Field evaluation of using coconut husk and fibre to control slope erosion

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Abstract. One of the most common temporary measures to control soil slope erosion is the placement of synthetic geotextile or biological cover over the sloping surface. However, synthetic geotextiles have some disadvantages. Firstly, they are much expensive compared to biological materials. Secondly, synthetic geotextiles made of polymeric materials are not biodegradable and are likely to cause soil pollution. The use of natural bio-resources, such as coconut husk and fibre, is less costly and they are readily available in tropical countries. It is environmentally friendly and also durable and will not decompose as fast as live mulches due to its high carbon to nitrogen ratio and lignin content. A field experiment is set up to test two designs of coconut mulches, coconut fibre net and coconut husk using onsite experimental erosion plots with a slope gradient of 27⁰. The results showed that the coconut husk placed in the correct orientation is effective in reducing soil loss (980 grams), produced two times less soil loss compared to the control plot of bare soil (2465 grams) and coconut fibre net (2410 grams). Both the mulch covers also enhanced soil and water holding capacity promoting vegetation growth.

1. Introduction

Rapid growth in industry, urban development and agriculture to support the demands from a growing population and global economy has led to more land development, especially in forested area. The forest, which provides temporary water storage, biodiversity conservation, maintaining an unique ecosystem and a carbon storage, has been rapidly cleared and removed – these have often resulted in significant soil erosion. Moreover, development projects often lead to an adverse effect by creating exposed steep soil surfaces, which are vulnerable to erosion and soil loss processes. The degradation of slopes causes onsite problems such as lower soil fertility and reduced soil water holding capacity, and offsite problems such as clogged drain increasing the vulnerability of floods in urban areas [1]. In addition, most climate change scenarios predict a significant increase in the frequency and intensity of rainfall which will, in turn, increase runoff and soil erosion [2]. Understanding the factors that control soil erosion is necessary to recommend suitable actions to protect soils and reduce their vulnerability.

The leading cause of accelerated erosion in Brunei is due to human activities such as the replacement of natural vegetation cover for development purposes [3]. This study has been developed to identify natural ways to help and manage slope erosion control by utilising coconut husk and fibre, which are biodegradable, renewable, low-cost and locally available material. Slope erosion may also cause other engineering and environmental problems such as slope failure which could result in socio-economic
consequences and approximately USD 3.6 million of government funds are being spent on average annually on slope rectification projects in Brunei [4]. Therefore, efficient methods of controlling slope erosion could reduce this factor as one of the underlying causes of slope failure. The use of biodegradable geotextile in controlling slope erosion is widely accepted being cheap, environment and eco-friendly [5]. The main aim of this project is to evaluate the performance of using coconut husk and fibre as a practical solution to control slope erosion.

2. Research background

2.1. Soil erosion
Soil erosion has three phases: 1) The detachment of individual soil particles from the soil mass; 2) The transport processes caused by erosive agents such as flowing water and wind; and 3) The deposition of soil particles occurs when the energy is no longer sufficient to transport the soil particles [6]. There are three divisions of the primary causes of soil erosion. The first division is the energy factors which include rainfall erosivity, runoff volume, wind strength, relief slope angle and slope length. The second division is the protection factors such as population density, plant cover, amenity value and land management. The third division is the resistance factors, such as soil erodibility, infiltration capacity and soil management [7]. Furthermore, the slope angle and gravity also influence soil erosion. In areas of high relief, the erosion on steep slopes occurred due to a process called mass-wasting, whereby the gravity, which is a passive force, helps to transport the weathered soil by causing the soil to fall from the original position [8].

2.2. Mulching method
Mulch is a layer of material applied on the surface of the soil to conserve moisture, improve fertility, protect the soil from the effects of raindrops, create soil crustin as well as temporarily stabilise the soil, by protecting the soil surface from erosive agents such as rainfall or wind [9]. Mulches protect the soil surface during the critical period of plant establishment. Mulches are categorised into organic and inorganic types: organic mulches are derived from living plants such as crop residues, for example, straw, hay, stalks and grass cuttings, while inorganic materials are derived from inert materials such as plastic, gravel, stones or fabrics. Mulches can reduce soil erosion by reducing raindrop impacts, increasing soil infiltration and storage, decreasing runoff velocity, improving soil structure and porosity, and improving biological activity in the soil. The effectiveness of mulch materials on controlling soil erosion depends on the types of material used, mulch morphology, application rate, method of application, soil type, slope, and climatic characteristics. Furthermore, the effectiveness lifespan of the mulch materials is affected by their durability [9].

3. Methodology

3.1. Study area
In order to evaluate the effects of coconut mulch on controlling soil erosion, the location of the study area should be open with no obstacles from tree cover and buildings, so that it is fully exposed to the agents that cause soil erosion. The area selected for this study based on these criteria was a vacant land plot on a medium slope located on the campus of Universiti Teknologi Brunei.

3.2. Coconut products as natural mulch
In this study, coconut husk and fibre are used to deploy the natural arrangement of mulching on a slope. The mulch from fibre netting or mats will increase surface roughness and slow down the velocity of the surface water runoff over the slope. Additionally, coconut fibre can absorb water and is durable due to its high carbon to nitrogen ratio [10]. Coconut fibres are also among the most durable natural fibres because of its high lignin content. Attractions of using coconut fibre matting are its light weight, less labour intensive easy laying and its biodegradability that will fit into the natural environment [11].
Coconut fibre has the high tensile strength (175 MPa) among natural fibres and also retains much of its tensile strength when wet [12,13].

3.2.1. Coco-net. Different mesh sizes of coco-net, ranging from 25mm x 25mm to 75mm x 75mm has been previously studied [14], and the results showed that all sizes of mesh were effective in minimising soil erosion regardless of the mesh size of the coco-net. For the current study, coconut fibres which were extracted from the coconut husk were used to set up the first experimental design. The coconut fibres were twisted, compressed and tied together to make the fibres into long ropes spanning the research plot. The coconut ropes were then tied together to produce a net with the mesh size of 200mm x 200mm.

3.2.2. Coconut husk. In the second experimental design, coconut husks were arranged in a consistent pattern directly on the surface of the soil. High strength, stiffness, bulkiness, and resistance to soil moisture and microbes are the properties that makes coconut husks suitable as long lasting mulch. It also has higher surface area compared to coco-net. Therefore, the coconut husk can be applied with excellent soil-retaining capability, thereby reducing erosion susceptibility.

Figure 1. Erosion plot layout.

3.3. Plot design
The erosion plot design was a closed system and was a modification of the design used by [15]. This study used three erosion plots with roughly the same size of approximately 16 m² on a slope of 27° angle. Figure 1 shows the schematics of the erosion plot. Plank boards of 20 cm deep, of which approximately 5 cm penetrated into the soil and 15 cm remained above the surface, enclosed the plot boundaries to prevent runoff and soil entering the plot. The bottom part of the plank board boundary has a triangle shape to direct the entire runoff into a PVC pipe of 40 cm in length and 8 cm in diameter. The PVC pipe in turn directed runoff and eroded soil into a 200-litre plastic barrel, which was placed underground at the bottom of each plot. The barrels were covered and sealed with plastic and tarpaulin to prevent direct rainfall on the barrels.

3.4 Plot layouts
As shown in figure 2 and figure 3, a total of three plots were constructed consisting of bare soil as a control plot (Plot A), coco-net (Plot B) and coconut husk (Plot C). Two layouts were evaluated in this study. Plots A and B were identical in both layouts, while the coconut husk mulches in Plot C were arranged vertically and horizontally in layout 1 and layout 2 respectively.
3.5 Data collection
Runoff collected from the plots were measured within the same day after each rainfall event. All runoff-producing rainfall events occurring within 24 hours were considered as a single event. It was assumed that there were no significant losses attributed to evaporation from the water drums sealed underground. A rain gauge was installed on the study area to determine the amount of rainfall while the duration of rainfall was obtained from the Brunei Darussalam Meteorological Department based on the nearest official weather station located at the Brunei International Airport, approximately 5 km away from the experiment plot. After each rainfall event, the surface runoff and sediment yield were collected, recorded and measured. Collected samples were stored in bottles for transportation purposes. Before transferring the collected samples into the bottles, water and sediment were stirred to ensure the sample was thoroughly mixed. After each collection, the barrels within each plot were cleared and cleaned up before the next rainfall event was recorded. The procedure was repeated for all plots.

The collected runoff and soil loss were weighed to determine its wet mass. The sediment is then separated from the water by settling and filtering with a fine cloth filter, dried in an oven at 105°C and weighed to determine the dry sediment weight. Actual runoff volume and sediment yield were then calculated.

In order to compare the runoff and soil loss values observed in each mulch plots with those of the control plot, the effective indexes as recommended by Alvarez et al. (2013) reproduced below were used in this study [1]:

\[ RRE_i = \left( \frac{R_{control} - R_i}{R_{control}} \right) \cdot 100 \]  \hspace{1cm} (1)

\[ SLRE_i = \left( \frac{SL_{control} - SL_i}{SL_{control}} \right) \cdot 100 \]  \hspace{1cm} (2)

\( RRE_i \) and \( SLRE_i \) are respectively runoff and sediment loss reduction effectiveness of a treatment (mulch) which are measured in percentage, whilst \( R_i \) and \( SL_i \) are the amount of runoff and soil loss from the treatment, respectively.
Positive value of effectiveness indicates that the mulch effectively reduces runoff and soil loss, whereas a negative value corresponds to mulch indicates that the treatment produces more runoff or soil loss than the control. Generally, the effectiveness has been calculated either by using runoff measurements or soil loss measurements [1].

4. Results and discussion

4.1 Rainfall events
During the study period, from January to May 2020, a total of 43 rainfall events were recorded by the Brunei Darussalam Meteorological Department. However, only 9 rainfall events were studied in this experiment because the other 34 rainfall events were either non-erosive rainfall, or erosive rainfall events which exceeded the capacity of the water barrels that were excluded from the analysis. Monthly rainfall records over the study period are shown in figure 4.

![Figure 4. Monthly rainfall records January to May 2020.](image)

4.2 Rainfall and runoff
The relationship between rainfall and runoff during the study period are shown in table 1. For layout 1, the total amount of runoff collected was 7.6 L, 33.1 L and 49.7 L, and for layout 2, the total amount of runoff collected was 286.8 L, 320.2 L and 151.6 L from the plots A, B and C respectively.

4.3 Rainfall and soil erosion
Table 1 also shows the relationship between rainfall and soil erosion for both layout 1 and layout 2. For layout 1, the total amount of soil eroded was 30.5 g, 138.5 g and 100.7 g, while for layout 2, the total amount of soil eroded was 2465 g, 2410 g and 980 g from the plots A, B and C respectively.

4.4 Influence of mulch covers on runoff
For layout 1, the result shows that Plot A (bare plots) produced the least amount of runoff compared to Plot B (coco-net) and Plot C (coconut husk) which produced approximately 4 to 7 times more runoff than Plot A respectively. The entire surface area of soil for Plot A is exposed, thus allowing a large volume of water to be infiltrated and absorbed into the soil. When comparing both of the mulch plots, it is clear that Plot C produced much higher runoff than Plot B. This can be associated with the amount of surface area covered by coconut husk which is higher than coco-net.

The expectation is to reduce the runoff volume by introducing a mulch cover. However, this experiment has shown otherwise for both coco-net and coconut husk indicating negative runoff reduction effectiveness (RRE) for both cases. At least 17 research studies on the effectiveness of geotextile show geotextile cover either biological or synthetic, was found to be ineffective in reducing runoff [16].
Similarly, it was observed under laboratory condition that overland flow simulation also demonstrated that both biological and synthetic geotextiles had little effect in reducing runoff [16].

A previous study also suggested that both biological geotextiles and synthetic polyester textile produced 2-3 times higher runoff volumes than the control (bare soil) plots [1]. It was concluded that when the coconut fibres are wet (due to rainfall), the fibres expanded causing the coco-net geotextile to be lifted up from the soil surface, even though it was adequately attached down. The failure in the ability of the coconut fibre strand to adhere to the soil surface likely caused the runoff flow velocity beneath it to increase hence limiting the time for the precipitation to infiltrate into the soil and therefore increasing runoff volume [17]. The influence of geotextiles on runoff generation is also related to the slope gradient. Biological geotextiles were found to be much more effective in reducing runoff on a medium slope (15°) compared to a steep slope (45°) [18]. The contact between geotextile and soil has been found to decrease as the slope increases. These void spaces cause enhance flow paths underneath the geotextile further limiting infiltration of rainwater into the soil and promoting runoff downslope underneath the geotextile fibres [19].

Additionally, both coco-net and coconut husk mulches have an impermeable surface thus increasing and concentrating the runoff in the areas between and around the coconut fibres. As a result, both of the mulch covers were not effective in reducing runoff velocity as they intercepted the rainfall and allowing the water to flow down the slope increasing the runoff velocity and volume and at the same time increasing the transport capacity of sediment and hence increasing the rate of soil loss in both of the mulch plots. In contrast, the result from layout 2 in table 1 shows that by changing the orientation of the coconut husk, there is a significant decrease in runoff volume for Plot C. The result shows positive RRE for Plot C and in comparison, it produced about 76% and 96% less runoff volume than Plot A and Plot B respectively. This can be attributed to the observation that the coconut husks acted as miniature dams serving as a catchment structure to retain the eroded soil as shown in figure 5. This in turn reduced the runoff velocity by increasing the surface roughness of the slope – hence allowing more time for precipitation to infiltrate into the soil.

Although both mulch covers in layout 1 were unable to reduce the amount of runoff, the result suggests that bare plots are more prone to over-saturation of the soil due to the high infiltration rate. In contrast, mulch covers limit the rate of infiltration into the soil and thereby prevents over-saturation of soil. Over time, this may cause affect the slope stability, particularly during the rainy season when rainfall events are much more intense and frequent. The wet soils have been found to double the runoff coefficient and shorten the time to runoff, compared with the same soils when it is dry [20]. Saturated soils may also offer reduced shear resistance, and thus become prone to erosion [21].

**Table 1.** Amount of runoff and soil erosion produced from different experimental layouts.

| Experiment | Date       | Layout 1         | Layout 2         |
|------------|------------|------------------|------------------|
|            | 9/2/2020   | 5/3/2020         | 10/3/2020        |
| Total rainfall (mm) | 6.0        | 6.6              | 7.3              |
| Rain duration (hr:min) | 3:35       | 9:55             | 6:25             |
| Runoff Plot A (L) | 2.9        | 0.3              | 4.4              |
| Runoff Plot B (L) (RRE) | 8.5 (-1.9) | 1.2 (-3.0)       | 23.4 (-4.3)      |
| Runoff Plot C (L) (RRE) | 15.0 (-4.2) | 4.8 (-15.0)      | 29.9 (-5.8)      |
| Erosion Plot A (L) | 15         | 0.5              | 15               |
| Erosion Plot B (L) (SLRE) | 65 (-3.3)  | 0.7 (-0.4)       | 35 (-1.3)        |
| Erosion Plot C (L) (SLRE) | 65 (-3.3)  | 3.5 (-6.0)       | 70 (-3.7)        |

The failure in the ability of the coconut fibre strand to adhere to the soil surface likely caused the runoff flow velocity beneath it to increase hence limiting the time for the precipitation to infiltrate into the soil and therefore increasing runoff volume [17]. The influence of geotextiles on runoff generation is also related to the slope gradient. Biological geotextiles were found to be much more effective in reducing runoff on a medium slope (15°) compared to a steep slope (45°) [18]. The contact between geotextile and soil has been found to decrease as the slope increases. These void spaces cause enhance flow paths underneath the geotextile further limiting infiltration of rainwater into the soil and promoting runoff downslope underneath the geotextile fibres [19].

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Although both mulch covers in layout 1 were unable to reduce the amount of runoff, the result suggests that bare plots are more prone to over-saturation of the soil due to the high infiltration rate. In contrast, mulch covers limit the rate of infiltration into the soil and thereby prevents over-saturation of soil. Over time, this may cause affect the slope stability, particularly during the rainy season when rainfall events are much more intense and frequent. The wet soils have been found to double the runoff coefficient and shorten the time to runoff, compared with the same soils when it is dry [20]. Saturated soils may also offer reduced shear resistance, and thus become prone to erosion [21].
4.5 Influence of mulch covers on soil loss

Soil erosion involves the removal of soil by natural agents such as rainfall and wind. Erosion due to rainfall is caused by raindrops of high kinetic energy striking the bare soil surface loosening the bonds between the soil particles. The result shows that for layout 1, Plot A (bare soil) produced the least amount of soil loss compared to Plot B (coco-net) and Plot C (coconut husk). Plot B and Plot C produced about 2 and 4 times more soil loss than Plot A respectively. The soil loss reduction effectiveness (SLRE) result also shows the negative value of both mulch plots. As mentioned above, for layout 1, both coco-net and coconut husk mulch resulted in higher runoff rates than the control plot. As excess water runs down the slope, it carries a higher amount of detached soil particles and increases the sediment transport capacity.

For layout 2, Plot C (coconut husk) produced the least amount of runoff, and consequently, the least amount of soil loss compared to Plot A (bare soil) and Plot B (coco-net). The result shows that the coconut husk plot produced two times less soil loss compared to control plot and coco-net plot. In addition, the overall soil loss reduction effectiveness (SLRE) value for layout 2 indicates a positive value for coconut husk plot. This may be attributed to the observation that the coconut husk mulch plot has reduced transport capacity as less water runs down the slope, reducing the kinetic energy to carry and preventing the detached soil particles from being washed down the slope. The result also indicates that the coconut husk mulch may be able to reduce surface erosion by acting as a reservoir to collect the sediments as shown in figure 5. The flow velocities may also be reduced. However, further studies are required to evaluate the effectiveness of this mechanism, especially after the coconut husks have completely filled up with soil sediments.

![Figure 5. Coconut husk retained eroded soil.](image)

Both of the mulch covers were observed to promote vegetation growth at the study area due to their enhanced soil and water holding capacity, as shown in figure 6. This suggests that over time, the mulch cover may provide an additional benefit as the development of vegetation plays a vital role as a long-term erosion protection measure [22]. On the other hand, in Plot A (bare soil), no vegetation growth was observed as shown in figure 7. In addition, the sediment concentrations measured in these mulch covered plots were lower than the bare soil plot. This supports the hypothesis that runoff mostly flowed through or over the fibres of coco-net and coconut husks and thus causing slow runoff speeds. Higher sediment concentration in the control plot also indicates that unprotected bare soil is more susceptible to erosion than the mulch plots.
Figure 6. Shows the development of vegetation growth for both mulch plots.

Figure 7. No vegetation growth observed for bare soil plot.

5. Conclusion
The performance of coco-net and coconut husk mulch cover were evaluated on a study area with a 27° slope in terms of their effects on runoff and soil loss. For layout 1, both of the mulch covers resulted in an increased runoff volume of about 4 and 9 times for coco-net and coconut husk respectively when compared to the control bare soil plot. This produced negative runoff reduction effectiveness (RRE), suggesting that rain may flow over the fibres of both mulch coco-net and coconut husk without infiltrating into the soil. Such reduced infiltration causes increased runoff and consequently, increased soil loss. The same result also can be observed in layout 2 for both Plot A (bare soil) and Plot B (coco-net). However, in contrast, Plot C (coconut husk) mulch shows a reduction in runoff compared to the control bare soil plot and coco-net plot. The result shows that it produced about 76% and 96% less runoff volume than Plot A and Plot B. This produced positive reduction effectiveness (RRE) which indicates that by changing the orientation of the coconut husk mulch, it is effective in reducing the runoff volume.

This study demonstrated that mulch covers, particularly for layout 1, are not effective in reducing runoff volume when compared to bare soil. However, in the long run, especially during the rainy season, mulch cover will help to prevent over-saturation of soil by maintaining the capacity of the soil to absorb water, reducing the erodibility of the soil and the transport capacity of runoff, hence reducing soil loss and preventing slope instability. Conversely, this also means that an increase in rain occurring within a short period might cause high runoff and soil loss in bare soil plots, which can be attributed by an increase in soil moisture content, reducing the shear strength of the soil, increasing its erodibility. While for layout 2, the coconut husk on Plot C is able to collect and retain the soil, increasing the surface roughness and reducing the slope steepness by developing a series of “miniature stairstep” thus reducing both runoff and soil loss. Both mulch covers also promote the growth of new vegetations by absorbing water and preventing the topsoil from drying out therefore further contributes towards reducing soil erosion. This may prove to be beneficial for slope surface protection in the long run.
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