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To cite this article: M.F. Chow *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **551** 012008

IOP Conf. Series: Materials Science and Engineering **551** (2019) 012008 doi:10.1088/1757-899X/551/1/012008

Investigating the effectiveness of Water Hyacinth Fiber Mat for Soil Erosion Control

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Abstract. The usage of natural fiber mat has created much attention especially in soil erosion control sector due to low cost and sustainable materials. This study investigated the effectiveness of natural fiber mat made from water hyacinth stems for soil erosion control. The water hyacinth fiber mat (WHFM) was fabricated with mesh opening size of 30 mm × 30mm and tested at 30 degree slope inclinations under simulated rainfall with constant intensity. Results revealed that soil with treatment (covered by WHFM) significantly decreased sediment yields and volumes, with average 78.74% reduction efficiency compared to untreated soil (bare soil).

1. Introduction

Soil erosion is a major environmental problem in many regions of the world. Typically, the process of erosion begins with wind blowing or water falling on unprotected slopes, causing detachment of soil particles from small amount to a larger displacement of soil which moves down slope. Vegetation provides good protection for soil cover as it can reduce the impact of rain drops, as well as its roots are able to hold soil in place [1]. However not every places are covered by vegetation due to climate properties, causing vegetation establishment gets slow or difficult. Due to this matter, the applications of geotextiles are being introduced as alternative to vegetation. They are made from both natural and synthetic materials in different forms, sizes, and physical characteristics. In recent years, the usage of natural fibers as reinforcement in polymer composites has created much attention especially in soil erosion control sector due to low cost materials of engineering.

Erosion control mats can be effective in minimizing the erosive effect of rainfall when used to cover bare or newly planted soil. There are biodegradable materials that can be used to protect new plantings and reduces soil erosion such as coir and jute. Natural vegetation for sustainable erosion control and slope protection is a proven choice of soil conservation along hilly terrain. Vegetation growth in a troubled slope is occasionally met with problems such as absence of initial binding material in the soil, washing away by runoff, etc. In such conditions, natural fiber mat serve the purpose of protecting the soil and the seeds in the initial stage of vegetative growth [2]. They absorb moisture and are suitable in areas of low rainfall and situations where the establishment of vegetation takes a long time, leaving slopes susceptible to erosion. Natural fiber mats degrade and form organic mulch and this in turn helps in hastening the establishment of vegetation. Different natural fiber mat have different rates of degradation and this rate depends on site conditions.

Natural fibers are very abundant, especially those derived from water plant as they are very easy to grow up [3]. One of thus is water hyacinth or also known as Eichhornia Crassipes that grow very rapidly and floating on the water surface. Its growth is very difficult to control, which often provides some problems such as covering the surface of water thus affecting on decreasing the production in the fisheries sector, evaporating water rapidly and developing sector for growing mosquitoes. In most countries, water hyacinth is recognized as a big threat to agriculture, water mitigation, and aquatic ecosystem because of its rapid growth and widely spread forming dense floating mats that cover large areas of water surface [4].

Rapid urbanization process in developing country has increased the transports of numerous nutrients and pollutants into the freshwater bodies [5,6,7]. As a consequence, river or lake water pollutions tend to encourage the growth of weeds in the water bodies [8,9]. In Malaysia, it was found that water hyacinth is among four problematic weeds in the country. The favorable tropical climate and environmental factors had helped to trigger the massive growth of these weeds. Since water hyacinth is an invasive plant with rapid growth, control measures always needed to be taken to eliminate these plants from the water bodies. The common practice of authority bodies is to remove these plants routinely and end up burning it which leads to another pollution. The better way of handling this water hyacinth plant, is by recycling them as a new source of natural fibers product. Indeed, as natural fibers, water hyacinth fibers are very useful to be applied as reinforcement material in polymer composites due to their interesting characteristics; relative high celluloses contents and small cellulose diameter. From laboratory test results, woven water hyacinth can be utilized for erosion control in field applications because the moisture retained in woven water hyacinth was high thus it can help the growth of vegetation [10].

This paper studied the effectiveness of water hyacinth fiber mat as soil erosion control which evaluated in terms of soil volumes transported, sediment yield and soil loss reduction efficiency compared with the bare soil slope.

2. Methodology

2.1 Fiber mat development

The erosion mat used in the study was made from the stem of water hyacinth harvested from Sg. Ramal Lake in Kajang, Malaysia. The leaves and roots of water hyacinth were cut and removed from the stems. Meanwhile the stems were cut into half and dried under the sun for 10 hours. The fibers were not treated with any treatment as proposed by few researchers, as to maintain the characteristic of self-degradable of the natural fiber mat. Production of single spline rope was carried out through the process of twisting two even section of the stems in the same direction. As the twisting continued, the two sections of stems will begin to wrap around one another, forming a rope. As the near end of the first bundle reached, another two more section of stems were attached together by overlap the tails of the original stem sections with the heads of the new sections, so that the new stems are anchored into place. This process continues until desired length of rope achieved. The water hyacinth fiber mat (WHFM) weaving process follows the traditional open-weave pattern by interlacing the single splined fiber ropes at right angle with each other. The mesh opening size used for WHFM was 30 mm × 30mm. The coverage area of each WHFM is set as 1m (length) x 0.5 m (width).

2.2 Laboratory experiment

Two soil testbeds with slope of 30° and dimension of 1 m × 0.5 m were prepared for simulated rainfall test (as shown in Figure 1. The soil testbeds were setup for control plot (bare soil) and treated plot (soil covered by WHFM). Type of soil used was clay with bulk density measured was 1.36g/m³. The erosion control test was performed by using artificial rainfall which consists of two sprinklers installed on top of soil testbeds. The rainfall intensity was maintained constant for 30 minutes. The sediments yields were collected every 5 minutes and oven-dried before their masses are measured.

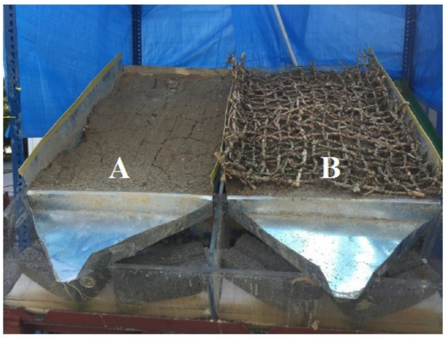

Figure 1. Experimental soil testbeds with slope of 30 degree setup for A) bare soil; and B) WHFM

3. Results and Discussion

3.1 Sediment yield

Sediment yield is defined as the amount of sediment per unit area transported by flowing water during specific rainfall event. The mass of sediments were measured after sediments were oven-dried. It was estimated by using equation (1) [11].

$$SY=\frac{S_m}{tA_b} \quad (1)$$

Where SY is sediment yield (g/m².hr), S_m is mass of oven-dried sediment collected, A_b is area of soil test plot and t is duration of rainfall simulation (hr). The sediment yield results for both bare soil and WHFM testbeds are summarized in Table 1. It is observed that soil treated with WFHM shows significant reducing trends of sediments yield compared to the bare soil testbed.

Table 1. Sediment yields for bare soil and WHFM testbeds

Rainfall duration (minute)	5	10	15	20	25	30
Bare soil (g/m².hr)	4352.16	2070.72	1115.52	677.40	551.09	200.32
Treated with fiber mat (g/m².hr)	931.20	464.40	214.72	156.54	99.74	46.60

3.2 Wash-off sediment volumes

Sediment volumes wash-off during the simulated rainfall were calculated for every five minutes interval up to 30 minutes by using equation (2) and the results are presented in Table 2. It was observed that bare soil testbed showed significantly faster response to rainfall as higher soil volumes were transported compared to the soil testbed treated by WHFM.

$$\text{Sedimen: volume} = S_m \times \text{soil bulk density} \quad (2)$$

The sediment volumes transported during the simulated rainfall for both soil testbeds are plotted in Figure 2. It shows that the sediment volume were decreasing over time for both soil testbeds, specifically greater soil volume was washed off at the bare soil testbed. However, the soil testbed covered with WHFM showed much lower sediment quantity as the fibre mat act as a protective layer

IOP Conf. Series: Materials Science and Engineering **551** (2019) 012008 doi:10.1088/1757-899X/551/1/012008

for the soil slope. This proved that the WHFM feature of remarkable amount of hollow cavity does contribute to its water absorption and reducing the raindrop impact onto the soil surface layer.

Table 2: Sediment volume wash-off during simulated rainfall test for bare & treated soil testbeds

Rainfall duration (minute)	5	10	15	20	25	30
Bare soil (cm^3)	134.33	127.82	103.29	83.63	85.04	37.10
Treated with fiber mat (cm^3)	28.74	28.67	19.88	19.33	15.39	8.63

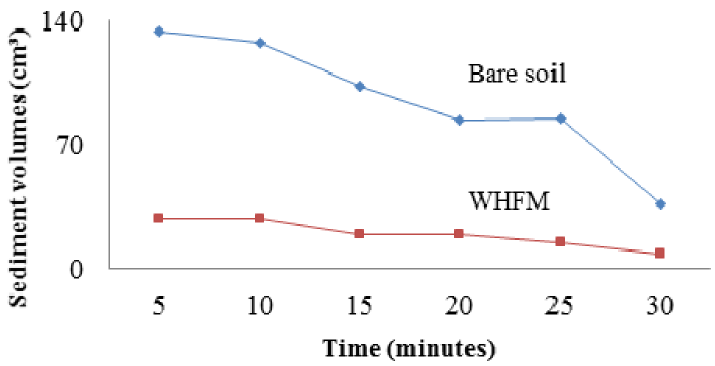

Fig. 2: Sediment volumes wash off during the simulated rainfall test for both soil testbeds

3.3 Soil loss reduction efficiency

The effectiveness of fiber mat in reducing the soil loss is determined by calculating the soil loss reduction efficiency (SLRE) using equation (3) as recommended by [12,13].

$$SLRE = \frac{SY_b - SY_g}{SY_b} \times 100 \quad (3)$$

SLRE is soil loss reduction efficiency (%), SY_b is sediment yield from bare soil (g/m².hr), SY_g is sediment yield from soil protected by fiber mat (g/m².hr).

The results of SLRE for soil testbed treated with WHFM at every 5 minutes during the simulated rainfall are tabulated in Table 3. The result revealed that WHFM has an average of 78.74% reduction efficiency for 30° slope.

Table 3: Soil loss reduction efficiency calculated for WHFM at every 5 minutes interval

Time (minute)	5	10	15	20	25	30
SLRE (%)	78.6	77.6	80.8	76.9	81.9	76.7

4. Conclusions

The performance of water hyacinth fibre mat (WHFM) as soil erosion control blanket has been investigated in this study using artificial rainfall. From the laboratory results, the sediment yields were significantly reduced when the soil testbed was treated with WHFM. The WHFM has reduced the impact of raindrops, acted as a shield between raindrops and soils by absorbing some amount of water. The soil loss had reduced by average of 78.74% when the 30 degree soil slope covered by WHFM compared to bare soil. This study has proved that WHFM is an effective and sustainable natural geotextile that can be implemented as soil erosion control for hilly slope condition.

Acknowledgements

The authors would like to thank the YCU grant (Project No. 201801001YCU/16) provided by Yayasan Canselor UNITEN (YCU) and Seed Fund provided by Tenaga Nasional Berhad (Project No. U-TG-RD-17-06).

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