa utama lignoselulosa yang terhasil daripada proses pembuatan minyak sawit yang kini telah menjadi isu dalam pengurusan sisa industri. Pada dasarnya, proses kitar semula adalah merupakan salah satu daripada hierarki pengurusan sisa buangan. Memandangkan penggunaan kedua-dua sisa tersebut adalah berpotensi sebagai penutup bumi dalam sesebuah kawasan tadahan, justeru kajian lanjut berkenaan kesan aplikasi terhadap kualiti air adalah amat penting. Kajian ini mempunyai tiga objektif; (1) menentukan kadar penyerapan air dan sifat pembengkakan ketebalan palet OPEFB-POME. (2) menilai tahap keberkesanan penggunaan palet OPEFB-POME bagi mengurangkan hakisan tanah. (3) mengkaji kesan penggunaan palet OPEFB-POME ke atas kualiti air. Fokus kajian ini adalah terhadap keberkesanan penggunaan campuran sisa POME terawat dan tandan sawit kosong (OPEFB) sebagai penutup bumi terbiodegradasi menggunakan plot simulasi hujan bersama penentuan penggunaan jumlah pellet dalam plot khas, 0 g/ ft2, (T1), 154 g/ ft2, (T2), 310 g/ ft2, (T3), 465 g/ ft2 (T4), and 620 g/ ft2, (T5). Kajian ini diikuti oleh penilaian kualiti air, di mana kandungan oksigen terlarut (DO), kadar kemasinan, suhu, kadar kekeruhan, nilai pH, kekonduksian elektrik (EC),

jumlah pepejal terlarut (TDS), jumlah keperluan oksigen kimia (COD) dan fosforus (P) akan dianalis menggunakan ANOVA sehala dan Analisis Komponen Prinsipal (PCA). Kadar penyerapan air dan pembengkakan ketebalan palet telah dinilai mengikut ASTM D-1037-99 sebelum pelaksanaan ujian simulasi yang telah ditetapkan. Cadangan telah menunjukkan bahawa palet-II (OPEFB-POME 40:60 ratio) mempunyai kestabilan dimensi yang lebih baik. Peningkatan penggunaan jumlah palet akan menambah baik kadar kekeruhan dalam sampel air, walaubagaimanapun, keputusan ujian tersebut telah menunjukkan nilai kekeruhan ($p<0.05$) yang ketara serta kemerosotan kualiti air (fosforus yang ketara, kadar kemasinan, kadar kekonduksian, TDS, dan COD) dalam kedua-dua plot T1 dan T5, justeru, menyarankan bahawa jumlah penggunaan palet ke atas tanah perlulah terkawal bagi mengurangkan risiko kemerosotan kualiti air. Justeru, palet OPEFB-POME yang berjumlah 154 g/ ft^2 (T2) adalah disyorkan sebagai penggunaan penutup tanah yang sesuai dalam memberi kesan yang minimum terhadap kualiti air.

APPLICATION OF OIL PALM EMPTY FRUIT BUNCH (OPEFB) – TREATED PALM OIL MILL EFFLUENT (POME) SLUDGE PELLET ON SOIL EROSION AND ITS IMPLICATION ON SIMULATED EXPERIMENT

ABSTRACT

Palm Oil Mill Effluent (POME) sludge and Oil Palm Empty Fruit Bunches (OPEFB) are two major by-products of lignocellulosic biomass and now become a major disposal problem. Fundamentally, recycle is one of the waste management hierarchy. Given the fact that potential utilization of both by-products in soil management within the watershed, hence, it warrants further investigation on possible implications of the water quality of the adjacent water bodies. This study has three objectives; (1) To determine the water absorption and thickness swelling behaviours of the OPEFB-POME pellets. (2) To evaluate the effectiveness of plot OPEFB- POME pellets application for soil erosion mitigation. (3) To investigate the effect of the plot OPEFB-POME pellets application on the water quality. Hence, the focus will be on the effectiveness of blended treated POME sludge and OPEFB pellets as biodegradable soil cover using rainfall simulator with different amount of pellets applied in the specific plot, 0 g/ ft^2, (T1), 154 g/ ft^2, (T2), 310 g/ ft^2, (T3), 465 g/ ft^2 (T4), and 620 g/ ft^2, (T5). These experiments followed by water quality assessment, where dissolved oxygen (DO), salinity, temperature, turbidity, pH, electrical conductivity (EC), total dissolved solids (TDS) chemical oxygen demand (COD) and phosphorus (P) are analysed. Statistical analysis i.e., ANOVA one-way and Principle Component Analysis (PCA) were used to provide quantitative analysis of this study. Note, water absorption and thickness swelling of the pellets are measured according to ASTM D-1037-99 prior to rainfall simulator testing. It is suggested that pellets-II (OPEFB-POME 40:60 ratio) has a better dimensional stability. Increase the amount of pellets application will improve the turbidity value in water

samples, however the results show significant ($p<0.05$) turbidity values and water quality deterioration (significant P, salinity, conductivity, TDS, and COD) in T1 and T5, respectively, suggesting the amount of the applied pellets on soil must be controlled accordingly to avoid significant water quality deterioration. Hence, the OPEFB-POME pellets with the amount of 154 g/ ft^2 (T2) are recommended for soil cover application to reduce turbidity with minimal impact on the water quality.

CHAPTER 1
INTRODUCTION

1.1 Background

Oil palm has been cultivated commercially in Malaysia since 1917. The oil palm processing industry is playing a key role in the economic growth of the country by contributing significantly to the gross domestic product (GDP), gross national income (GNI) and foreign exchange (Nambiappan et al., 2018). In 2017, the total export revenue raised sharply to RM 77.85 billion as compared to the RM 67.92 billion during 2016 (Kushairi et al., 2018). Sustainability of the palm oil industry has made as the key area of economic growth of Malaysia and also of South East Asia (Krishnan et al., 2017).

The industry has led to waste management issues in Malaysia. The palm oil processing steps are summarized in Figure1.1. The components of waste generated from palm oil industry are in the form of mesocarp fibre (12%), empty fruit bunch (EFB) (23%), kernel shell (5%), and mill effluent (POME) (60%) (Baharuddin et al.,2010), where POME sludge and empty fruit bunch (OPEFB) appear as two major wastes generated from palm oil processing plants (Figure1.2) (Nyakuma et al., 2019).

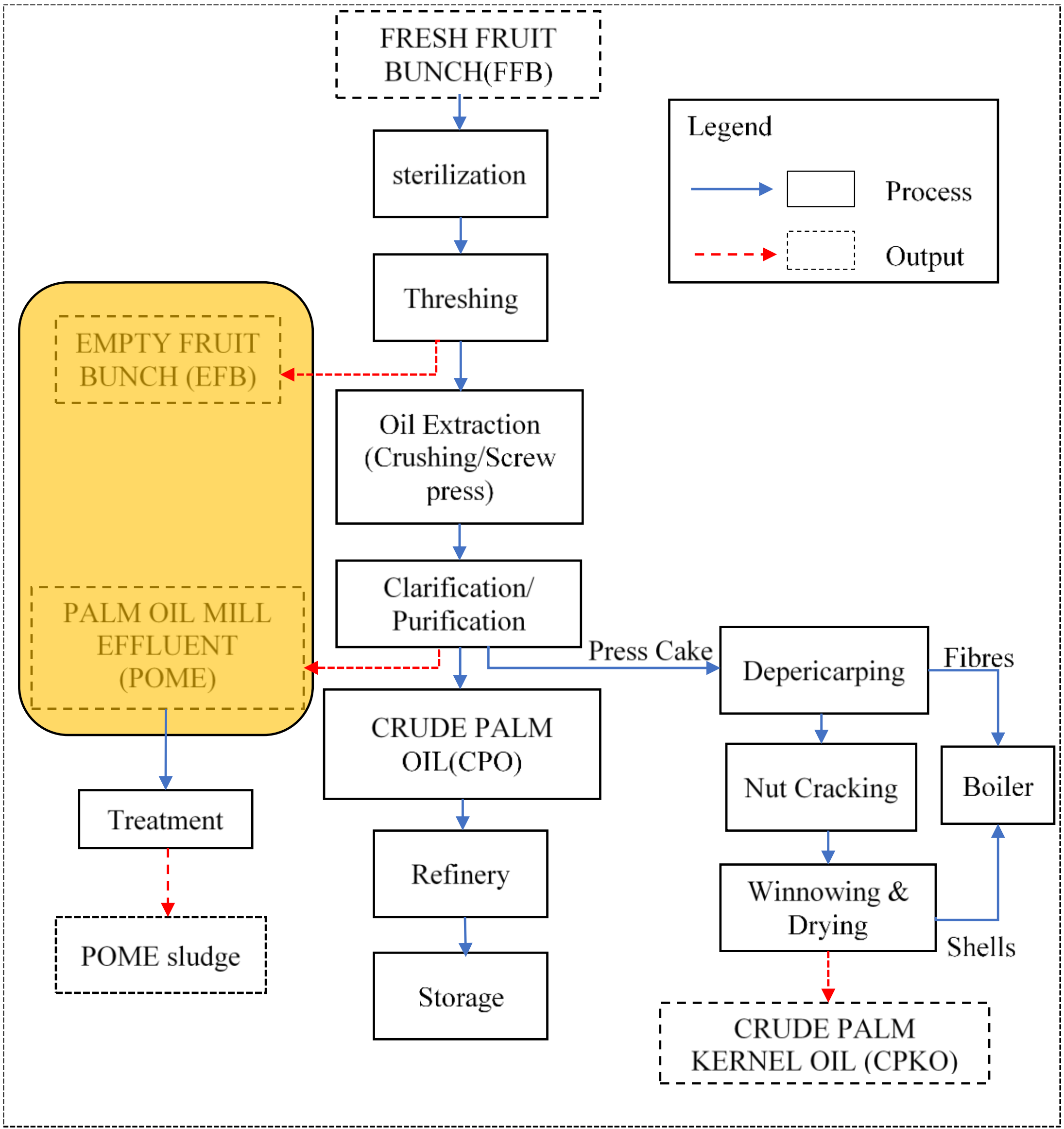

Figure 1.1: Palm oil process

According to Khairuddin et al., (2016) dried POME sludge could be employed as a fertilizer because of its high mineral contents such as potassium (5.16%), calcium (2.55%), phosphorus (1.25%) and magnesium (1.41%). Drying is mostly practiced in the open ponds, however, this process becomes tedious and impractical due to the higher moisture and slow rate of drying due to tropical climate factor (rainy season) (Zainudin et al., 2017).

Figure 1.2: Oil palm empty fruit bunch (OPEFB) (A) and palm oil mill effluent (POME) sludge (B)

In the case of OPEFB, it is generally incinerated to obtain potash rich ash for agricultural application as a fertilizer to various crops. However, the burning of OPEFB is no longer acceptable as common practice in the industry because of strict act on controlling air pollution. Unlike other waste by-products i.e. POME and decanter cake slurry, OPEFB could be utilized as mulch without any further treatment (Baharuddin et al., 2009). Nonetheless, high costs for transportation and distribution is part of challenges in applying the OPEFB as mulching material (Yahya et al., 2010).

Rich in cellulose and hemicellulose, OPEFB has received greater attention as a cheaper biodegradable material. In addition, its excellent hydrophilic nature has made it an ideal biodegradable material for soil cover application. In this context of study, the POME sludge is selected as biodegradable matrix for OPEFB to bind the physical structures of resultant bio- composite. POME sludge is considered as a good fertilizer due to its ability to improve soil structure amelioration and deliver macro (e.g., nitrogen, phosphorus, potassium) and micro nutrients (e.g., iron, manganese, zinc, copper) (Khairuddin et al., 2016).

The utilization of bio-composite (OPEFB- POME sludge) as a soil cover in oil palm plantation can be an alternative approach to the conventional OPEFB-based mulch (figure1.3). Such alternative application could minimize the cost of OPEFB transportation and make the soil cover application more effective i.e the pellet size enable for suitable spots selection for soil cover application, either in the terrace or flat land. Hence, the use of pellets will help the industry to minimize the volume of OPEFB and POME sludge waste generation, in line with Sustainable Development Goals (SDGs), sustainable production & consumption as emphasized during Roundtable on Sustainable Palm Oil (Tan et al., 2010). In fact, the pellets could emerge as a good raw material for possible use as fertilizer by creating a win-win scenario for sustainability through a circular economy approach (Figure 1.4) (Baharuddin et al.,2010).

Figure 1.3: Oil palm empty fruit bunches (OPEFB) applied as mulch in palm oil plantation (A) (Source from: Bakar et al., 2011) and pellets (B)

In this study, the biodegradable pellet is developed from OPEFB-POME sludge by blending in different ratios of OPEFB-POME sludge to investigate its dimensional stability i.e. water absorption and thickness swelling. Knowledge on OPEFB-POME pellet dimensional stability is important for rainfall simulation setting, so the pellet will be tested on its effectiveness as soil cover, followed by its implication on water quality. Results from these experiments provide a better idea on the effectiveness of OPEFB-

POME pellets as a biodegradable and environmentally friendly material for soil cover application.

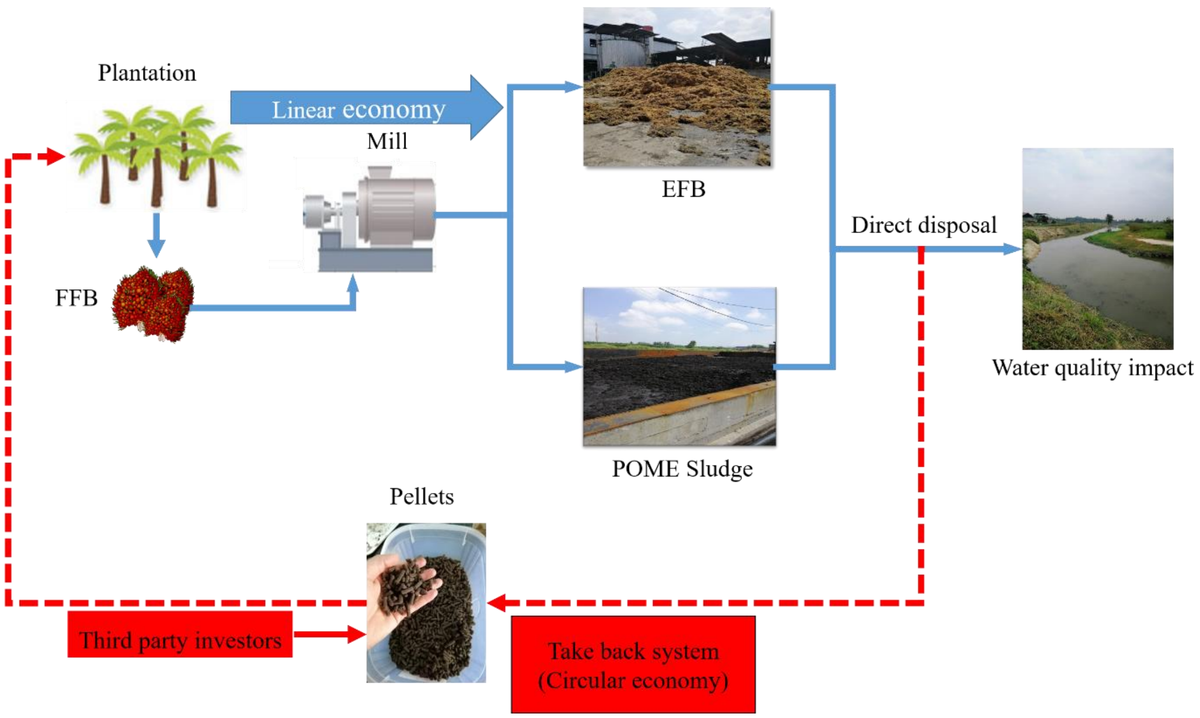

Figure 1.4: circular economy approach

1.2 Problem statement

Malaysia is among the largest exporter of palm oil with the ever-rising demand of vegetable oil along with production of biodiesel and other oleo-chemicals (Khatun et al., 2017). On the other hand, high production of palm oil is resulting in massive production of waste. Palm Oil mill effluent (POME) and Oil Palm Empty Fruit Bunches (OPEFB) with respective production of 1.8 Mt and 19 Mt are the major by-products waste (Hau et al., 2020). These by-products may have undesirable environmental impacts (water and air pollution) if no proper planning of waste management (Chinyere et al., 2018).

In the past, OPEFB has been employed as fuel for steam generation at palm oil mill and where the ash from combustion is rich in potash of which is useful as fertilizer.

However, the incineration and landfill disposal of OPEFB were ceased under the Environment Quality Act 1974 (Baharuddin et al., 2011; Hau et al., 2020). Therefore, the OPEFB has been employed as soil mulching in oil palm plantations as an alternative approach in managing the by-product. However, the conventional mulching of OPEFB is laborious due to high volume, weight and sizes, thus, imposed high cost of OPEFB transportation (from mill to estates). Moreover, longer degradation time of OPEFB also poses other risks i.e. harbouring the rodents and reptiles (Hamzah et al., 2018). OPEFB also contains cellulose, hemicellulose and lignin, with cellulose having the greatest proportion (65%) and therefore offers the best prospects to be an effective reinforcement polymer in the pellets.

The POME sludge is sun dried in open pond and later employed as organic fertilizer. Nonetheless, bad smell, nutrient leaching and sludge flooding during the rainy season will result in environmental pollutions i.e. water pollution etc. Today, researchers are still looking for cost-effective yet sustainable innovations to address the issues of POME management (Zainudin et al., 2017). Recycling of the by-product is one option towards eco-friendly production of palm oil industry (Chiew & Shimada, 2013). The lignocellulose component found in POME sludge might be used as a pellet matrix. Furthermore, POME sludge is high in nutrients including potassium, phosphorus, calcium, and magnesium, which are all beneficial to soil fertility (Baharuddin et al., 2010).

For this reason, this study is to explore production of blended OPEFB and treated POME sludge in a small pellet form as an alternative to current OPEFB mulching approach in oil palm estates. Note, the effect of the pellets on water quality during the soil mulching application will be investigated too.

1.3 Research Questions

Given the fact of OPEFB-POME pellets potential as an alternative to current mulching practices in oil palm estates, here are the list of research questions as a guideline to set the scope of study:

a) What are the water absorption and thickness swelling percentages of the OPEFB-POME pellets?

b) How do the pellets regulate the soil erosion under the simulated rainfall intensity?

c) What is the impact of OPEFB- POME pellets application on soil to water quality?

1.4 Research Objectives

The main motivation of this study is to evaluate the effectiveness of the proposed application of OPEFB-POME pellets on soil as part of green management practices in oil palm estates. Three objectives have been determined as below:

a) To determine the water absorption and thickness swelling behaviours of the OPEFB-POME pellets.

b) To evaluate the effectiveness of plot OPEFB-POME pellets application in controlling soil erosion under simulated rainfall intensity.

c) To investigate the effect of the plot OPEFB-POME pellets application based on lab simulation setup on the water quality.

1.5 Hypothesis

Hypothetically, OPEFB fiber and POME sludge are proved to have high water absorption capacity owing to the presence of cellulose containing free hydroxyl groups in both materials. This study used hydrophilicity in both the reinforced and matrix materials because they are highly potential in the purpose of mitigating soil erosion in order to reduce the effects caused by its direct discharge to the surrounding environment. Remarkably, the unique hydrophilic property of these natural materials plays an important role in absorbing, retaining and releasing the impact of raindrops and water, in a gradual manner upon degradation (Syakir et al. 2016). Such a mechanism will stabilize the soil and improve the turbidity value in water body.

Moreover, when runoff occurs, nutrient loads in the waterways will increase as a result of the application of pellets as soil cover especially with regard to the risks of exporting nutrients to the waterways due to their rich nutrient elements (e.g., organic matter, phosphorus and chemical oxygen demand) and thus deteriorating water quality. In addition, we expected that the water quality deterioration to OPEFB and POME sludge application would be stronger at higher application rates.

1.6 Limitation of the study

The oil palm empty fruit bunch OPEFB-POME pellets are developed for possible mulching material particularly at the clearing plots (for new planting or replanting) of the estate. However, this investigation processes are performed at the lab scale only. For dimensional stability, water absorption and thickness swelling tests were carried out based on ASTM D 1037-99. For the surface water quality assessment, nine parameters were measured based on National Water Quality Standards for Malaysia by using rainfall simulator test due to these nine parameters related to this study. In addition, these parameters were selected based on availability of equipment in the lab. These parameters were important because they gave an indication of the water quality level and thus, reflecting the sustainability of aquatic life in the river.

1.7 Significance of Study

High palm oil production also generates abundant biomass resources such as oil palm empty fruit bunch (OPEFB) and palm oil mill effluent (POME). These by-products may have undesirable environmental impacts. However, OPEFB and POME are lignocellulosic which demonstrate potential as an alternative to current mulching practices in oil palm estates. Thus, the amount of applied pellets per unit area is the key determinant factor in evaluating the effectiveness of pellets in regulating the turbidity and the side effect of application on water quality. This study will provide an innovative utilization of agriculture by-products like OPEFB-POME pellets for soil protection and conservation as well as water resource protection as part of green management practice.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The processes of palm oil (PO) generate abundant waste every year. Empty fruit bunch, fibre and palm shells, and palm oil mill effluent (POME) are the examples (Figure1.1). For record, POME (direct discharge) is the major contributor to water pollution (Abdullah et al., 2015) of which generated for about 60 Mt annually in Malaysia. OPEFB appears as the highest biomass waste by volume (Brunerová et al., 2018).

The utilization of agro-waste for soil amendment is one way of waste recycle (Hau et al., 2020)Studies have shown that almost one-third of OPEFB and POME produced in Malaysian palm oil industry is recycled (Oseghale et al., 2017) to minimize the negative impact on the environment (Chiew & Shimada, 2013), hence increase environmental performance of the industry.

Since these wastes have high content of organic matter and mineral elements, they can potentially be used to restore soil fertility (Baharuddin et al., 2010). The recycling of these organic residues (OPEFB/POME) in the soil can mitigate environmental hazards resulting from palm oil industry (Baron et al., 2019). Land application of EFB and POME leads to considerable nutrient recovery. Thus, recycling reduces not only environmental burdens; it also leads to net environmental benefit regarding most environmental impact categories, e.g., acidification potential, eutrophication potential, ozone layer depletion potential, etc. due to the avoided emissions from inorganic fertilizer production (Stichnothe et al., 2010). In addition, the application of OPEFB and POME on palm oil plantations has further benefits. These include the temporary storage of soil carbon, improvement of soil quality and protection from soil erosion (Nutongkaew et al., 2014).

Baharuddin et al. (2009) carried out a study with the objective of investigating the physicochemical changes during co-composting of Empty Fruit Bunch (EFB) with partially treated palm oil mill effluent (POME) on a pilot scale. The final compost contained a considerable amount of nutrients (carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and iron) and trace amounts of manganese, zinc, copper. Additionally, very low levels of heavy metals were also detected in the compost. The compost product finally obtained can be used in palm oil plantations as soil amendment. Co-composting of POME and EFB can serve as a clean technology by reducing the bioavailability of the heavy metals due to the mechanisms such as metal binding, microbial immobilization and oxidation (Krishnan et al., 2017). Krishnan et al. (2017) supported Elbersen, (2013) by demonstrating that the EFB and POME co-composting can reduce greenhouse gas emissions by 76%. This was achieved by avoiding open dumping of EFB and pond treatment of POME.

The EFB is being used as a source of soil nutrients for the nearby oil palm plantations (Anyaoha et al., 2018), and as a result increases organic matter content of soil. The EFB is usually left to decompose on plantations helping to return organic matter to the soil, control weeds and prevent erosion as well as retain soil moisture, when placed around young palms (Carron et al., 2015). Sung et al., (2010) used EFB as mulching materials and compared their effects on soil water content, demonstrating that the soil mulched with EFB had 38% more water than the control (without any mulch). The advantage of using mulches for erosion control include reducing soil loss and protecting grass seeds and soil amendments from being washed away. The EFB mulches reduce soil loss by dissipating rainfall impact, and they protect seeds by moderating soil temperature, reducing evaporation losses, and preventing soil crust formation. EFB application significantly increased the soil pH, and cation exchangeable capacity more than chemical fertilizer, also recovers the main soil properties lost due to the palm oil agriculture replanting (Bakar et al., 2011). Land application of EFB and POME in plantation has an effect on several soil physical and chemical properties: increase of soil organic matter content, infiltration, aeration, soil fauna microactivity and cation exchange capacity, improvement of soil structure and soil water retention, root density and growth, soil temperature fluctuation, and support of weed suppression. These effects result in higher yields compared to untreated plantations (Stichnothe & Schuchardt, 2010). A study by Bakar et al. (2011) found that throughout the ten-year application of EFB on oil palm plantation had increased the carbon and nitrogen content in soil resulting higher FFB yield.

The POME increases pH (towards neutral), organic carbon, total, nitrogen, phosphate, sulphate, phosphorus, sodium, potassium, calcium, magnesium, aluminum and hydrogen (Okwute & Isu, 2007) The availability of nutrients including sodium, phosphorus and potassium enhances plant growth. The available phosphorus in the POME soil leads to high absorption of material. These findings attest to a possible use of POME as a bio fertilizer if properly harnessed and managed (Chinyere et al 2018). The discharge of POME into soil affects its pH, which is one of the main factors influencing nutrient availability to plants (Okwute & Isu, 2007). This is because most plant grow and do better within a pH range of 6.5 – 7.5 (Izah et al., 2016). The soil can be impacted through the leaching of heavy metals and other POME physico-chemical properties into the soil. The changes in the soil physico-chemical properties and other vital nutrients via POME discharge have the potential of affecting the soil texture and particulate size. Organic matter plays an essential role in soil productivity because the solids in raw POME are good organic matter sources (Eyo et al., 2018). POME discharge into the soil increases the soil bulk density (Izah et al., (2016). Again, textural class of the soil is dependent on the organic matter content of the soil which POME is discharged into. The POME on soil retains water due to the presence of unrecovered oil and debris from processing.

2.2 Bio-composite

2.2.1 Bio-composite: Definition and Properties

Bio-composites are a mixture of natural fibres such as wood (hard and soft wood) or non-wood fibres (i.e. rice straw, banana, hemp, sugar cane, pine apple, jute, oil palm, sisal, flax) with sustainable and non-renewable polymer matrices. The word 'bio-composites' applies widely to composites where at least one constituent is bio-based (Mitra, 2014). The strengthening of fibres is typically tougher and relatively rigid than the matrix (Dahy, 2017).

In bio-composites, strengthened fibres act as the base, providing the bio-composite with mechanical reinforcement, while matrix functions as a binder polymer (Kim et al., 2006). OPEFB is generally used as reinforcing fibres, while treated POME sludge is employed as a matrix. Pellet shape has been used to enhance the bio-composite feature, since it facilitates the transport and lowers humidity (Chiew & Shimada, 2013).

2.3 Biodegradation of Polymer

In vast industries, such as packaging, automotive and medical industries, the production of biodegradable polymer has been commonly considered. This is because of general anxiety over environmental concerns because these synthetic polymers from petroleum sources have taken a very long time to break-down and their impact on the public health remains unclear. The increasing interest in natural fibres to reinforce polymer composites stems mainly for their low cost, renewability, lower manufacturing energy, lower density, reasonable basic properties, ease of preparation, better biodegradability, broader supply and relatively non-abrasive nature than conventional synthetic reinforcing fibres (Jawaid et al., 2011).

The biodegradable polymer is commonly referred to as waste or organic matter which, through the activity of aerobic and anaerobic microorganisms, can be transformed into carbon dioxide, methane, water, or simple organic components. Mitra (2014) reported that the two forms of biodegradable polymers are starch and cellulose. Biodegradable polymers possess several similar characteristics between them. Often the green sources, such as agricultural plant and animal products are employed to produce those polymers.

In agriculture, the plastic polymer like the polyethylene mulch has been substituted by the starch mulch (Briassoulis & Dejean 2010, Li et al. 2014), and as it comes into contact with soil microorganisms, it disintegrates into non-toxic items. The use of biodegradable polymer in soil has tremendous potential for increasing soil quality and efficiency, since polymers appear to serve as composite fertilisers after decomposition (Syakir et al., 2016). Biodegradable polymers not only promote the agricultural sector by enhancing soil physical structures, but also improve the permeability, which inevitably avoids erosion and runoff.

Two examples of possible biodegradable polymers in agriculture are OPEFB and the treated POME sludge. While OPEFB is being used as a soil erosion control material, treated POME sludge is employed as a fertiliser for the exceptional nutrient quality that is important to the growth of the plant and soil structure improvement (Khairuddin et al., 2016).

The usage of biodegradable polymers on soil will increase soil quality and sustainability because polymers are used as compost fertilisers after decomposition

(Abdul Khalil et al., 2016). Both of the materials, OPEFB and treated POME sludge are biodegradable polymers that are employed in the present study.

2.3.1 Oil Palm empty fruit bunch (OPEFB)

OPEFB is one of by-products generated from the palm oil processes. OPEFB is a big-size brown bunch containing almost 20% of fruit by weight and is a by-product of extraction of palm oil (Mohammad et al., 2012). OPEFB is the remaining press solid residues generated from the palm oil processes (Kelly-Yong et al., 2007). Research has revealed that the OPEFB was utilized as co-composting materials in the estates (Baharuddin et al., 2009). As well, OPEFB has been used as fuel to for steam generation where the ash is used as fertiliser (Nieves et al., 2011). It is known that incineration of OPEFB will generate air pollution due to the release of particulate matter. Thus, the incineration of OPEFB was therefore, not permitted. As an alternative, new approach is introduced to add value of OPEFB i.e. bio-composites (Wirjosentono et al., 2004; Rivai et al., 2014).

2.3.1(a) Properties

OPEFB consists of cellulose that are incorporated with both hemicellulose and lignin (Hamzah et al., 2018). High moisture of OPEFB make it less suitable as biofuel. More heat is required to minimise the amount of moisture. The porous fibre surface morphology promotes the mechanism of water sorption through capillary action and stronger surface interlocking with the matrix (Abdul Khalil et al., 2008). OPEFB is best used as a mulching material, of which increase the soil fertility (Chang, 2014), the coverage amount per unit area will also mitigate the soil erosion (Ashikin al., 2019). Essential properties of OPEFB based on recent literature are provided in Table 2.1.

Table 2.1 shows that the OPEFB cellulose accounts for up to 65% accompanied by 13.71% lignin and 14.83% hemicellulose. Such components of lignocellulosic account for the strength of fibre. Figure 2.1 shows the structural composition of the three major structural constituents of the fiber, fibres are composites made up of hollow cellulose fibrils fused together by hemicellulose and lignin matrix, the nature of cellulose and its crystallinity correlates to the reinforcing efficiency of the fibres, the stiffness of the hemicellulose/cellulose composite is increased by a network of a lignin which acts as a coupling agent in the fibre cell, lignin which is also responsible for tough and stiffness properties of the fiber, once this lignin gets degrade, the inner content becomes more prone to degradation and the fiber starts losing the surface characteristics (Barkoula et al., 2008 ; Kabir et al., 2012). The chemical structure of cellulose (Fig. 2.2a) consists of three hydroxyl groups (OH). Two of them form hydrogen bonds within the cellulose macromolecules (intramolecular) whilst the rest of the group forms hydrogen bond with other cellulose molecules (intermolecular). OPEFB fibres are characteristically hydrophilic in nature because of the existence of a large number of hydroxyl groups (OH) in cellulose and hemicellulose. However, not all constituents contribute to the absorption of moisture. Cellulose, which forms the major part of the fibre, is hydrophilic in nature and it can absorb water molecules. Even though cellulose has a large OH, a small amount OH groups are exposed or accessible as cellulose is semicrystalline. The highly crystalline region of the cellulose is virtually inaccessible to water molecules but the water molecules are able to penetrate and gain access into the amorphous region of the cellulose (Kabir et al., 2012). On the other hand, hemicellulose is predominantly amorphous with high OH making it highly accessible to water molecules. Hemicellulose has branched polymers containing five and six carbon sugars (Fig. 2.2b) of varied chemical structures. Hemicellulose is partially soluble in water and hygroscopic due to its open structure which contains of acetyl and hydroxyl groups. Hemicellulose molecules are hydrogen bonded with cellulose fibrils and they form cementing materials for the fibre structure. Lignin is amorphous and has an aromatic structure, is coupled with the cellulose–

hemicellulose network and provides an adhesive quality to hold the molecules together. This adhesive quality is the cause for the strength and stiffness properties of the fibre. Lignin, however, is hydrophobic in nature and has low OH (Fig. 2.2c), Owing to its hydrophobic character, lignin reduces the penetration of water across the cell walls, which is made up of amorphous hemicelluloses and cellulose fibres (Mokhothu & John, 2015). When the OPEFB fibres absorb water molecules, they swell up due to water molecules occupying the space between the microfibrils. This space that the water molecules occupy is known as the temporary microcapillary network. The water molecules within the natural fibres can either form a monolayer, which associate closely with the available OH groups, or form a multilayer at which not all water molecules are in intimate contact with available OH groups (Hanan et al., 2017).

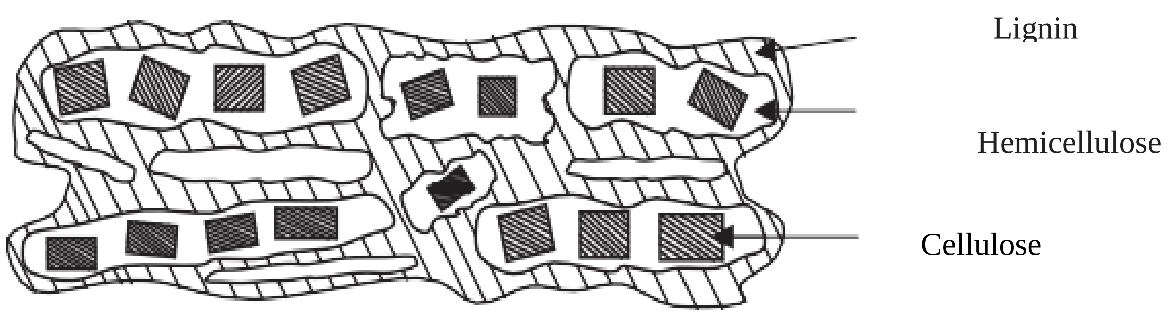

Figure 2.1: Structural organization of the three major constituents in the fibre cell wall (Source from: Kabir et al., 2012).

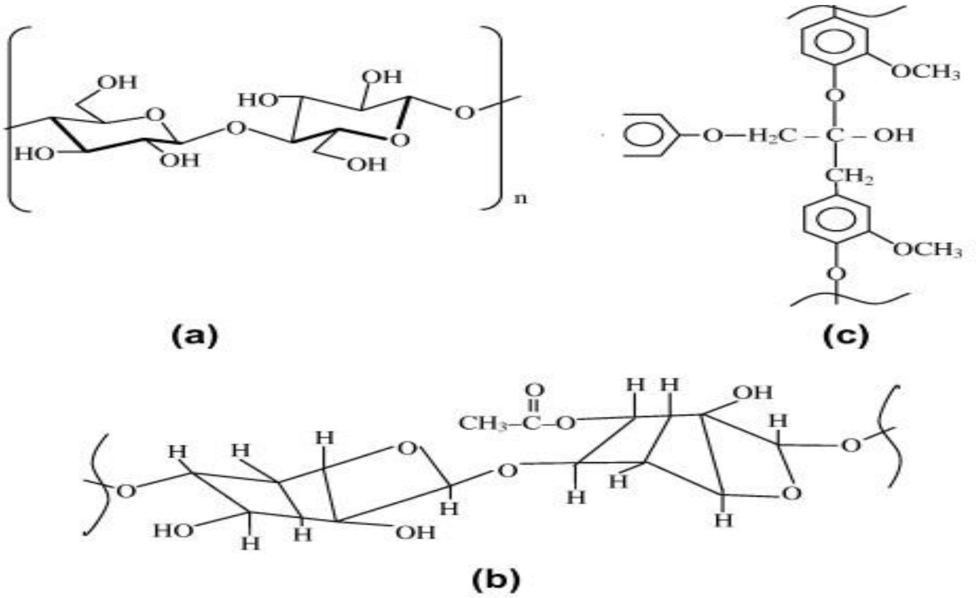

Figure 2.2: Chemical structures of (a) cellulose (b) hemicellulose and (c) lignin. (Source from: Mokhothu & John, 2015)

OPEFB's hydrophilic properties have been documented by Baharuddin et al. (2011) in relation to the lignocellulosic substances. Three primary carbon-based polymers, i.e., cellulose, hemicellulose and lignin are the building blocks of lignocelluloses. In fibre reinforcement, these major carbon polymers play an important function. OPEFB could be used as an efficient polymer reinforcement in the bio-composite industry because of its significant cellulose content (65.81 %) as well as toughness value (Razak & Kalam, 2012; Fang et al., 2017).

Table 2.1: Properties and composition of the oil palm empty fruit bunch (OPEFB)

Parameter	**Value/ Percentage**
Moisture	29.3± 3.8 (%)
Carbon	43.49± 3.1 (%)
Nitrogen	0.8 ±0.1 (%)
C/N	54.4
Phosphorus	0.08± 0.02 (%)
Cellulose	65.81 ± 8.1 (%)

Hemicellulose	14.83 ± 2.3 (%)
Lignin	13.71 ± 0.9 (%)
pH	6.90± 0.2

Source: (Baharuddin et al., 2011)

2.3.2 Treated Palm Oil Mill Effluent (POME) Sludge

The POME sludge is a dense brownish slurry of both the dissolved and suspended solid particles that sediment resulting by anaerobic processing of POME. In palm oil mill, POME is originated during different processes such as washing, condensate sterilisation, segregation of the hydro-cyclone, and oil clarification (Sethupathi, 2004). POME (palm oil mill effluent) is discharged from the mill after the final stage in the manufacturing line of palm oil. POME is normally non-toxic, since during the refining of crude oil no additives are applied (Rupani et al., 2010). The key compositions of POME are oil, water, dissolved and suspended solids. Nevertheless, the POME is considered a significant source of aquatic pollution because of the depletion of available oxygen by the organic nutrients (Rupani et al., 2010).

The solids that remained suspended and dissolved after POME recovery are generally referred to as POME sludge. Study has been performed on the co-composting of POME sludge with OPEFB (Baharuddin et al., 2010). Due to higher level of nitrogen and other nutrients, POME sludge could also be used as fertiliser (Khairuddin et al., 2016). POME sludge is obtained either by aerobic or anaerobic treatments, however, Anaerobic treated POME sludge is used in this study.

2.3.2(a) Properties

The lignocellulose substance in POME sludge can be potential material as matrix for pellet (Table 2.2). In addition, the POME sludge is rich with nutrients such as potassium, phosphorus, calcium and magnesium, of which very useful to soil fertility

(Baharuddin et al., 2010). Moreover, the (anaerobic) POME sludge demonstrates pH value close to neutral with low heavy metal concentration (Copper, Chromium, Cadmium, Zinc, Plumbum, Nickel, Manganese) (Khairuddin et al., 2016). POME (anaerobic) sludge has a high moisture content of 94% with a low C/N ratio (up to 8) compared to the OPEFB. The combination of OPEFB and POME (anaerobic) sludge is therefore a desirable pellets material due to the presence of lignocelluloses in both by-products (Baharuddin et al., 2011).

Table 2.2: Characteristic of the treated POME sludge

Parameter	Value / Percentage
Moisture	94.03 (%)
pH	7.41
C	37.51 (%)
N	4.68 (%)
C/N	8.0
Oil and other lipids	183.00 ± 10.1 (mg/L)
Total suspended solids	34.00 (g/L)
Total solids	55.8 (g/L)
Phosphorus	1.25 (mg/L)
Potassium	5.16 (mg/L)
Calcium	2.55 (mg/L)
Magnesium	1.41 (mg/L)
Nickel	14.0 (mg/kg)
Cellulose	10.45 (%)
Hemicellulose	6.01 (%)
Lignin	48.13 (%)

Source: (Baharuddin et al., 2010)

2.4 The environmental impact of POME and OPEFB

Utilization of POME on oil palm plantations was evidenced to increase fresh fruits yield by 35.3 % and enhance the soil properties, which ameliorated pH, available P, total N, and exchangeable cations (Baharuddin et al., 2010; Ermadani & AR, 2013). However, the acidic characteristic and high level of suspended particulate solids and chemical oxygen demand (COD) (Sethupathi, 2004), may deteriorate the water quality, hence, jeopardize the wellbeing of aquatic life (Edward et al., 2015). According to Edward et al. (2017) the TSS in the river water surpassed the acceptable limits of the World Health Organization (WHO). These suspended solids can easily reduce water transparency, therefore limit the passage of light through water (Edward et al., 2017).

In fact, rivers, and streams in vicinity of oil palm mills are reported to receive frequent pollution due to POME discharge. The impact of POME on aquatic ecosystems (e.g. high BOD and COD) was worrisome (Dislich et al., 2017). The majority of POME was produced by conventional operators subjecting to very little or no treatment and was typically released into the surrounding water bodies (Okwute & Isu, 2007), resulting in water quality deterioration (Ohimain et al., 2012; Soleimaninanadegani & Manshad, 2014).

POME is a breeding habitat for mosquitoes during the rainy season and creates bad odors. Discharge of POME into an aquatic habitat changes the water into brown stinky slime (Awotoye et al., 2011) that may damage both the aquatic life and quality of water for domestic applications (Ezemonye et al., 2008). The Environmental Quality Regulations 1997 (Department of Environment, Malaysia, 1999), has stipulated the BOD limit is less than or up to 100 mg/L before discharge and below 5000 mg/L for land application (Okwute & Isu, 2007).

Awotoye et al. (2011) observed that POME has demonstrated significant values of total alkalinity, total solids (total dissolved and suspended solids), iron, calcium, zinc, manganese, magnesium, potassium, sodium, sulphate, chloride, phosphate, nitrate, biological oxygen, dissolved oxygen, pH and temperature, in agreement with Edward et al. (2015) who has reported the physico-chemical characteristics (such as temperature, pH, alkalinity, biochemical oxygen demand, dissolved oxygen, total suspended solid, phosphate, potassium, nitrate, oil and grease) of the water of Ayanyan River at Ekiti state in Nigeria that exceeded the permissible limits, hence, limit the water resource availability. The presence of excessive concentrations of nutrients in water like phosphate may result in possible eutrophication.

Take the Pawan River and Jelai River as example, the POME disposal was reported to cause an adverse impact on water quality (Hindersah et al.,2018). In this study, the BOD, COD, chlorine, phenol, iron, and total coliform were identified as determinant factor of water quality deterioration in both rivers. BOD and COD are estimated for biological and chemical pollutants that consumed oxygen during the reaction processes in water body (Eludoyin & Ijisesan, 2020). Chemical Oxygen Demand (COD) shows the need for chemical oxygen for oxidation of organic compounds in water (Hindersah et al.,2018). COD is important parameter in water quality as it gives information about the amount of oxygen that can be consumed by reactions in a measured solution. It is expressed in mass of oxygen consumed over volume of solution which in SI units is milligrams per litre (mg/L).

As well, multiple experiments have shown that POME pollution has a detrimental effect on the variety of phytoplankton and disrupt the fish reproduction (Akmal et al., 2018; Muliari et al., 2020). Given the fact that the metabolic activities rely on pH, the changes of pH too will affect the biodiversity of aquatic species (Bolaji et al., 2017). In addition, Briggs et al. (2007) found that changes in pH (5.4 – 6.2) has affected the heavy metal concentration level in the river.

Chemical fertilizers are applied systematically in oil palm plantation for nutrients supply. However, recently, utilization of palm oil residues are employed as natural and organic fertilizers, to limit the usage of chemical fertilizers, thus in line with Sustainable Development Goals (SDGs) of United Nations, including achieve the sustainable management and efficient use of natural resources, from Development Goal 12 (Crespo et al., 2017). OPEFB is one of the major by products, that was proven to improve soil fertility and crop yield in Indonesia and Malaysia (Comte et al., 2015; Tao et al., 2017). However, little is known regarding the OPEFB impact on environment (Carron et al., 2015; Tao et al., 2016; Tao et al., 2018). Planting leguminous cover crops (LCC) and the recycling of OPEFB and POME as fertilizer is highly encouraged in plantations management in order to minimize the amount of soil erosion and to preserve the soil fertility. Such eco-friendly activities will minimize the usage of mineral fertilizers, hence, protect the adjacent water resources (Comte et al., 2012).

2.4.1 Eutrophication

Eutrophication is known as a global problem which causes excessive algal growth in the aquatic system as a result of the enriching dissolved nutrients (Withers et al., 2014). The "natural" eutrophication mechanism through which energy and nutrients are or are obtained from within the system has been differentiated from "cultural" eutrophication whereby the added nutrient is either allochthonous or external to the system. With the increased population of phytoplankton and in particular blue-green algae, eutrophication is synonymous with water pollution and a somehow negative connotation has formed by the word itself (Zhang et al., 2018).

Eutrophication can, in principle, occur through any terrestrial or marine habitat, but is more commonly extended to wetlands, reservoirs and other impoundments, estuaries and coastal shelf seas naturally. A variety of modifications arise during the rise of levels of nutrients that eutrophicate simply the water with which they are supplied. These, though, are not the real eutrophication itself, rather they are the effects of elevated water nutrient status. The development of biomass, first of all from plants (including algae, photosynthetic bacteria) and subsequently from animals and other species increases. The rate of processes such as photosynthesis and respiration increase, which boost the need for other resources and the influx of eutrophicating substances for nutrients (Ortiz-Reyes & Anex, 2018).

One critical factor is oxygen, which increases several times greater than usually observed amount every day while increased photosynthesis is there in the water column. However, at night, as photosynthesis reduces, respiration and metabolism continue, such that oxygen quantity falls so low that aerobic forms of life, such as some fish and invertebrates feel tough to survive. This is particularly valid in deep seas, where oxygen demand (OD) is also rising as a consequence of the increasing quantities of dead organic material falling into deep waters and decomposing (Cabrita et al., 2015).

Consequently, the composition of the environment may shift after eutrophication, and at the same time, composed species may substitute the original populations with more tolerable conditions. Again, oxygen is essential, however, due the lower concentration the stenoxybiontic species (species surviving at constant supply of oxygen) are replaced with euroxybiontic species (species surviving at lower concentrations of oxygen). Likewise, the increased biomass generated now exerts a greater pressure on water supplies and demand extra light. This causes a drastic decrease in the number of organisms that could not withstand shading.