# OIL PALM EMPTY FRUIT BUNCH-SEAWEED BIOCOMPOSITE AS POTENTIAL SOIL EROSION MITIGATION FOR OIL PALM PLANTATION

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**by**

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Nurin Syahindah Syasya binti Nor Ashikin

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| 11MP | Eleventh Malaysian Plan |
| BMP | Best management practise |
| C | Carbon |
| Ca | Calcium |
| CPO | Crude palm oil |
| DO | Dissolved oxygen |
| EMC | Equilibrium moisture content |
| FAO | Food and Agriculture Organization |
| FFB | Fresh fruit bunch |
| HOF | Horton overland flow |
| -OH | Hydroxyl group |
| JGT | Jute geotextile |
| K | Potassium |
| Mg | Magnesium |
| MPOB | Malaysian Palm Oil Board |
| MPOCC | Malaysian Palm Oil Certification Council |
| N | Nitrogen |
| OPA | Oil palm ash |
| OPEFB | Oil palm empty fruit bunch |
| OPEFB-SW | Oil palm empty fruit bunch-seaweed biocomposite |
| P | Phosphorus |

| | |
|---|---|
| PAM | Polyacrylamide |
| PHA | Polyhydroxyalkanoates |
| PHB | Polyhydroxybutyrate |
| PLA | Polylactic acid |
| POME | Palm oil effluent |
| PORIM | Palm Oil Research Institute of Malaysia |
| SCP | Sustainable consumption and production |
| SDGs | Sustainable development goals |
| SPSS | Statistical Package for the Social Science |
| SW | Seaweed |
| TSS | Total suspended solid |
| UNEP | United Nations Environment Programme |
| USDA | United States Department of Agriculture |
| $H_2O$ | Water |
| WWF | World Wildlife Fund |

## LIST OF UNITS

| | |
|---|---|
| cm | Centimeter |
| $cm^3$ | Cubic centimeter |
| ° | Degree |
| °C | Degree celcius |
| 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 |

**POTENSI BIOKOMPOSIT HAMPAS KELAPA SAWIT-RUMPAI LAUT UNTUK MITIGASI HAKISAN TANIH DI LADANG KELAPA SAWIT**


## ABSTRAK

Kajian terdahulu membuktikan bahawa pertanian seperti ladang kelapa sawit merupakan punca utama kepada pemendapan sungai akibat hakisan tanih dari aktiviti pembersihan tanah. Hakisan tanih mempunyai empat peringkat yang berlainan yang terdiri daripada percikan, lembaran, tumpukan, dan saluran. Pelbagai pendekatan mitigasi hakisan tanih menggunakan sisa pertanian telah dikaji. Walau bagaimanapun, pendekatan yang dilakukan sukar untuk digunakan dan tidak inovatif lalu mengehadkan potensi sisa pertanian untuk digunakan di kawasan kelapa sawit yang matang sahaja. Selain itu, pendekatan semasa menggunakan gentian semulajadi secara langsung dan digunakan pada percikan (peringkat pertama) dan tumpukan (peringkat ketiga) hakisan tanih sahaja. Oleh yang sedemikian, dalam kajian ini potensi tandan buah sawit kelapa sawit (OPEFB) dan tumbuhan akuatik liar (rumpai invasif) sebagai satu biodegradasi komposit telah dikenalpasti untuk mengurangkan hakisan tanih pada hakisan lembaran (peringkat kedua) bagi meningkatkan penyusupan air ke dalam tanih dengan mengawal isi padu air larian. OPEFB sebagai gentian semulajadi untuk mengukuhkan struktur komposit didapati mempunyai potensi yang besar sebagai penstabil tanih kerana ciri hidrofilik semulajadinya. Selain itu, komposit seperti ini dapat dihasilkan dengan kos yang rendah apabila dicampurkan dengan rumpai laut liar sebagai bahan matriks. Penyelidikan ini berdasarkan pemikiran ekonomi pekeliling yang menekankan pemulihan produk dan pertumbuhan semula pertanian untuk memulihkan sistem tanih yang terdegradasi. Oleh itu, objektif utama kajian ini adalah untuk menentukan keberkesanan komposit tersebut dalam mengawal isi padu air larian dan mengekalkan kualiti airnya. Oleh hal yang sedemikian, kajian terhadap jumlah, kekeruhan, dan total pepejal terampai (TSS) dalam air larian pada kadar komposit yang berbeza iaitu 0 g/ft$^2$ (T1), 250 g/ft$^2$ (T2), 350 g/ft$^2$ (T3), and 500 g/ft$^2$ (T4) telah dijalankan. Di samping itu, ujian penyerapan air dan ketebalan benjolan juga telah dilakukan mengikut kaedah piawaian ASTM D 1037-99. Peratusan penyerapan air dan ketebalan benjolan komposit masing-masing telah mencatatkan sebanyak 117.22 ± 7.14% dan 10.52 ± 1.73%, menunjukkan keupayaannya yang tinggi untuk menyerap air sambil mengekalkan struktur fizikalnya sehingga hari ke-4 eksperimen dijalankan. Secara keseluruhannya, komposit ini membuktikan keupayaannya untuk menyerap kesan hentaman titik air hujan sehingga menstabilkan struktur tanih dengan mengurangkan detasmen tanih. Secara purata, komposit ini dapat mengurangkan jumlah air larian, kekeruhan, dan jumlah pepejal terampai (TSS) dengan masing-masing sebanyak 39.1 ± 10.07%, 89.42 ± 5.17%, dan 98.88 ± 0.27% dalam air larian berbanding dengan plot terkawal. Walau bagaimanapun dalam kajian ini, 350 g/ft$^2$ (T3) dicadangkan sebagai kadar terbaik dalam menyediakan perlindungan tanih yang mencukupi. Hasil dari kajian ini boleh menjadi sebagai data asas untuk mengawal penghakisan tanih berpasir di ladang kelapa sawit pada masa hadapan.

**OIL PALM EMPTY FRUIT BUNCH-SEAWEED BIOCOMPOSITE AS POTENTIAL SOIL EROSION MITIGATION FOR OIL PALM PLANTATION**

## ABSTRACT

Past study confirmed that agriculture (*e.g.*, oil palm plantation) is the main culprit to river sedimentation due to massive erosion from land clearing activities. Soil erosion has four different stages comprising of splash, sheet, rill, and gully. Numbers of soil erosion mitigation approaches using agricultural by-product have been studied. However, current approaches are laborious and not innovative thus, limit the potential of by-product to be applied on matured oil palm plantation only. Plus, current approaches were introduced at splash (first stage) and rills (third stage) erosions only. In this study, we examine the potential of oil palm empty fruit bunch (OPEFB) and wild seaweed (invasive species) as a biodegradable composite for soil erosion mitigation at sheet erosion to increase soil infiltration capacity by regulating runoff volume. The recovery of OPEFB as a reinforced natural fiber in composite has a great potential in absorbing raindrop impact due to its natural hydrophilic characteristic. Besides, such green composite can be developed at lower cost by blending with abundance wild seaweed as a matrix. This research provides an alternative thought of circular economy which emphasizes on agriculture by-product recovery and regeneration to restore a degraded soil system. Therefore, the main objective of this study is to determine the efficiency of the biocomposite in regulating runoff volume and maintaining its water quality. For this reason, investigation of runoff volume, turbidity, and total suspended solid (TSS) on different rates (0 g/ft$^2$ (T1), 250 g/ft$^2$ (T2), 350 g/ft$^2$ (T3), and 500 g/ft$^2$ (T4)) of the composite were observed. In addition, the water absorption and thickness swelling tests of the studied composite was performed according to ASTM D 1037-99. Water absorption and thickness swelling percentages of OPEFB-SW were recorded to be 117.22 ± 7.14% and 10.52 ± 1.73% respectively, showing the capability of this composite to absorb high amount of water while maintaining its physical structure until day 4 of the experiment. Overall, our studied composite demonstrating its capability to absorb rainfall impacts hence stabilize soil structure by reducing soil detachment. In average, it is evidenced that runoff volume, turbidity, and TSS were significantly reduced until 39.1 ± 10.07%, 89.42 ± 5.17%, and 98.88 ± 0.27%, respectively with compared to control plot. Nevertheless, it is suggested that 350 $g/ft^2$ (T3) is the best rate in providing sufficient soil cover. These results served as a baseline data for future soil erosion control in sandy soil texture in oil palm plantation.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Study

Soil erosion is one form of soil degradation and is mainly driven by water and wind. Although soil erosion is a natural process, anthropogenic activities tend to increase soil erosion rate. During the critical stage of oil palm establishment, the exposed surface soil is at the most vulnerable state towards erosion, particularly during rainy season. As a result of that, many crisis like water pollution (quality) and scarcity or flooding (quantity) become critical and in a serious threat if prevention steps are not taken.

Soil erosion comprises of four main phases that are splash, sheet, rill and gully (UNEP, 1994; Boardman, 2006; Monsieurs et al. 2015). Splash erosion is the least severe stage in soil erosion processes, followed by sheet, rill, and gully, which are the most damaging ones (Zachar, 1982). Therefore, preventive measures should be taken at the early stage of splash or sheet erosion so that the damages of soil structure can be controlled. Currently, most researchers focused to prevent soil erosion during splash and rill stages.

Additionally, past studies regarding soil erosion and sedimentation controls were mostly limited to forest and highway (Juyal and Dadhwal, 1996; Haywood, 1999; Choudhury and Sanyal, 2010; Prats et al. 2014; Fernández and Vega, 2016b; Zhao et al. 2018) and only a few focusing on activities related to oil palm plantation and even if there is any, the quantitative estimate of soil loss rates in oil palm plantation in Malaysia is still very limited (Sahat et al. 2016).

Wood (1990) mentioned that Malaysia was recorded among the 14 countries with annual deforestation rates exceeded 250 000 hectares per year, mainly contributed by timber and oil palm plantation industries and by 2020, the expansion of oil palm in Malaysia is predicted by USDA (2011) to extent until 5.6 million hectares. Deforestation put the soil surface at high risk to erode due to the absence of forest canopy and vegetation cover. Soil compaction, as a result of the use of heavy machinery for land preparation, worsened the situation by reducing water infiltration of soil and subsequently accelerates soil losses in deforestation area.

Therefore, various strategies are implemented to reduce soil erosion in oil palm plantation including cover crop establishment, frond pruning, oil palm empty fruit bunch (OPEFB) mulching, eco-mat, terracing hills and construction of silt pits (Ping et al. 2012; Sahat et al. 2016). Although soil erosion controls such as OPEFB mulching and eco-mat are proved to reduce soil erosion and nutrient leaching in oil palm plantations, but such direct application approach is the limiting factor which is laborious and in fact, it increases the maintenance cost of plantation.

In tropical regions, cover crop establishment and terracing hills are sufficient to control soil erosion (Hartemink, 2006). Nevertheless, while the establishment of vegetation cover is a time-consuming (reaching full ground coverage after 9-18 months) (Mathews, 1998; Chee, 2007), terracing hills involves the modification of soil structure, requires higher labour costs to construct and maintain, not practical for soil and water conservation practice and is the most expensive soil conservation practices (Dorren and

Rey, 2004; DelVenado, 2017). Plus, the abandoned terraces may be resulting in gully formation, the most damaging stage of soil structure (DelVenado, 2017).

Additionally, most of previous studies provide the methods to control soil loss during matured stage of oil palm tree only. Therefore, an innovation to a new method to control soil erosion during land clearing or replanting stage through the establishment of composite from oil palm by-product, OPEFB and wild brown seaweed, will unlock the limitations of these conventional methods by providing a lighter and easy-to-be-used product to regulate runoff volume and maintain its water quality.

OPEFB is among the major by-product that usually being destroyed by burning at the site, in order to obtain the recycle ash as a fertilizer for plantation (Abdul Khalil et al. 2010). This conventional method is discouraged by Malaysian government due to the extensive air pollution problems. Nonetheless, OPEFB recently has received significant attention in diverse fields as it contains high cellulose and hemicellulose that makes it a great potential as a basic raw material. Besides having excellent hydrophilic characteristics, OPEFB is also accessible and a cost-effective material for any application.

While OPEFB demonstrates its good properties, seaweed is identified as one of the potential biodegradable polymers that acts as a matrix for OPEFB which hypothetically enhances the physical structures of the composite. Moreover, seaweed is used in the agricultural industry as a fertilizer because it ameliorates soil structure and enriches it with various type of elements and nutrients (Arthur et al. 2003; López-Mosquera et al. 2011; Elansary et al. 2016). Pelagic seaweed particularly genus *Sargassum* (class Phaeophyceae) is normally found offshore and stranded onshore numerously in few countries including Malaysia. It is identified as an invasive species, motivated by the changing of ocean temperature due to global warming and excessive nutrients and pollutants in ocean water (UNEP, 2016). Although this seaweed is not toxic, massive (tonnage scales) decomposition may lead to anoxia which triggered 'fish-kill' and mortalities of coastal invertebrates (Wright and Gribben, 2008; Wright et al. 2010; UNEP, 2016). Potentially, such environmental problem can be leveraged through it utilization as a bio-matrix in OPEFB. Plus, raw seaweed as a bio-matrix is less studied, regardless of no chemical and energy consumption is needed which makes the preparation of material is simpler and less expensive (Abdul Khalil et al. 2016).

As well, the blended wild seaweed with OPEFB may augment nutrient content in the composite. The nutrients will be recycled back to the plantation site and such nutrients will enhance soil fertility. Later, soil structure can be ultimately stabilized by improving the inter-particle attraction forces between soil aggregates thus, reduces the impact of soil erosion (López-Mosquera et al. 2011; Zaidi et al. 2016). Plus, the ability of such composite to absorb raindrop impact and retain the water at a certain period of time before releasing the water and nutrient into the soil steadily upon its degradation (Syakir et al. 2016) will gradually decrease soil moisture content by reducing soil moisture evaporation rate, especially during dry season.

From the literature review, it is clear that the study of biocomposite for soil erosion mitigation is poorly constrained. Furthermore, there is no research to show that OPEFB and raw seaweed were used to produce a composite for soil erosion control purpose. Therefore, in this study the OPEFB-seaweed biocomposite (OPEFB-SW) was established, later, water absorption and thickness swelling behaviour of the composite were examined first before tested using rainfall simulator to investigate its ability in reducing runoff volume and soil loss. Therefore, the aim of this study is to determine the hydrophilic properties of OPEFB-SW and its effects in reducing direct impact of raindrops on the bare soil surface. Thus, this study provides a better idea to control soil erosion through the benefits of the studied biocomposite in terms of accessibility and practicality.

## 1.2 Problem Statements

Post land clearing or replanting stage in oil palm plantation is critical to soil erosion, particularly during heavy rainfall, due to the absence of vegetation cover in providing protection to soil surface from raindrop impact (Lord and Clay, 2006). Despite the fact that various soil erosion mitigation studies were conducted in oil palm plantation, most of them are focused at matured oil palm areas only. In addition, conventional method by using agricultural waste to mitigate soil erosion are still on direct application (e.g., OPEFB mulching, eco-mat, frond pruning) thus, limits the potential of by-products to be applied at land clearing or replanting stage.

To date, the used of biocomposite for soil erosion mitigation is poorly utilised despite the fact that biocomposite is lightweight and flexible, which make it easy in terms of storage, transportation, and application. This is due to the nature of its application which is very specific to particular application in soil erosion mitigation (*e.g.,* dam, arid and semiarid soil, mine land reclaimation). In fact, to the best knowledge of the author, there is no research, so far, employed OPEFB and raw seaweed as a composite in soil erosion control applications.

Therefore, in this study the author attempt to unlock the limitations of such conventional methods by providing an innovative approach through the establishment of

OPEFB-seaweed biocomposite (OPEFB-SW) which its application is aiming at sheet erosion (the early phase of soil erosion), particularly during land clearing or replanting stage at oil palm plantation area. OPEFB-SW is believed to play a significant role in stabilizing soil structure by enhancing soil infiltration capacity, regulating runoff volume, and improving its water quality through the reduction of soil detachment and soil losses.

### 1.3 Objectives of the Study

The main objective of this research is to assess the effectiveness of the developed biocomposite for the reduction of soil erosion and runoff water quality improvement. OPEFB-SW production is solely aimed to control soil erosion as it provides a primary barrier against direct impact of raindrop on the bare soil surface. The effect of different OPEFB-SW rates in reducing soil loss is also verified to ensure the increment of its rates is proportional to reduction of soil loss.

Therefore, four rates of OPEFB-SW are introduced which were 0 $g/ft^2$ (control plot), 250 $g/ft^2$, 350 $g/ft^2$, and 500 $g/ft^2$. To achieve these objectives, a lab-scale size of rainfall simulator model modified from Kibet et al. (2014) was used. In this study, water absorption and thickness swelling behaviour of OPEFB-SW were also identified. Hence, the objectives discussed above are summarised into three main aspects:

1. To analyze the water absorption and thickness swelling percentages of OPEFB-SW.
2. To evaluate the percentage of OPEFB-SW in reducing volume, turbidity, and total suspended solid (TSS) of water runoff compared to control plot.
3. To determine the effectiveness of different OPEFB-SW rates in mitigating soil loss.

## 1.4 Hypothesis

Hypothetically, OPEFB fiber and seaweed are proved to have high water absorption capacity owing to the presence of cellulose containing free hydroxyl groups in both materials. While most research unfavorable to hydrophilic nature of natural material as it is a major drawback for being used with hydrophobic matrix in composite production (Harmaen et al. 2013; Then et al. 2013; Birnin-Yauri et al. 2016), this study utilised the hydrophilicity in both reinforced and matrix material as it is very potential in soil erosion mitigation purpose. Remarkably, unique hydrophilic characteristic of these natural materials plays a significant role in absorbing, retaining, and releasing raindrops impact and water, in a gradual fashion upon degradation (Syakir et al. 2016) (Figure 1.1). Such mechanism will stabilize soil structure and improve water quality in the runoff.

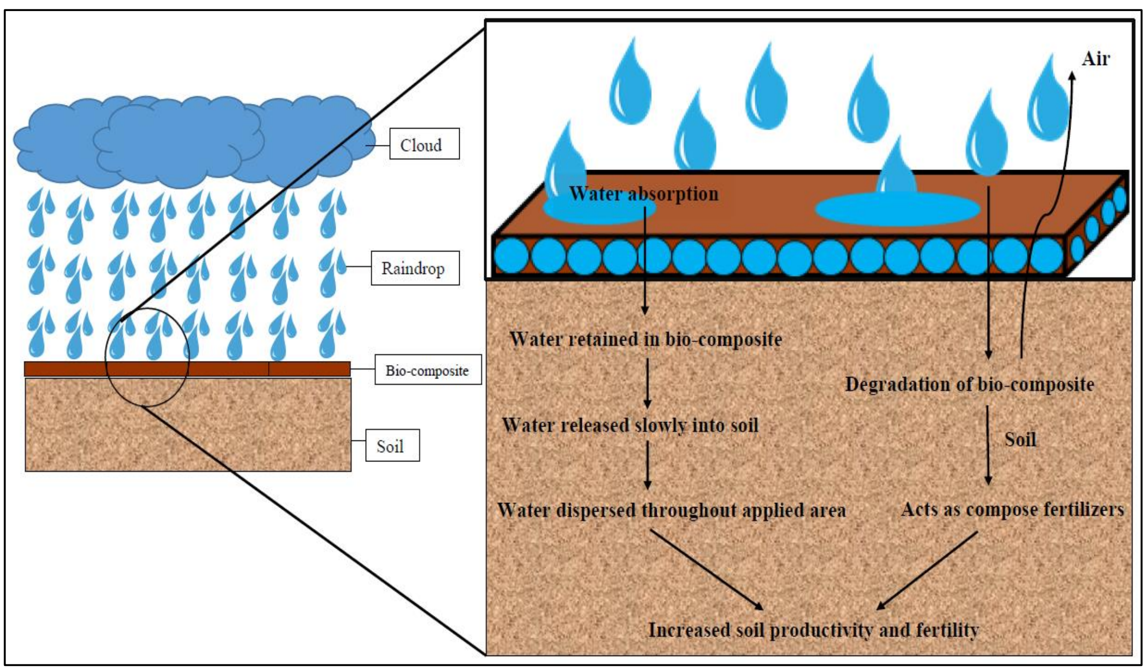


Figure 1.1: Illustration of biocomposite's roles in reducing soil erosion

Moreover, at decomposition phase, natural materials which contain distinctive nutrients are essential for soil fertility and plant growth. Note, for our case, the studied biodegradable composite consists of OPEFB fiber and seaweed as a reinforced and matrix, respectively. The rich nutrient elements in seaweed give and added value as a potential matrix. As well, the presence of cations in seaweed and OPEFB (e.g., $Ca^{2+}$, $Na^{+}$, $K^{+}$, and $Mg^{2+}$) (Lim and Zaharah, 2000; Syad et al. 2013) increases the inter-particle attraction forces and critical shear stress between soil aggregates hence, stabilizes soil structure by enhancing soil water infiltration (Tao et al. 2016). As a result, depletion of topsoil and soil erosion is reduced.

## 1.5 Limitations of the Study

The composite is specifically designed to be applied in oil palm plantation, hence, explaining the title of the thesis despite the fact that there is no field application was conducted in this study. Instead, this study is only focused on the lab scale approach which underlines the effectiveness of OPEFB-SW in reducing runoff volume, soil loss, and maintain the water quality in runoff.

The outcome from this study are only valid with the condition stated in this document. Further studies and pilot scale approach should be considered in the future to acquire a clear vision of the biocomposite’s potential. Currently, the application to mitigate soil erosion by using this biocomposite is found to be none and therefore, it is impractical to compare the result with the other studies.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In National Environmental Policy, the government of Malaysia is committed to pursue sustainable development in economic, social, cultural, and environment. The innovation through research and development projects to minimise waste is therefore encouraged. The Eleventh Malaysian Plan 2016-2020 (11MP) is hence, derived based on these elements. In 11MP, the sustainable consumption and production (SCP) was introduced where the government encouraged the production of eco-friendly products by recycling and recovering waste.

Nevertheless, in its journey to achieve sustainable development, Malaysia is criticized by two main issues, palm oil production and illegal logging (Hezri and Hasan, 2006; Yeoh, 2015). This is because more than 35% of land use in Peninsular Malaysia is allocated to agriculture, mining, urbanization, and infrastructure industries. The land use for agricultural activities (e.g., deforestation, land clearing, etc.) are not just causing air and water pollution but also soil erosion. Soil erosion from agricultural land is the main culprit for river sedimentation. Therefore, it is critical to come up with various soil conservation techniques to control erosion and runoffs strategically, particularly, during the expansion of the agricultural land (Hezri and Hasan, 2006; Mokthsim and Salleh, 2014).

Malaysia is listed to be among the highest Asian countries with agricultural waste after Japan, Republic of Korea, and Singapore (Hsing et al. 2004). In every year, 1.2 million tonnes of agricultural waste in Malaysia is discarded into the landfills. Palm oil industry is the main contributor of agricultural waste in Malaysia (94%), followed by wood industry (4%), rice (1%), and sugarcane (1%) (Agamuthu, 2009). Some of the wastes produced in palm oil industry are including palm fronds, palm trunks, palm kernel shell, palm kernel cake, palm oil mill effluent (POME), mesocarp fiber, and empty fruit bunch (EFB) (Foo and Hameed, 2010). Among that, EFB appears as the highest biomass produced in this industry after POME (Ng et al. 2012).

Nonetheless, Malaysia has taken an initiative in engaging agricultural waste-to-energy technologies of sustainable development. While palm kernel cake, POME, and mesocarp fiber are often used as a source of energy (Sadeghi et al. 2015), EFB is unfavorable due to its high moisture content (60-70%) hence, it is utilized to ameliorate soil quality by composting and mulching (El-Haggar et al. 2004; Paepatung et al. 2009; Hansen and Nygaard, 2014, Sadeghi et al. 2015). EFB too, is incinerated, mulched or dumped in open landfills with other palm oil wastes (Ng et al. 2012). Additionally, incineration of palm oil wastes released the potential pollutants into the atmosphere and caused air pollution. This issue remains as a major problem in the palm oil wastes management (Mokthsim and Salleh, 2014).

As soil degradation in oil palm plantation is critical (particularly during land clearing and replanting), this study offers a solution through an innovative approach for soil erosion mitigation, by utilizing EFB as a reinforcement material and abundance wild seaweed as a matrix. In this context, this study supports 11MP and 17 Sustainable Development Goals (SDGs) under Goal 2 and Goal 15 where the sustainable agriculture practices and land degradation control are being the main focus.

## 2.2 Soil Erosion in Oil Palm Plantation in Malaysia

### 2.2.1 Soil Erosion

The removal of vegetation covers or crop residues accelerates soil erosion (Sheng and Liao, 1997; Vacca et al. 2000; Kimoto et al. 2002). Soil erosion is a process which comprises of three distinct actions; soil loosening, movement, and deposition. The loss of topsoil reduces the fertility of the soil and contributes to the pollution of water bodies. Generally, water and wind are two agents that contribute to large amounts of soil loss in each year. In tropical regions, soil erosion is mainly driven by water especially during monsoon season. Soil erosion occurs due to the exposure of soil surface. Once the soil surface is exposed, erosion will gradually take place through a sequence of process starting with the detachment of soil particle by rainfall splash, progressing onto sheet, rill, and gully erosion (Figure 2.1).

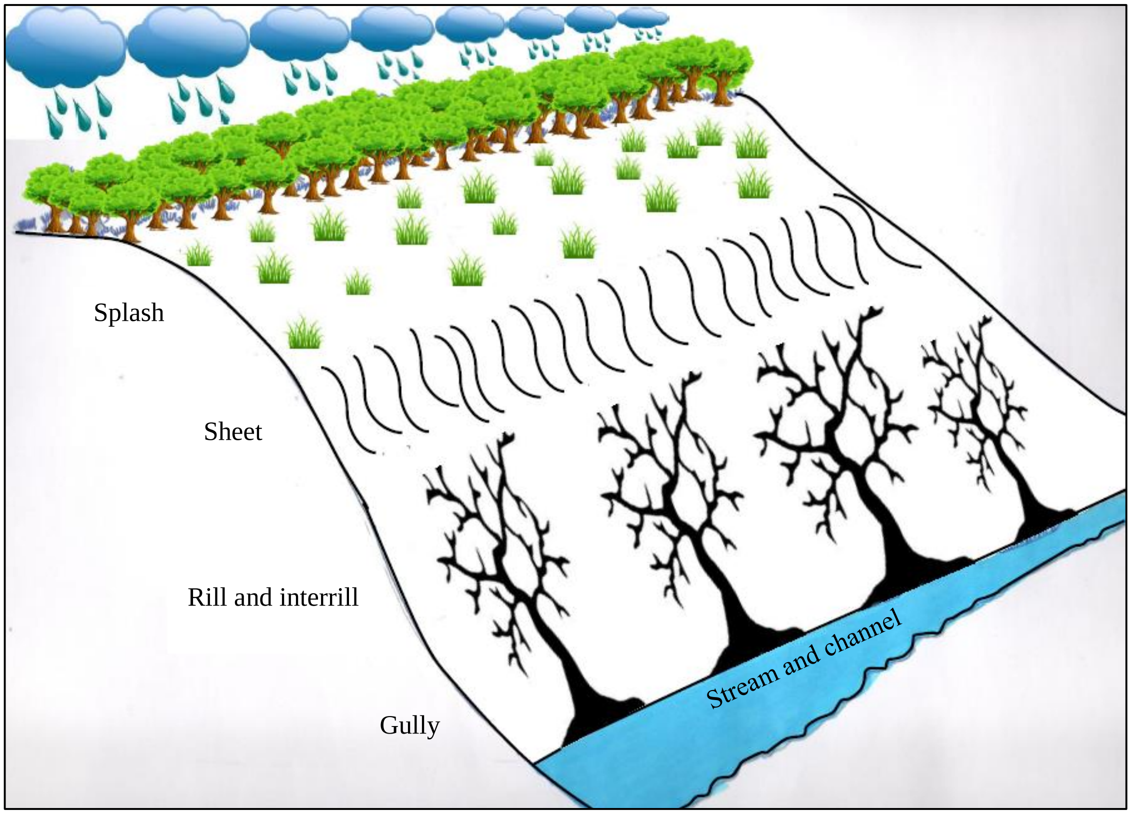


Figure 2.1: The stages of soil erosion on an exposed slope (Source from: UNEP, 1994)

Splash erosion is known as the least severe stage in soil erosion process followed by sheet erosion, rill erosion and lastly, the most severe stage is gully erosion. In splash erosion, during rainfall, raindrop strikes onto bare soil surface and disintegrates the soil aggregates apart from each other. This weakens the force existed between soil particle which is inter-particle attraction force, causing the structure to become loose. The disaggregation of soil particles throws up these fine particles in all directions at a distance up to one meter and clog into soil pores (Derpsch, 2004). The clogged pores create a surface seal, which decreasing the movement of water into the soil. As a result, soil becomes impermeable towards the water, resulting in surface runoff and eventually causing soil erosion. If there is no prevention step taken in the first process, sheet erosion will occur.

Sheet erosion occurs when rainfall intensity exceeds the capacity of soil to infiltrate the water. It involves the removal of a thin layer of topsoil that comprises most of the nutrients and organic matters in the soil by the action of raindrop splash. The removal of topsoil causing the damage at down-slope site by transporting the nutrients and soil particles thus, resulting in sedimentation of water basin. Soil erosion is a gradual process and remains unnoticed, however, it can be accelerated to an alarming rate and causing a severe loss of topsoil. Soil erosion on steep hillslopes can rapidly evolve from splash or sheet erosion to rill erosion when there is an extra energy of rainfall exerted on the soil or sufficient overland flow (Stefano et al. 2013).

Rill erosion is the intermediate stage between the sheet and gully erosions. Rills are small channels created by water runoff with the depth of less than 0.3 m. Commonly, they can be spotted in the cultivated field and can cause extensive soil losses (Govers and Poesen, 1988; Miao et al. 2011) especially during the development of rill network as they can significantly be affected by rainfall intensity (Shen et al. 2015).

Gully erosion is the advancement of rill erosion. It can be formed by runoff water concentrating or by gradual deepening of rills where the channel depth can reach until 2-3 m (Zachar, 1982). Normally, this type of erosion is clearly noticeable as it affects soil productivity and damages the roads and buildings (Department of Natural Resources and Water, 2006).

The preventive measures of soil erosion should be taken at early stage of splash or sheet erosion to stop severe damages of soil structure. Meyer et al. (1970) added that preventive measures such as mulches are generally ineffective once rills are formed. On the other hand, the controlling of soil erosion is seemed to be less effective during gully erosion stage due to the worst soil condition. Therefore, another soil protection strategy should be involved to impede the formation of the gully in future.

Soil erosion leads to surface runoff as a result of rainfall impact. Water runoff transports eroded soil into river and this activity eventually causing sedimentation. Besides deteriorating water quality (e.g., turbidity and total suspended solids) and aquatic ecosystem, sedimentation also shallows the water bodies until at some points, the river cannot sustain water loaded any longer, an overflow occurs thus, flood disaster will happen.

### 2.2.2 Impacts of Runoff on Water Quality

Land use activities such as land clearing and agricultural activities speed up soil erosion and runoff rates to occur. Such activities, without soil conservation, can influence the quality (e.g., sedimentation, deterioration of water quality) and quantity (e.g., increasing of water levels) of water bodies, particularly during monsoon season. Water quality refers to the basic chemical and physical characteristics of water that determine its suitability for life or for human uses. Sedimentation deteriorates water quality through the increasing amounts of suspended solids and turbidity of water. This limits the penetration of light into the water, hence reducing the survival rate of photosynthetic aquatic plants that need sunlight to make their own food.

Sedimentation also causes the increasing of water temperature. The rising of water temperature has some negative consequences towards water chemistry as it can reduce the availability of important gases to aquatic life (e.g., oxygen and carbon dioxide). Plus, metabolic rate of aquatic organisms rises along with high water temperature, ensuing in oxygen demand (USDA, 2011). This worsens the situation with the low availability of oxygen content as the water temperature increases. The extended period of warm temperature may eventually result in the change of species diversity and death of aquatic organisms.

Besides, excessive suspended sediments also tend to damage fish gills and devastate the protective mucous covering the eyes and scales of fish, making them vulnerable towards infection and disease (Kerr, 1995). A worse situation may occur if the sediment brings along toxins such as heavy metals and pesticides from either agricultural or industrial industry. Deformities or mortalities of fish occur if toxins are discharged in the habitat (DFO, 2000). Consequently, these morphological deformities can be inherited by several generations of exposure (Arambourou et al. 2014).

Agricultural runoff is always associated with eutrophication. Eutrophication can be explained briefly as the enrichment of water body with nutrients such as Potassium and Nitrogen. The excessive nutrients in water bodies encourage algal bloom event to take place. The algal bloom depletes the dissolved oxygen (DO) in the water. DO is a measurement of oxygen content in the water to serve as an indicator of the metabolic activities and ecological health status of an aquatic ecosystem (Mader et al. 2017). As an example, the decreasing of DO in water bodies indicates the excess respiration in water due to the blooming of algae. Algal bloom does not just increase the respiration rate of water bodies but also accelerates the decomposition rate of submerged water plants due to the restriction of light penetration. This exacerbates the DO level status in water bodies due to the presence of decomposers (e.g., bacteria, fungi, etc.) that consume oxygen while breaking down organic matter (US Department of Commerce, & National Oceanic and Atmospheric Administration, 2004). In extreme cases, sudden mixing of gas during the decomposition process (Hydrogen Sulfide) into the upper water column can cause mortalities of fish.

### 2.2.3 Runoff and Erosion Controls by Using Natural Fiber from Agricultural Waste

Therefore, many farmers and plantation managers take a wise approach by utilizing by-products from agriculture industries through mulching to reduce soil erosion and runoff as well to increase the soil productivity (Al-Kaisi, 2000; Deumlich et al. 2006; Gruver, 2013). In this context, by-products are cost-effective not just to control soil erosion but also provide nutrient and increase organic matter content in soil with the minimum usage of fertilizers and pesticides (Hellin, 2003; New Agriculturalist, 2009). The main idea behind mulching concept; - everything that is eliminated from the soil-crop system is safe enough to be returned back to the plantation after proper plot (Khalid and Tarmizi, 2008). Soil erosion controls using agricultural wastes from past studies are arranged in chronology presented in Table 2.1 to identify the gap in past research. Table 2.2 stated the chemical compositions and total nutrients in selected agricultural by-products' fiber. Meanwhile, Table 2.3 discusses the strengths and weaknesses of these agricultural wastes including jute, kenaf, oil palm empty fruit bunch, hemp, coir, and straw which are currently used to control soil erosion .

Table 2.1: Chronological of soil erosion control by using waste from agriculture

| No. | Soil erosion mitigation method | Type of soil | Stage of erosion | Slope steepness (%) | Lab (L) / field (F) | References |
|---|---|---|---|---|---|---|
| 1. | Manure and wheat straw mulching | Silt loam | *N/A | 2-3 | F (Cornfield) | Borst and Medersk, 1957 |
| 2. | Straw mulch | Loam | N/A | 15 | F (Oat crops) | Meyer et al. 1970 |
| 3. | Straw mulch | Silt loam | Interill | 2, 6, 12, and 20 | L (Rainfall simulator) | Lattanzi et al. 1974 |
| 4. | Oat straw | Clay loam | Splash | 9 | L | Singer and Blackard, 1978 |
| 5. | Rice (*Oryza sativa*) straw | Clay | N/A | 5 | F (Cleared land) | Lal et al. 1980 |
| 6. | Corn and soybean residues | Silty clay loam and silt loam soil | N/A | 5 and 10 | F (Rainfall simulator at universities plots) | Dickey et al. 1985 |
| 7. | Corn residues | Silt loam | N/A | 5.2 | F (Rainfall simulator at university plots) | Gilley et al. 1986a |
| 8. | Sorghum and soybean residues | Silty clay loam | Rill and interill | 6.4 | F | Gilley et al. 1986b |
| 9. | Rice straw mulch | Alfisols | N/A | N/A | F (Pearl millet and sorghum crops | Perrier, 1987 |

Table 2-1. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 10. | Straw mulch | Silt loam | Interill | 2.5 | L | McGregor et al. 1988 |
| 11. | Corn stalk | Silt loam and silty clay loam | Rill | 7-11 | F (Abandoned crop site) | Brown et al. 1989 |
| 12. | Jute geotextile | Sandy loam soil | N/A | 50 | N/A | Ingold and Thomson, 1990 |
| 13. | Farmyard manure, rice straw | Patancheru series | N/A | 2 | F (Research farm) | Smith et al. 1992 |
| 14. | Jute geotextile | Sandy loam soil | N/A | 50 | F (watershed area) | Juyal and Dadhwal, 1996 |
| 15. | Coconut fiber mat | Tropudult | N/A | 9 | F (University experimental station) | Mapa, 1996 |
| 16. | Barley straw mulch | Fine sandy loam | N/A | N/A | F (Potato crops) | Edwards et al. 2000 |
| 17. | Straw, rice straw, straw/coconut, coconut, and aspen fibers (excelsior) | Sandy clay loam | N/A | 60 | F (A site on the college campus) | McCullah and Howard, 2000 |
| 18. | Jute mat | Decomposed granite soil | N/A | 60 | N/A | Ahn et al. 2002 |

Table 2-1. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 19. | Straw and wood strands | Gravelly sand | Rill | 30 | L | Foltz and Dooley, 2003 |
| 20. | Cellulose mulch | Gleysol hydroameliorated | N/A | N/A | F (Bell-pepper crops) | Romic et al. 2003 |
| 21. | Coir geotextile | Sandy loam | N/A | 49 | F (Hill slope) | Lekha, 2004 |
| 22. | Wood strand | Gravelly sand and sandy loam | N/A | 5 | L | Yanosek et al. 2006 |
| 23. | Coir rolled | Clay | Splash | 9 | F (Experimental station) | Sutherland and Ziegler, 2007 |
| 24. | Wood strand | Silt loam | N/A | N/A | L | Copeland et al. 2009 |
| 25. | Wood shred | Sandy loam and gravelly sand | N/A | 30 | L | Foltz and Copeland, 2009 |
| 26. | Palm, corn, rice straw and bagasse geotextiles | Sandy loam | Interrill | 15 and 45 | L | Smets and Poesen, 2009 |
| 27. | Palm-mat geotextiles | Loamy sand | Splash | 0 | F (Experimental station) | Bhattacharyya et al. 2010 |

Table 2-1. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 28. | Jute geotextile (JGT) | Silty-clay soil | Gullies | N/A | F (Highway) | Choudhury and Sanyal, 2010 |
| 29. | Wheat straw mulch | Sandy loam and silt loam | Splash | N/A | L | Kukal and Sarkar, 2010 |
| 30. | Compose and mulch | Silt loam | N/A | 3.5, 4, 8, 16 | L and F (Farm) | Bhattarai et al. 2011 |
| 31. | OPEFB mulch, Eco-mat, silt pit, and pruned oil palm fronds | Sandy clay texture | Eight-years oil of oil palm tree | 11 | F (Oil palm plantation) | Teh et al. 2011 |
| 32. | Straw and wood strands | Gravelly loamy sand and loamy sand | N/A | N/A | L | Foltz, 2012 |
| 33. | Rice straw mat, sawdust, and gypsum mulches | N/A | N/A | 10 and 20 | L | Lee et al. 2012 |
| 34. | OPEFB mulching and matting | Typic Paleudult (Renggam Series) | Ten-years old of oil palm tree | 11 | F (Oil palm plantation) | Ping et al. 2012 |
| 35. | Sweetgum (*Liquidambar styraciflua*) fruits, riprap, sod | Silt loam | Rills | 4.3 | F (Hillside) | Alqusaireen et al. 2013 |

Table 2-1. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 36. | Rice straw mulch | Sandy loam soil | Splash | 30 | L | Gholami et al. 2013 |
| 37. | Jute net and coir blanket | Silty clay loam | N/A | 100 and 173 | F (Experimental plot) | Álvarez-Mozos et al. 2014 |
| 38. | Jute geotextiles | Peat soil and black cotton soil | N/A | N/A | L | Ghosh et al. 2014 |
| 39. | Barley straw mulch | Sandy loam | Splash | 9 | L | Gholami et al. 2014 |
| 40. | Wood mulch | Clay | N/A | 47 | F (forest) | Prats et al. 2014 |
| 41. | Rice straw blanket | N/A | N/A | N/A | N/A | Deshmukh et al. 2015 |
| 42. | Pruned palm fronds, empty fruit bunches mulches, and Eco-mat | Sandy clay loam | Cultivated with eight-year old oil palm | 11 | F (Oil palm plantation) | Moradi et al. 2015 |
| 43. | Straw mulch | Loamy sand | N/A | 35 | F (Hillslope of mountainous area) | Fernández and Vega, 2016a |

Table 2-1. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 44. | Bark strands | Sandy loam | N/A | 22 - 55 | F (Highway) | Fernández and Vega, 2016b |
| 45. | Barley straw mulch | Sandy | Rill and gully | 6 | F (Vineyard) | Prosdocimi et al. 2016 |
| 46. | Jute and coir blanket | Gravelly loam | N/A | 16 and 51 | L and F (railway corridor) | Kalibová et al. 2016 |
| 47. | Frond pruning | Sandy clay texture | Ten-years old of oil palm | 21, 28 and 42 | F (Oil palm plantation) | Sahat et al. 2016 |
| 48. | Wood fiber mulch | Loamy sand | Rill | 40 | L | Prats et al. 2017 |
| 49. | Hardwood sawdust, rice straw | Silt loam to loamy | Splash | 15-24 | F (Forest) | Jourgholami and Abari, 2017 |
| 50. | Straw mulch | Silt loam and clay loam soil | N/A | 8.7, 18.3, 26.8 | L | Rahma et al. 2017 |
| 51. | Wheat and straw mulch | Loamy sand | N/A (wind erosion) | N/A | F (Experimental plot) | Robichaud et al. 2017 |
| 52. | Corn stalk | Silt loam | N/A | 5 | L | Wei et al. 2017 |

Table 2-1. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 53. | Wood fiber bundle | Clay loam and loam | Gully | 2.3 - 5.3 | F (river basin) | Frankl et al. 2018 |
| 54. | Wheat straw mulch | Sandy loam | Gully | 58, 70 and 84 | L | Lin et al. 2018 |
| 55. | Straw and wood mulch | N/A | Rill | N/A | F (Hillslope) | Schmeer et al. 2018 |
| 56. | Wood fiber | Silt loam | Gully | 100 | F (Highway) | Zhao et al. 2018 |

*N/A= not available

Table 2.1 is summarized as below:

1) 42% of the researchers used straw fiber to control soil erosion, 20.3% used wood shred, 11.9% used jute fiber and the remaining used varies natural fibers such as coir, corn stalk, palm, and bagasse.
2) Silt loam is the most type of soil being tested followed by sandy loam.
3) Slope steepness is varying from 0º to 60º.
4) More than half of the studies do not mention the stage of erosion to be addressed. Nevertheless, many researchers focus during splash and rill stages.
5) Soil erosion control by using agricultural waste in oil palm plantation is still small (5%). Nonetheless, current soil erosion controls in oil palm plantations is emphasized on the matured stage of oil palm and none of them practicing soil erosion control during land clearing and replanting stages.
6) Furthermore, the oil palm plantation research is mainly focused on technique to increase the yield production of oil palm. Although soil erosion and declination of soil fertility are of concern in some studies, but in most plantations, these are resolved by cover crops and inorganic fertilizer applications (Hartemink, 2005).