Empty Fruit Bunch-Seaweed Biocomposite as Potential Soil Erosion Mitigation Material for Oil Palm Plantation

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A composite prepared from oil palm empty fruit bunch (OPEFB) and abundantly available wild seaweed showed great potential as a soil stabilizer, which is attributed to its natural hydrophilic nature. The water absorption and thickness swelling percentages of the oil palm empty fruit bunch-seaweed composite (OPEFB-SW) were recorded at 117.2% (± 7.1) and 10.5% (± 1.7), respectively. The main objective of this study was to determine the effectiveness of the biocomposite in regulating runoff volume and water quality due to soil erosion from the experimental plots. Hence, the volume, turbidity, and total suspended solids (TSS) of the water runoff were investigated. A rainfall simulation test was conducted to test the effectiveness of the cover material (biocomposite) at different application levels (0 kg/m^2 (T1), 3.0 kg/m^2 (T2), 4.0 kg/m^2 (T3), and 5.0 kg/m^2 (T4)) of the composite in reducing soil erosion. Overall, the OPEFB-SW composite demonstrated its capability to absorb rainfall impact and therefore stabilize the soil structure. The runoff volume, turbidity, and TSS were reduced significantly to 49.1%, 94.6%, and 99.2%, respectively. In addition, the plot with 4.0 kg/m^2 indicates the best treatment in regulating runoff volume, turbidity, and TSS.

Keywords: Soil erosion control; Oil palm empty fruit bunch; Seaweed; Biocomposite; Oil palm plantation; Agricultural waste; Turbidity; Total suspended solids; Runoff volume; Water quality

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INTRODUCTION

Soil erosion is mainly driven by natural agents, water and wind. It is manifested as four main phases: splash, sheet, rill, and gully (Monsieurs *et al.* 2015). Past studies regarding soil erosion and sedimentation controls have focused mostly on preventing soil erosion during the splash and rill stages in forests and highways. However, few studies have focused on oil palm plantations (Sahat *et al.* 2016).

Although soil erosion control practices, such as OPEFB mulching and eco-mat, have been shown to reduce soil erosion and nutrient leaching in oil palm plantations (Sahat *et al.* 2016), nevertheless, such approaches are limited by factors such as high labor requirements and high costs of transportation of waste (EFB) from mills to estates. Such limitations, therefore, have resulted in less attention being paid to mitigation of soil erosion, especially in new replanting areas. To date, the application of EFB can be performed only at matured oil palm areas, which is not the main targeted area for soil erosion mitigation.

To unlock such limitations, oil palm empty fruit bunch (OPEFB) and wild seaweed (SW) were utilized in the form of a biocomposite as an innovative approach to control soil erosion, particularly at the land clearing or replanting stage. In this matter, OPEFB and SW appear to play roles as a reinforced material and matrix, respectively, in the biocomposite.

To date, the use of biocomposites for soil erosion mitigation is poorly utilized. In fact, there has been no research yet on OPEFB and raw seaweed as a composite due to their unfavourable hydrophilic nature in commercial applications (Al-Oqla and Omari 2017). However, in this study, hydrophilicity of materials is vital to achieve the objective. While OPEFB is used as a mulching material to control soil erosion, seaweed is commonly used as a fertilizer due to its outstanding nutrient content, which is crucial to improving plant growth and soil structure (Elansary *et al.* 2016).

Therefore, the aim of this study is to investigate the effectiveness of the OPEFB-SW composite as a micro-regulator of runoff volume, turbidity, and total suspended solids (TSS) that result from erosion.

EXPERIMENTAL

Materials

The OPEFB was obtained from a selected oil palm plantation premise in Peninsular Malaysia, while the abundant brown seaweed (*Sargassum*) was collected along the coastal area of Malaysia. The species can be identified through the World Register of Marine Species (Flanders Marine Institute, n.d.). The OPEFB fibers and seaweed were washed thoroughly with tap water to remove any impurities before being air-dried overnight and then oven-dried at 80 °C until a constant weight was achieved (Fang *et al.* 2017). They were then ground by a rapid granulation (coarse grinding) before being further granulated into a powder form *via* hammer milling (fine grinding) (Eik Seng Machinery Sdn Bhd, Penang, Malaysia) with a sieve size of approximately 1 mm. The powder form of the fibers and seaweed were stored in tight bottles for the composite preparation.

Methods

The composite was prepared by mixing the seaweed to OPEFB with the weight-based ratio of 3:7. The preparation of the composite was made using a pellet mill that produced oil palm empty fruit bunch-seaweed composite (OPEFB-SW) approximately 0.5 cm in diameter. The OPEFB-SW was freeze-dried until a constant weight was achieved. Prior to the water absorption, thickness swelling, and soil erosion mitigation tests, the final product of OPEFB-SW was stored in sealed packaging to maintain its moisture content. The characteristics of the OPEFB-SW are recorded in Table 1.

The water absorption and thickness swelling tests were assessed and calculated by following the ASTM D1037-99 (1999) standard. For soil erosion mitigation test, a rainfall simulator model (Fig. 1), modified from Kibet *et al.* (2004) was used. The rainfall intensity for each set of experiments was between 76.8 and 87.2 mm/h with a water pressure of 138 kPa (20 psi) and a flow rate of 5 L per min.

Table 1. Basic Characteristics of OPEFB-SW

Characteristics	
Length (cm)	1 to 2
Diameter (cm)	0.05
Weight (g)	0.2766 ± 0.04
Volume (cm^3)	0.382 ± 0.01
Density (g/cm^3)	0.724
Moisture content (%)	15.22

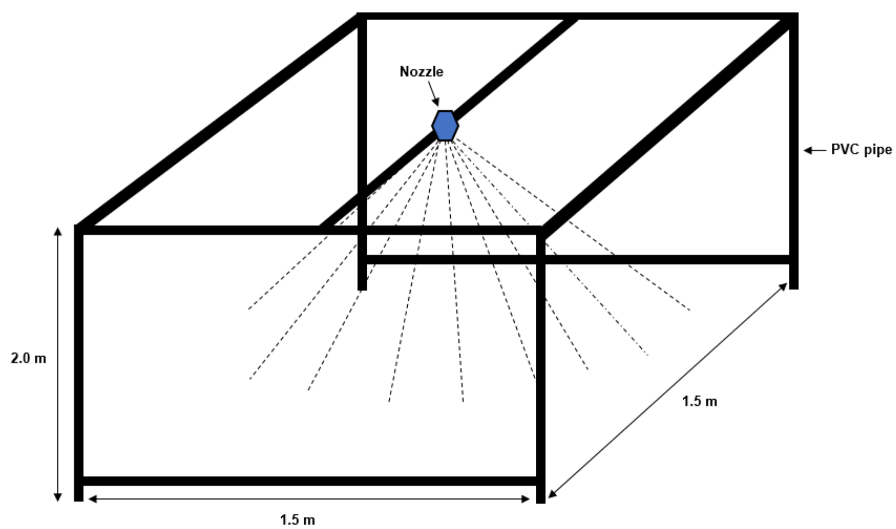

Fig. 1. Illustration of rainfall simulator model with nozzle attached

Soil containing 88.5% sand, 11.5% silt, and 0% clay with a moisture content of 19.6% and a bulk density of 1.6 g/cm^3 was mixed and placed in a soil box. The soil box was custom-made from a Perspex acrylic sheet with dimensions of 0.4 m length, 0.2 m width, and 0.09 m depth. The soil box was placed at a height that allowed for the placement of the collection bottles with further elevation of the box by 3 cm so that the back of the box was always 3 cm higher than the front of the box, resulting in a 3% slope (Kibet *et al.* 2004). The runoff samples were collected every 5 min for 1 h by switching the collection bottles for each time interval. The data collected for this research included: (i) total runoff volume (L), (ii) turbidity (NTU), and (iii) total suspended solids (g).

Most cover material studies suggested that the cover material for soil erosion control was determined based on the mass to surface area ratio, varying from kg to tonnage and m^2 to hectare, respectively. In this study, considering the plot size, the OPEFB-SW that was used as the cover material was set as 0, 3.0 kg/m^2, 4.0 kg/m^2, and 5.0 kg/m^2 that covered for 0, 50, 70, and 100% of the plot surface, respectively. Note that 5.0 kg/m^2 was the maximum capacity for the respective plot size. Each rate was weighed before it was applied randomly onto the surface soil. The results for the rainfall simulation test were recorded and organized using an Excel spreadsheet (Microsoft, 16.0.4266.100, Redmond, WA, USA). A IBM SPSS Statistics 20 software (Armonk, NY, USA) was used to determine the significant difference of means for each plot.

RESULTS AND DISCUSSION

Water Absorption

The water absorption of the OPEFB-SW composite is presented in Fig. 2. Progressive absorption was observed until day 4. This explained the capillary action that occurred in the tiny spaces within the OPEFB fiber, allowing the water to transfer naturally (Jayamani *et al.* 2015) into the pellet, which resulted in an increase in moisture content.

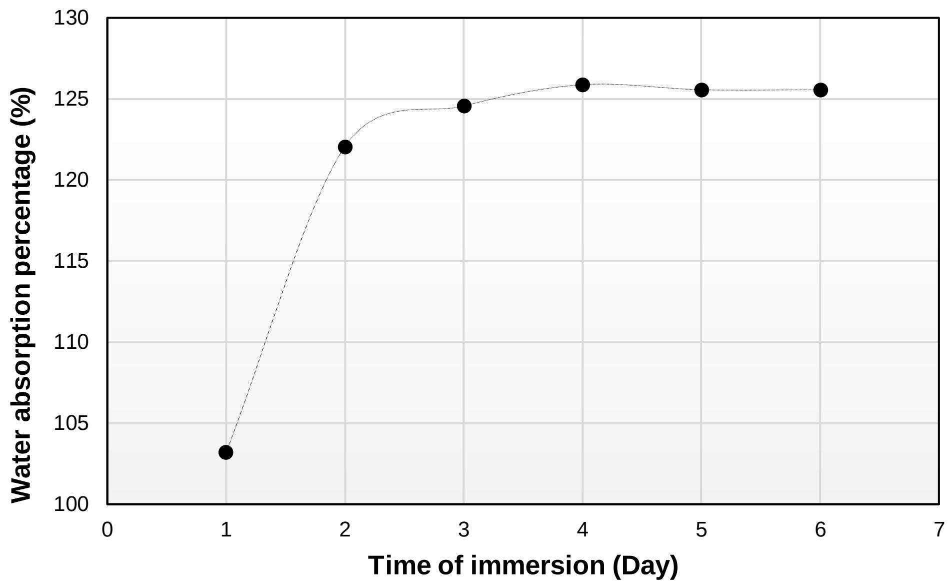

Fig. 2. Water absorption curve during the immersion of the OPEFB-SW composite in water

The average water absorption percentage of the OPEFB-SW was 117.2% ± 7.1%, suggesting a hydrophilic characteristic due to the presence of cellulose in the cell walls of the OPEFB and seaweed. Hydroxyl groups in the cellulose formed hydrogen bond with water molecules, thus causing the bio-composite to absorb high amount of water (Ashori and Sheshmani 2010). The constant pattern of water absorption percentage after day 4 marked the saturation point of the composite where the water movement diffused equally in and out from the composite. At equilibrium conditions, the diffusion phenomenon ceased due to the elimination of the driving force (Khazaei 2008). Nevertheless, the water molecule motion still progressed, but there was an absence of any net water movement.

Thickness Swelling

The absorption of water led to a moisture build-up in the fiber-matrix interface and the fiber cell wall, resulting in fiber swelling (Ashori and Sheshmani 2010). The water absorption swelled up the cell wall of the OPEFB fiber to its saturation point. Moreover, debonding of the fiber (OPEFB fiber) and the matrix (seaweed) occurred after day 4 due to the active action of the water molecules in attacking the interface of the fiber and the matrix. Continuous immersion of the composite in water resulted in dimensional instability, as demonstrated in Fig. 3.

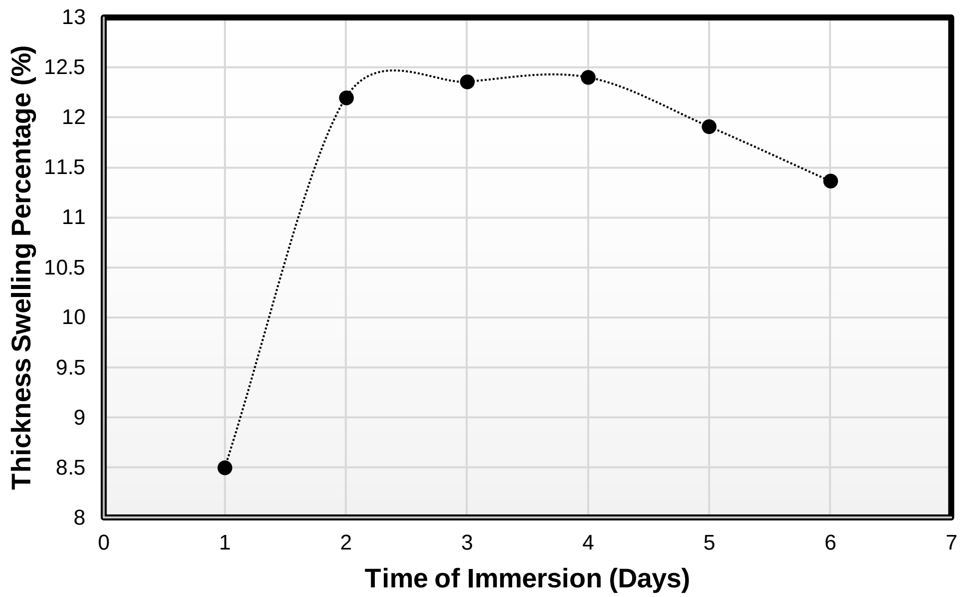

Fig. 3. Thickness swelling curve during the immersion of the OPEFB-SW composite in water

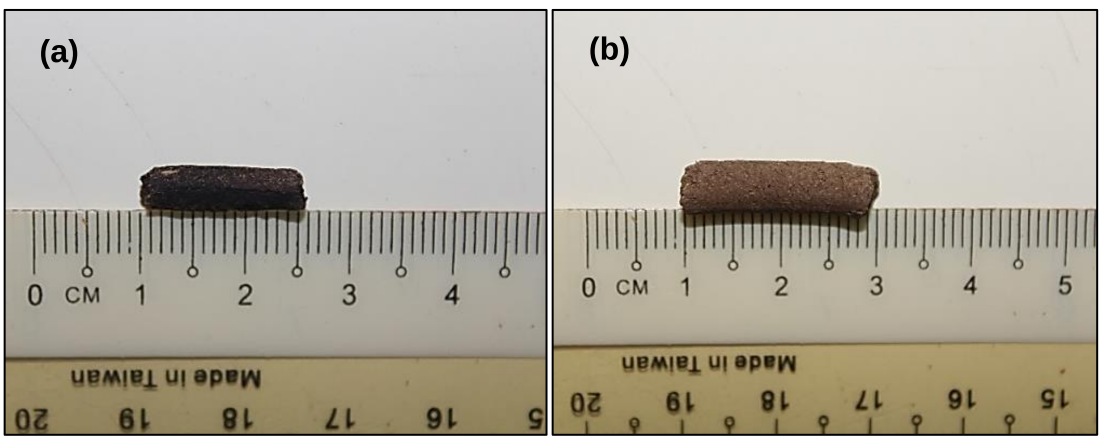

Fig. 4. Comparison of size between the OPEFB-SW (a) before water immersion and (b) after weeks of water immersion

Figure 4 shows the reduction of the OPEFB-SW size after the thickness swelling test. The thickness swelling of the OPEFB-SW composite followed the similar trend of the water absorption behaviour. The composite started to deteriorate only after day 4 when debonding of the fiber-matrix structure from the composite was observed. This was attributed to the reduction of stress transfer between the fiber in the composite and the matrix (Farahani *et al.* 2012). The average thickness swelling of the OPEFB-SW was recorded as 10.52% ± 1.73%, which shows that when the water molecules entered the cellulose network, the OPEFB fiber was strong enough to support the swelling and provide a rigid increment of thickness swelling.

Soil Erosion Mitigation

For the effectiveness of the biocomposite, the average result for runoff volume, turbidity, and TSS is tabulated in Table 2 and illustrated in Fig. 5.

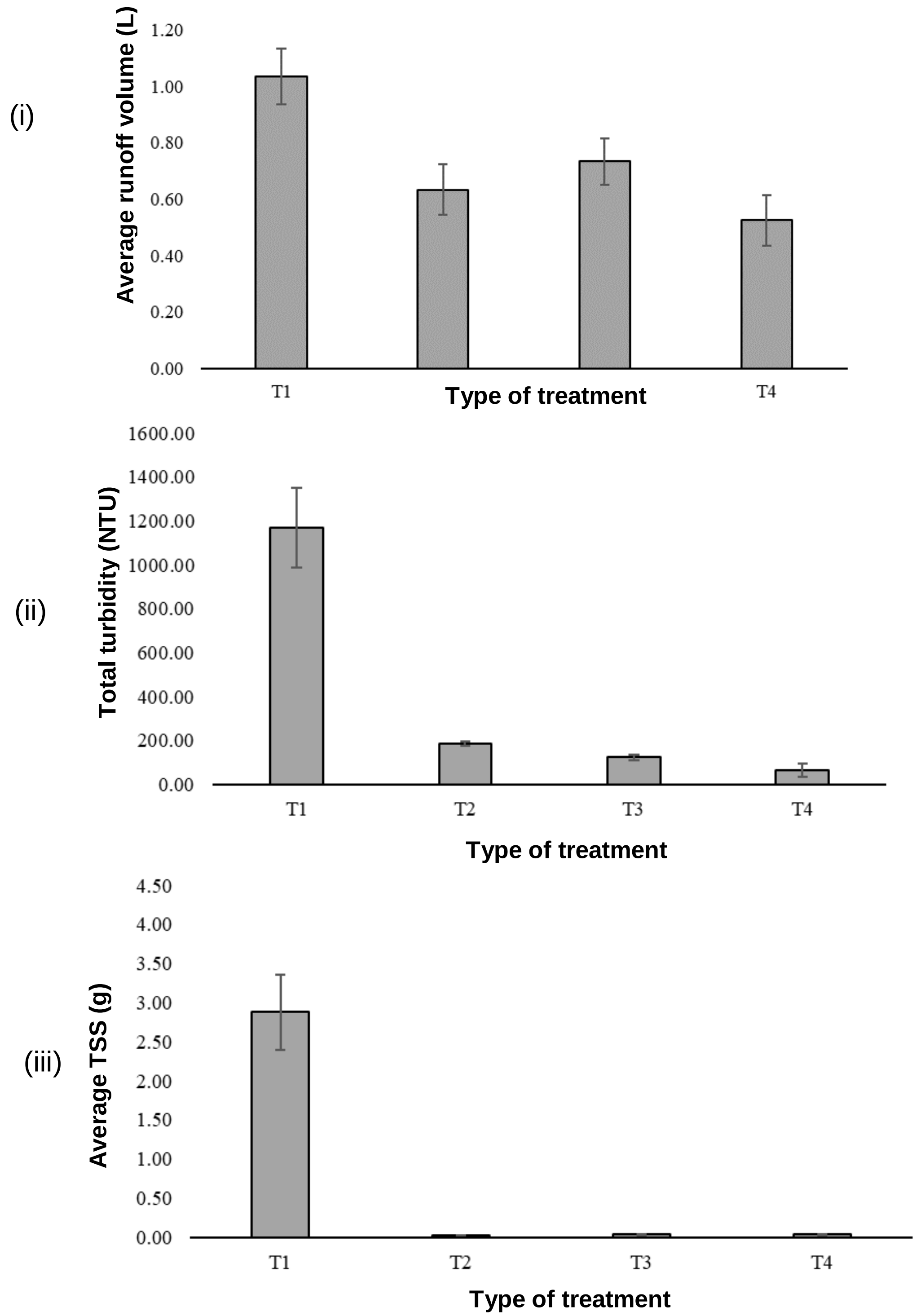

Fig. 5. Average results for (i) volume, (ii) turbidity, and (iii) TSS of runoff water for four different cover rates of OPEFB-SW in 60 min of experiment. Details are presented in Appendix 1 and 2.

Table 2. Average Results for Runoff Volume, Turbidity, and TSS in T1, T2, T3, and T4 with Standard Deviation.

Treatments	Runoff volume (L)	Turbidity (NTU)	TSS (g)
0 kg/m^2 (T1)	1.04 ± 0.10	1168.61 ± 179.92	2.88 ± 0.48
3.0 kg/m^2 (T2)	0.63 ± 0.09	184.44 ± 30.88	0.04 ± 0.01
4.0 kg/m^2 (T3)	0.73 ± 0.08	122.96 ± 13.19	0.03 ± 0.01
5.0 kg/m^2 (T4)	0.53 ± 0.09	63.69 ± 9.72	0.02 ± 0.01

Runoff volume

Figure 5(i) illustrates the runoff volume for all plots in 1 h. It can be perceived that T1 (control plot) had the highest mean runoff volume as expected, while T4 plot had the lowest total runoff volume. Nevertheless, there was no significant difference between different OPEFB-SW application rates (T2, T3, and T4). Even though there was not much reduction of runoff volume with the increment of the OPEFB-SW rates, in general, soil with the OPEFB-SW contributed to lower runoff volume compared to the control plot. This was due to the fact that the biopolymers contained in the biocomposite absorbed and retained water excellently before slowly releasing it to the sandy soil. This allowed more time for water to infiltrate into the soil by holding more water at the soil surface through mechanical impedance (Gorman *et al.* 2000). Therefore, less water was available as runoff.

However, an unexpected increase of runoff volume was observed in T3 where the higher rate of the OPEFB-SW produced more runoff volume compared to the lower rate (T2). This was at least partly due to the characteristic of the composite itself. In the water absorption and thickness swelling results, it was observed that the water absorption and thickness swelling behavior of the OPEFB-SW fluctuated over time. This was due to the high hydrophilic characteristic of the OPEFB and seaweed in the composite that caused the composite to saturate faster with water. Subsequently, the water molecules simply diffused in or out of the composite, which caused the inconsistency of the runoff volume result. This was one of the limitations of this study driven by the natural properties of these materials.

Yet, all of the OPEFB-SW composite treatments effectively reduced runoff volume compared to the control plot. The OPEFB-SW reduced runoff volume until 49.3% compared to the control plot. Besides excellent water absorption behaviour, the covered soil surface from kinetic energy of raindrop impact reduced the surface sealing, and thus increased the infiltration capacity of water in the soil profile (Lalljee 2013).

Turbidity

In Figure 5(ii), T1 (control plot) recorded the highest turbidity compared to the other treatments. This occurred because the bare soil was vulnerable to raindrop impact, as there was no cover material on the soil surface. Such a setting has resulted in splash erosion where soil particles can be easily detached, eroded, and transported by the runoff, causing high turbidity.

Generally, as the ratio of mass-to-surface area of the OPEFB-SW increased, the turbidity of water runoff decreased. As the ratio (mass-to-surface area) of the OPEFB-SW increased, the high surface area of the OPEFB-SW allowed it to absorb the energy from the rain drops, hence, it reduced the soil detachment and resulted in low turbidity in the runoff.

Table 2 shows that all the treatments had turbidity below 200 NTU, except for T1. The T4 was the most remarkable and effective rate evaluated, with an average turbidity of 63.7 NTU throughout the experiment, followed by the T3 and T2 treatments with 123.0 NTU and 184.4 NTU, respectively. Overall, all plots covered by the OPEFB-SW pellets showed a reduction in turbidity > 80%, while T1 (control) marked the highest turbidity of 1168.61 NTU.

Total suspended solids

Figure 5(iii) illustrates the TSS observed from all plots including the control plot (T1). The results indicated that the control plot demonstrated the highest suspended solid in water runoff compared to other treatments, because the soil particles were exposed without cover, and thus easily detached by rainfall drop impact. In contrast, for soil with the OPEFB-SW cover, it slowed down the raindrop impact by acting as a protective cushion and further decreased soil detachment by raindrops (Foster and Meyer 1977). Overall, all of the OPEFB-SW plots contained the lowest values of TSS.

It was observed that the total TSS decreased with increased OPEFB-SW rates (kg/m^2), in agreement with Shi *et al.* (2013). The higher ratio of cover material applied on the soil surface resulted in higher amounts of soil particles, which were trapped within the cover materials, hence minimising soil erosion. In fact, an increased soil cover (kg/m^2) reduced the area of soil disaggregation and surface sealing. The cover materials served as raindrop interception, thus, dissipating the energy (Smets *et al.* 2008).

Impact of OPEFB-SW Cover in Mitigating Soil Losses

The sole purpose of placing a cover on the bare soil is to provide temporary protection against the raindrop impacts during the critical stage of vegetation establishment. According to Foltz and Copeland (2009), the mitigation of soil loss is defined in Eq. 1,

$$M = \left(\frac{M1 - M2}{M1}\right) \times 100 \qquad (1)$$

where M is the mitigation percentage (%), M_1 is an average sediment loss of bare soil treatment (g), and M_2 is the average sediment losses for that particular treatment (g). Therefore, the TSS data for each treatment were averaged across all the samples taken during the rainfall simulation test, and the results are listed in Table 3. The percentage of soil loss reduction compared to the bare soil plot was recorded as well.

Table 3. TSS Results in All Treatments and Reduction of Soil Loss in Percentage for OPEFB-SW Treatments

Treatments[1]	Average TSS (g)	Mitigation of Soil Loss[2]
T1 (Control Plot)	2.88 ± 0.48	-
T2	0.04 ± 0.01	98.62%
T3	0.03 ± 0.01	98.86%
T4	0.02 ± 0.01	99.16%

[1]OPEFB-SW biocomposite cover percentage (%);
[2]Percent reduction compared to control, $\left(\frac{Bare - treatment}{bare}\right) \times 100$

Generally, the application of the OPEFB-SW cover mitigated soil erosion > 95%. The OPEFB-SW pellets reduced the detachment of soil by creating barriers and obstructions against the impact of the raindrops. The reduction of raindrop impacts is through hydrophilic characteristics of natural materials to absorb, retain, and release water in a gradual fashion upon detachment (Syakir *et al.* 2016). This resulted in the reduction of soil content and the carrying capacity of the runoff. Additionally, the cationic bridges between the soil and the OPEFB-SW composite formed, enhanced the inter-particle attraction forces between soil particles, stabilized the soil aggregates by reducing the shear stress, decreases soil detachment, and lowered the amount of soil loss in the runoff (Foster and Meyer 1977; Lee *et al.* 2010).

From Table 2 it can also be noticed that T2, T3, and T4 plots performed similarly with an average TSS of 0.04 g, 0.03 g, and 0.02 g, respectively, compared to the control plot (T1) that recorded the highest TSS among all (2.88 g). It can be said that the percentage of reduction of soil detachment increased with the increment of the OPEFB-SW cover percentage. Nonetheless, the differences between each rate were not significant.

In contrast, the result from the statistical analysis indicated that there was a significant difference in the runoff volume, turbidity, and TSS between the OPEFB-SW plots (T2, T3, and T4) and the control plot (T1). Nevertheless, the results demonstrated that the different OPEFB-SW rates showed no significant difference.

CONCLUSIONS

1. The average water absorption percentage of the composite was 117.2% ± 7.1%. Meanwhile, for the thickness swelling percentage, the composite recorded an average of 10.5% ± 1.7%.
2. The oil palm empty fruit bunch – seaweed composite (OPEFB-SW) plots reduced runoff volume, turbidity, and total suspended solids (TSS) by 49%, 80%, and 95%, respectively.
3. The effectiveness in reducing runoff volume and TSS differed significantly between the OPEFB-SW treatments (T2, T3, and T4) and the control plot (T1) only.

4. There was no significant difference between the T2, T3, and T4 treatments in runoff volume and TSS.
5. For turbidity, T4 showed a significant difference with T2 only.
6. Results from experiments with simulated rainfall (76.81 to 87.21 mm/h with water pressure of 20 psi and a flow rate of 5 Lpm) in 1 h on 3% gradient sandy soil covered by 4 kg/m^2 (T3) of the OPEFB-SW appeared to provide sufficient soil cover to prevent erosion from raindrop impact.
7. All the OPEFB-SW treatments had significant differences with the control plot (T1), suggesting the effectiveness of OPEFB-SW in regulating the amount of runoff, turbidity, and TSS to water body.

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SUPPLEMENTARY INFORMATION

Table A1. Statistics of Runoff Volume, Turbidity, and Total Suspended Solids for T1, T2, T3, and T4, Respectively

Runoff Volume	T1	T2	T3	T4
Mean	1.04	0.63	0.73	0.53
Standard Error	0.10	0.09	0.08	0.09
Median	1.15	0.76	0.70	0.65
Mode	1.20	0.00	0.70	0.65
Standard Deviation	0.34	0.31	0.29	0.31
Minimum	0.00	0.00	0.00	0.00
Maximum	1.20	0.85	1.10	0.85
Sample Size	12.00	12.00	12.00	12.00
Confidence Level (95.0%)	0.22	0.20	0.18	0.20

Turbidity	T1	T2	T3	T4
Mean	1168.61	184.44	122.96	63.69
Standard Error	179.92	30.88	13.19	9.72
Median	948.62	189.09	124.80	68.95
Mode	-	0.00	-	0.00
Standard Deviation	623.26	106.97	45.71	33.68
Minimum	0.00	0.00	0.00	0.00
Maximum	2424.33	362.84	193.83	106.40
Sample Size	12.00	12.00	12.00	12.00
Confidence Level (95.0%)	396.00	67.97	29.04	21.40

Total Suspended Solid	T1	T2	T3	T4
Mean	2.88	0.04	0.03	0.02
Standard Error	0.48	0.01	0.01	0.01
Median	2.71	0.04	0.03	0.02
Mode	-	0.00	-	0.00
Standard Deviation	1.66	0.02	0.02	0.02
Minimum	0.00	0.00	0.00	0.00
Maximum	5.12	0.07	0.08	0.07
Sample Size	12.00	12.00	12.00	12.00
Confidence Level (95.0%)	1.06	0.01	0.01	0.01

a) Control plot b) OPEFB-SW plot

Fig. 1A. Changes in turbidity observed in a) control plot and b) OPEFB-SW plot