

# EFFECTIVENESS OF COCONUT FIBER GEOTEXTILE AND VETIVER GRASS AS BIO-ENGINEERING TECHNIQUE IN MITIGATING SOIL EROSION ALONG BATO-BONTOC ROAD

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**Abstract**— This study investigated the effectiveness and suitability of coconut coir fiber geotextile with different mesh sizes planted with Vetiver grass as a soil erosion control measure, conducted along Bato-Bontoc Road, Province of Southern Leyte, Philippines. The study was carried out by a 3x2 factor factorial experiment in Completely Randomized Design (CRD). Geotextiles with mesh sizes of 0.5x0.5, 1.0x1.0, 1.5x1.5 inches in planted and unplanted experimental plots, which has 7m by 1m dimensions, were considered in the experiment. To measure the decrease in topsoil, 12 erosion pins were forced drive into the soil in every experimental plot. No interaction was found between the geotextiles and the plant used. Based on the analysis of variance, there is a very highly significant difference in the soil erosion between planted and unplanted experimental plots. Vetiver grass is more effective in reinforcing soil and controlling up to 56% of the soil erosion than no grass at all. Geotextile with eye-opening sizes of 0.5x0.5, 1.0x1.0, and 1.5x1.5 inches can mitigate up to 65%, 49%, and 40% of the soil erosion, respectively. Thus, all sizes are effective in controlling soil erosion compared to the control setup and the 0.5x0.5-inch eye-opening size is the best among others.

**Keywords**— Soil Erosion, Slope Protection, Geotextiles, Coconut Coir Fiber, Vetiver Grass

## I. INTRODUCTION

Soil erosion is the detachment and transport of soil materials brought about either naturally, through water, surface runoff, wind, gravity, earthquake, or animals and human interventions. Soil erosion along uncovered and cut slopes has been a problem in many areas throughout the county. These are mostly associated with human intervention either for urbanization or for other development activities (Lekha, 2004). About twenty-four (24) billion tons of soil are lost due to erosion every year and this is increasing from year to year. This remains to be a problem in most of the tropical countries

like the Philippines. The rapid growth of human developmental activities contributed to the increasing erosion recorded per year. These activities include road widening, mining, land conversion, among others, which mostly scoped by civil engineering. The impacts of this faster rate erosion could lead to substantial economic and environmental losses. Soil erosion could lead to degradation of slopes, reduced soil structure, reduced water holding capacity of the soil, low infiltration, and reduced fertility of the soil. Álvarez-Mozos et al. (2014) suggested from their work that soil erosion causes malfunction of gutters and drains which affects road conservation and safety. Therefore, it is realized as a problem that should be provided with efficient and cost-effective solutions.

Over the years of research and growing awareness in sustainable development, the focus was shifted to the use of cement plastering and slope matting using synthetic nets have been used as an engineering technique to mitigate erosion and ensure the stability along uncovered and cut slopes. However, cement plastering hinders the vegetation to grow and the synthetic nets that mainly used in the industry which has a long life and do not undergo biological degradation became liable in creating environmental problems in the long run (Beena, 2013).

Coir or coconut fiber is a 100% organic naturally occurring fiber, from a renewable source obtained from coconut husk (*Cocos nucifera*). These materials are excellent in absorbing moisture, pressure, sound, and odor, which is ideal for insulation. Coconut fiber is in demand for its toughness, strength, natural resilience, porous, hygroscopic, and biodegradable properties (Coir Board, 2016). Coconut fiber geotextile, popularly known as *coconet* in the Philippines, is biodegradable and degrades naturally as vegetation settles in the soil, which in contrast, other geotextiles degrade faster than plants can grow. Besides, the fiber has excellent water absorption and water-holding capability, which helps to prevent water from going directly into the soil that causes soil erosion. It also assists in creating hospitable conditions for plant growth.



A study from Delft University of Technology Water Resources Section in the Netherlands suggested that treatment with geotextile in combination with grass is an effective eco-hydrological measure to protect steep slopes from erosion (Vishnudass et al., 2006). This application is termed as bio-engineering. Allen and Leech (1997) defined bio-engineering as the combination of biological, mechanical, and ecological concepts to reduce or control erosion, protect soil, and stabilize slopes using vegetation or a combination of vegetation and construction materials.

Vetiver grass (*Vetiveria zizanioides L.*) has long been studied in tropical countries. It is a densely tufted perennial clump grass with stiff leaf bases and has been known to help control soil erosion. Another research conducted in Malaysia (Hengchaovanich and Nilaweera, 1996) concluded that the tensile strength of vetiver roots is inversely proportional to its diameter, suggesting that stronger fine roots provide higher resistance than larger roots. Besides, its root often grows vertically up to 5 meters deep, and has an average tensile strength of 75 MPa, which is corresponding to 1/6 of mild steel reinforcement (Truong, 2004).

This study examined the effectiveness and capability of coconut coir fiber geotextile with different mesh sizes planted with Vetiver grasses along Bato-Bontoc Road in mitigating or controlling soil erosion. To determine the physical and mechanical properties of the geotextiles used, samples were tested at the Department of Science and Technology-Philippine Textile Research Institute (DOST-PTRI) Testing Laboratory, Bicutan, Taguig City, Philippines. Moreover, the researchers determined and tested the equivalence of the soil physical/index properties (density, total porosity, moisture content, water holding capacity, particle size distribution, consistency limits) across experimental units, to ensure no other factors to influence the treatments or experimental set-up. Soil samples were processed and analyzed at Soil Mechanics Laboratory, Annex Building, College of Engineering, Visayas State University, Visca, Baybay City, Leyte, Philippines.

## II. METHODOLOGY

### A. The Experimental Design

The experimental design for this study is a 3x2 factor factorial experiment in Completely Randomized Design (CRD). The factors considered were (1) Coconut fiber geotextiles with three levels of treatment namely M1(0.5x0.5 in), M2 (1.0x1.0 in), and M3 (1.5x1.5 in) and (2) Grass cover with two levels of treatment namely P1 (plots planted with Vetiver grass) and P2 (unplanted plots) (Table 1). Six treatment combinations plus the control set-up (no geotextile and grass cover) were made from the experimental design. Having three replicates (R) per

treatment combination, a total of twenty-one (21) experimental units with a 7m x 1m dimension, were utilized in achieving the objectives of this study (Table 2). Experimental units were placed in random order in the actual experimental set-up. Experimental units were spaced 500mm from each other to eliminate border effect as well as the disturbance during the scheduled evaluation of changes in soil surface and vegetation.

Table 1: Factors considered and its levels of treatment

Factors	Levels
Coconut fiber geotextiles	M1 (0.5x0.5 in), M2 (1.0x1.0 in), M3(1.5x1.5 in)
Grass	P1 (planted with vetiver grass), P2 (unplanted)

Table 2: Treatment combinations

M1P1R1	M1P1R2	M1P1R3
M2P1R1	M2P1R3	M2P1R3
M3P1R1	M3P1R2	M3P1R3
M1P2R1	M1P2R2	M1P2R3
M2P2R1	M2P2R3	M2P2R3
M3P2R1	M3P2R2	M3P2R3
Control 1	Control 2	Control 3

## B. Experimental Investigation Phases

### 1. Site Identification

The study was conducted at Barangay Pamahawan, Bontoc, Southern Leyte, along Bato-Bontoc Road. The study area has 60° slope, located with coordinates of 10° 19.884' N and 124 54.544' E, and an elevation of 109 meters from mean sea level. The area was identified as a highly eroded area, thus, recommended by the local office of the Department of Public Works and Highways (DPWH) and Philippine Coconut Authority (PCA).

### 2. Preparation and Testing of the Geotextiles

Coconut fibers were first twined into strands and weaved into nets with one-meter width and varying mesh opening sizes of 0.5x0.5 in, 1x1 in, and 1.5x1.5 in. The geotextiles used were manufactured by the Philippine Coconut Authority- Southern Leyte (PCA). Physical characteristic of the geotextile used is presented in Figure 1.

Samples were taken from three different sizes of geotextile used for mechanical and physical properties determination. Laboratory tests were based on the American Standard for Testing Materials (ASTM International). These tests include the determination of moisture content, mass per unit area (ASTM-D5261-10), tensile strengths (machine direction, and cross-machine direction) (ASTM-D4595-11), average thickness (ASTM-D5199-2), and number of twines per one-meter length.



Figure 1: Coconut Fiber Geotextile

### 3. Preparation and Lay-outing of the Experimental Set-up

Before the setting of the geotextiles in the study site, it was manually scraped to attain more or less uniform surface, including the removal of sharp materials that were considered detrimental to the set-up. Existing vegetation was trimmed down to ensure that the geotextile is in close contact with the surface soil. Anchoring of the geotextiles was based on the Department of Public Works and Highways (DPWH) Standard Specifications for Coconet Bio-engineering Solutions, Item 518, with the aid of improvised bamboo stakes with dimension of 50-150 diameter and 500mm-1000mm length. A Hedgerow of vetiver grass were planted on slope with 250mm plant interval.

Twelve (12) erosion pins, with dimension of 15mm diameter and 500mm length, were installed in each experimental unit enough to provide an acceptable average erosion measurement for a 7m by 1m plot. Exposed parts of the erosion pins were enamel painted for easy identification during data collection. Average erosion was measured using a hand tape with 1mm precision.

### 4. Soil Sampling, Testing, and Analyses

Soil tests and analyses were done to see the equivalence of each soil index property across experimental plots. These were to ensure that there will be no other factors that can significantly affect each treatment, hence, considering only the different sizes of the geotextile and the presence/absence of the grass as the main sources of variation of erosion across experimental units.

Twenty-one (21) undisturbed soil samples, one soil sample per experimental unit/plot, were collected using core sampler. Another composite samples from each plot were collected from the subsurface soil, each was taken from the top, the middle, and the bottom part of the plot. The soil samples were air-dried, pulverized using mechanical soil grinder, and sieved. These samples were used in determining the following soil parameters:

#### a. Particle Size Distribution

Soil classification was determined using the Hydrometer method as described by the International Soil Reference and Information Center (ISRIC, 1995) and interpreted using USDA Soil Classification System.

Soil samples from the leftmost plot, rightmost plot, and middle plot were used in analyses. 25 grams of soil from each of the chosen sample were added 15mL 30% H<sub>2</sub>O<sub>2</sub> to destroy the organic matter. Dispersion was done by adding 10 mL sodium hexametaphosphate/Calgon solution. Readings were taken at 4 minutes following the onset sedimentation and after another 2-hours sedimentation. United State Department of Agriculture Soil Classification System (USDA) was used in the interpretation of the percentage of sand, silt, and clay.

The following formula were used in the calculation of soil particle distribution (%sand, %silt, %clay).

$$CF_{4mins} = -4+(T_s-T_b)$$

$$CF_{2hrs} = -2+(T_s-T_b)$$

$$CHR_{4mins} = (HR_s-CF)_{4mins}$$

$$CHR_{2hours} = (HR_s-CF)_{2hours}$$

$$\%clay = \frac{CHR_{2hours}}{Wt.of\ sample} \times 100$$

$$\%silt = \frac{CHR_{4mins} - CHR_{2hours}}{Wt.of\ sample} \times 100$$

$$\%sand = 100 - \%clay - \%silt$$

where:

CF<sub>4mins</sub> – correction Factor at 4 minutes

CF<sub>2hours</sub> – correction Factor at 2 hours

CHR<sub>4mins</sub> – correction of hydrometer reading at 4 minutes

CHR<sub>2hours</sub> – correction of hydrometer reading at 2 hours

HR<sub>s</sub> – hydrometer reading of the sample

#### b. Soil Density (Dry and In-Situ) and Porosity

Bulk density is the mass of soil per unit volume, including the air space. Soil density can vary substantially among different soil types and can significantly affect the erosion behavior of the soil. It is usually expressed in terms of grams per cubic centimeters (g/cm<sup>3</sup>).

Soil density was determined using core method as described by Blake and Hartage (1986). The core samplers were driven down into the soil until it is filled with soil. Core samplers were carefully removed from the soil to preserve a given soil volume as it existed in situ. Soil samples were oven-dried at 105° C for 24 hours.

Bulk density was calculated using the formula:

$$\text{Bulk density} = \frac{\text{Oven-dried weight of soil}}{\text{Volume of core sampler}}$$

Soil density at its in-situ state was calculated using the formula:

$$\text{In-situ Density} = \frac{\text{Fresh weight of soil}}{\text{Volume of core sampler}}$$



The total porosity was obtained from bulk density and particle density using the equation and relationship developed by Danielson and Sutherland (1986);

$$\text{Total Porosity} = 1 - \frac{\text{Bulk Density}}{\text{Particle Density}}$$

A particle density of 2.65 g/cm<sup>3</sup>, suggested by Fasinmirin and Olorunfemi (2013), is used as a default value based on the average bulk density of rock with no pore space.

### c. Soil Moisture Content

Water holding capacity of soil is the maximum moisture content that the soil can store or hold for a longer period time. Soil samples, collected using core samplers, were oven-dried at 105°C for 24 hours. Samples were weighed before and after oven-drying. The % moisture content of soil was calculated using the formula:

$$\% \text{ MC} = \frac{\text{FW} - \text{ODW}}{\text{ODW}} \times 100$$

where:

FW – fresh weight of soil

ODW – oven-dried weight of soil

### d. Consistency Limit

Consistency is the relative ease in which soil can be deformed. It is empirically developed but widely used method for describing the consistency of a cohesive soil. This include Liquid Limit, Plastic Limit, and Shrinkage Limit. The tests were done as per IS: 2720 (1985).

### e. Soil pH

This study used organic material and plant; thus, measurement of the alkalinity or acidity of soil is also necessary. It was determined using the method described by ISRIC (1995). Soil pH was determined using pH meter at the Department of Soil Science-SRTPA Laboratory, Visayas State University.

### 5. Data Gathering and Statistical Analyses

Amount of soil erosion was measured through erosion pins every four-week interval time, observed four months after the experimental set-up. The data gathered in this experiment were analyzed using two-way analysis of variance (ANOVA) to determine if there is a significant treatment effect on the means of the amount of soil erosion (millimeters). A multiple comparison procedure (post-hoc) specifically the Tukey's Honest Significant Difference (HSD) test was applied to examine all pairwise comparison of the treatment means and to determine the best treatment. These tests were subjected to a 5% level of significance.

## III. RESULTS AND DISCUSSION

### A. Physical and Mechanical Properties of Coconut Fiber Geotextile

There were 70 by 70, 40 by 40, and 26 by 26 twines of coconut coir fiber for Mesh 1, Mesh 2, and Mesh 3, respectively, considering 1-meter length from its crosswise and lengthwise direction. A total of eighteen samples were taken for its moisture content determination, brought to laboratory and oven-dried at 85°C for 24 hours. Having the arithmetic mean of the eighteen samples, the geotextile has an average moisture content of 12.93% with a standard deviation of 1.93%. Based on the results of the mechanical test, geotextile with mesh size of 0.5x0.5 in, 1x1 in, and 1.5x1.5 in. has mass per unit area of 885g/m<sup>2</sup>, 767 g/m<sup>2</sup>, and 652 g/m<sup>2</sup>, respectively. Moreover, tensile strengths (ASTM D4595-11 Wide-width method) of 7.8 kN/m, 7.2 kN/m, and 6.6 kN/m were determined in its machine direction and 8.2 kN/m, 7.2 kN/m, and 6.4 kN/m in its cross-machine direction for 0.5x0.5 in, 1x1 in, and 1.5x1.5 in. geotextile, respectively. All sizes of geotextiles have an average thickness of 10±1.0mm.

Based on the results, geotextile with smaller mesh sizes has a bigger mass per unit area and has higher tensile strength in all directions. The high tensile strength of coconut fiber geotextile implies that this could be a good slope reinforcement material.

### B. Soil Index Properties

The soil in the experimental site was classified as “clay-loam”, based on the USDA Textural Triangle. Brady (2005) revealed on his work that soil texture influences erosion occurrence, hence it was considered in the study. It has a mean dry density of 1.249 g/cm<sup>3</sup> and a mean in-situ density of 1.534 g/cm<sup>3</sup>. On the other hand, it has a moisture content at its natural state of 23.11% while its moisture content at its maximum water holding capacity is 38.51%. The average amount of pore space in the soil (total porosity) is 53%. For soil consistency limits, which refer to the highest and lowest water content in the plastic state and are significantly important in predicting the influence of surface runoff and rainfall on the erosion, it has a mean liquid limit of 49.01%, a plastic limit of 33.70%, and a shrinkage limit of 24.55%. In addition, the experimental area has an average soil pH of 5.96 before the application of the geotextiles and 6.10 pH level after three (3) months of observation. It has also found out in the analysis of this study that geotextile having a greater mass per unit area can contribute a greater change to the soil pH.

All soil index properties measured have no significant interaction between the two factors considered (geotextile and grass cover) tested at 5% level of significance and have no significant difference between the measured values of each plot, based on the analysis of variance (ANOVA). Thus, regardless of any levels of treatment applied to the



experimental plot, the soil physical/index properties are statistically equal across plots.

**C. Effectiveness of the Geotextile and the Vetiver Grass against Soil Erosion**

Figure 1 shows the summary of the average erosion measured per treatment combination, in millimeters. It can be noted that the decrease in topsoil measured varied from each reading, this was due to fluctuating rainfall events. The amount and intensity of rainfall events were not considered in the study because it cannot affect the treatments. It is known to be equal at all times across experimental units since the study uses only one small experimental area of approximately 240 square meters.

Based on the raw data, as presented in figure 1, 0.5x0.5 geotextile (M1) planted with vetiver grass (P1) has recorded less erosion compared to unplanted 0.5x0.5 geotextiles. The same occurrences were observed to 1x1(M2) and 1.5x1.5(M3) geotextiles. It can also be noted in the presented data that the sizes of geotextiles contributed variances in the observed/recorded erosion.

For the soil erosion, it can be concluded that there is no significant interaction between the mesh and the plant at 5% level of significance (Table 1). Moreover, the individual effect of the two (2) factors was possible to determine. From the analysis of variance, it revealed a very high significant difference on the soil erosion between the geotextile (mesh) and the plant (p-value<0.001) and showed significant treatment effect on both mesh and plant. The Tukey’s Honest Significant Difference (HSD) test was used to determine all pairwise comparisons on the levels of the geotextile and plant, and to identify which level of the mesh and plant is significantly different to the level of mesh and plant at 5% level of significance as a post-hoc analysis (Table 2). Based on the results, it can be concluded that Mesh 1 (0.5x0.5 inch-eye) has the smallest amount of soil erosion with a total average of 4.583 mm followed by Mesh 2 (1x1 inch-eye) with an average of 6.706 mm, lastly, Mesh 3 (1.5x1.5 in-eye) with an average of 7.903 mm. All these levels of the mesh/geotextile are

statistically different from the control which has a total average soil loss of 13.111 mm. The result indicates that the geotextile is effective in mitigating soil loss because it prevents too much water from penetrating the ground, hence, prevents too much saturation of soil. Saturated soil has less shear strength (Das, 2013) and may be prone to erosion. Besides protecting the soil surface, the coconut fiber geotextile dispels the energy of raindrop impact and facilitates the velocity of surface run-off water. It can be further inferred that the greater the mass per unit area of geotextile, the more that it can hold soil in place. Additionally, there is a significant difference of soil erosion on the planted experimental units. Planted plots have a total average soil erosion of 5.721 mm while the unplanted plots have 8.583 mm soil erosion on the average (Table 3).

Table 1. Analysis of variance (ANOVA) on the average decrease of soil measured in mm.

Source	SS	df	MS	F	p-value
Geotextile	115.915	3	38.6385	536.568***	0.0000
Plant	8.244	1	8.2442	114.487***	0.0000
Interaction	0.378	2	0.1892	2.628 <sup>ns</sup>	0.1074
Residuals	1.008	14	0.0720		
Total	125.546	20			

Root MSE: 0.268348 CV (%): 3.65  
 \*\*\*-Significant at 0.01% level ns - not significant

Table 2. Multiple Comparison (Post-hoc) Using Tukey’s Honest Significant Difference (HSD) Method on the different sizes of mesh

Treatment	Mean (mm)	Tukey’s HSD Groupings
Control	13.1111	a
Mesh 3 (1.5x1.5)	7.90278	b
Mesh 2 (1x1)	6.70581	c
Mesh 1(0.5x0.5)	4.58333	d

Note: Means sharing a letter in the group label are not significantly different at the 5% level of significance.

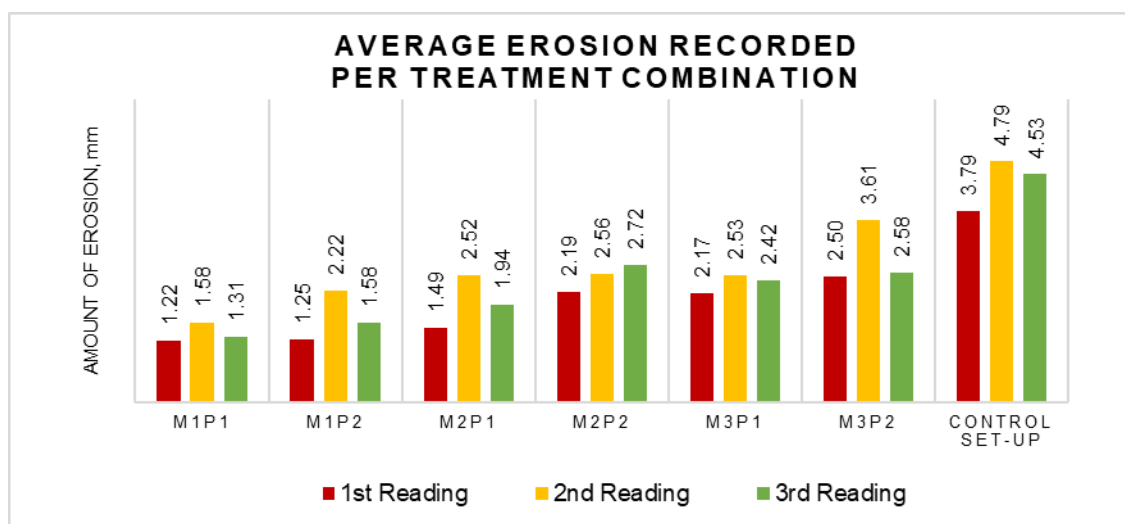


Figure 1. Average amount erosion per treatment combination

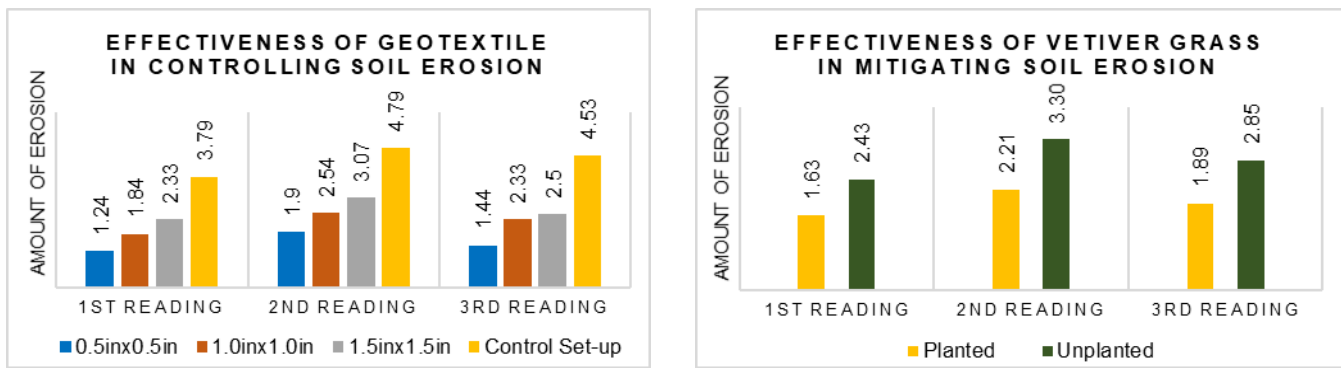


Figure 2. Average decrease of topsoil measured for (2a) geotextile and (2b) vetiver grass, in millimeters (mm)

Table 3. Multiple Comparison (Post-hoc) Using Tukey’s Honest Significant Difference (HSD) Method on the presence of vetiver grass

Treatment	Mean (mm)	Tukey’s HSD Groupings
Unplanted	8.58333	a
Planted	5.72054	b

Note: Means sharing a letter in the group label are not significantly different at the 5% level of significance.

#### IV. CONCLUSION

The study designed in 3x2 factor factorial experiment in Completely Randomized Design (CRD) has found no interaction between the geotextiles and the plant, hence individual effectiveness can be determined. There is a significant difference on the soil erosion between planted and unplanted plots. Vetiver grass is effective in reinforcing soil to mitigate erosion and can alleviate up to 56% of the total soil erosion. On the other hand, Mesh 1 (geotextile with 0.5x0.5inch eye-opening) has the smallest measured amount of soil erosion with an average of 4.583 mm followed by Mesh 2 (geotextile with 1.0x1.0inch eye-opening) with an average of 6.706 mm then Mesh 3 (geotextile with 1.5x1.5in0ch eye-opening) which has around 7.903mm. All sizes of mesh are statistically different from the control set-up with an average decrease of 13.111 mm, thus considered effective. Geotextile with 0.5x0.5inch eye-opening with can mitigate up to 65% soil erosion, geotextile with 1.0x1.0inch eye-opening can mitigate up to 49% of the soil erosion, and geotextile with 1.5x1.5in0ch eye-opening can mitigate up to 40% of the soil erosion.

It is strongly suggested to develop cost-benefit analyses in comparison between this method and the other slope protection techniques and to conduct the same study in different soil types and slope grades.

#### V. ACKNOWLEDGEMENT

The authors would like to express their thanks of gratitude to **Mr. Paulo G. Batidor** (Statistician), **Ms. Christine Mae Atup** (Soil Scientist), **Mr. Emiberto D. Acasio** of Philippine Coconut Authority Southern Leyte Office, Department of Civil Engineering (VSU) faculty and staff, and to all other individuals who were in any ways contributed in the completion of this work.

#### VI. REFERENCE

- [1] Lekha, K. R. (2004). Field instrumentation and monitoring of soil erosion in coir geotextile stabilised slopes. In: Geotextiles and Geomembranes 22. Elsevier Ltd. Kerala, India. pp. 399-413.
- [2] Álvarez-Mozos, J., Abad, E., Giménez, R., Campo, M. A., Goñi, M., Arive, M., Diego, I. (2014). Evaluation of erosion control geotextiles on steep slopes. Part 1: Effects on runoff and soil loss. *Catena*, 118, 168–178. <https://doi.org/10.1016/j.catena.2013.05.018>.
- [3] Beena, K. S. (2013). Case Studies on Application of Coir Geotextiles for Soil Stabilization. *International Conference on Case Histories in Geotechnical Engineering*. 7. [https://scholarsmine.mst.edu/icchge/7icchge/session\\_06/7](https://scholarsmine.mst.edu/icchge/7icchge/session_06/7)
- [4] Angara, E.V. et al., (2010). Field Testing of Bio-Engineering Techniques using Geo-textiles and Bio-Logs to Mitigate Soil Slope Erosion in Maria Aurora National Highway. *ASCOT Research International Journal*, Volume 3. Aurora State College of Technology, Baler, Aurora, Philippines, 3200. pp 1-10.
- [5] Gray, T. H. and Leiser, A. T. (1982). *Biotechnical Slope Protection and Erosion Control*. Krieger Publishing Company. Malabar, Florida. pp 271.



- [6] Coir Board. (2016). Compilation of Seminar Papers. Government of India. pp. 36-43, 62-66.
- [7] Troung, P. (2004). Vetiver System For Infrastructure Protection. Veticon Consulting. Brisbane, Australia. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.517.452&rep=rep1&type=pdf>
- [8] Vishnudas, S., Savenije, H., Van der Zaag, P., Anil, K.R., Balan, K.. (2006). The protective and attractive covering of a vegetated embankment using coir geotextiles. *Hydrology and Earth System Sciences*. 10. 10.5194/hess-10-565-2006.
- [9] Hengchaovanich, D. and Nilaweera, N. S. (1996). An assessment of strength properties of vetiver grass roots in relation to slope stabilization. *Proc. First Int. Vetiver Conf. Thailand* pp. 153-8.
- [10] Allen, H. H. And Leech, J. R. (1997). *Bioengineering for Streambank Erosion Control*. Technical Report EL-97-8. US Army Corps of Engineers Waterways Experiment Station. Vicksburg, MS. pp. 1-3
- [11] ASTM International (2012). ASTM D4595-17. Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method. doi:10.1520/d4595-11
- [12] ASTM International (2012). ASTM D5199-12, Test Method for Measuring the Nominal Thickness of Geosynthetics. doi:10.1520/d5199-11
- [13] ASTM International (2012). ASTM D5261-10, Test Method for Measuring Mass per Unit Area of Geotextiles. doi:10.1520/d5261-92r09
- [14] International Soil Reference and Information Center (ISRIC). (1995). *Procedures for Soil Analysis* (L.P. Van Reeuwijk, Editor). Wageningen, the Netherlands. pp. 106
- [15] International Soil Reference and Information Centre (ISRIC). (2017). *Encyclopedia of Soil Science*, Third Edition, 1232–1236. doi:10.1081/e-ess3-120041260
- [16] Blake, G.R. and Hartge, K.H. (1986). Bulk density. In: A. Klute (Ed.). *Methods of Soil Analysis. Part I. Physical and Mineralogical Methods*. 2nd. Ed., Agronomy No. 9 (part I). ASA-SSSA. Madison, Wisconsin, USA. pp. 363-375.
- [17] Fasinmirin, J.T. and Olorunfemi, I.E. (2013). Soil moisture content variation and mechanical resistance of Nigerian Alfisol under different tillage systems. *J. Agric. Eng. Technol.* 21(2):11-20.
- [18] Das, B.M., (2013). *Fundamentals of Geotechnical Engineering*, 4th Ed., Cengage Learning Asia Pte Ltd. p. 228
- [19] Danielson R.E., and Sutherland P.L. (1986). Porosity. In: *Methods of Soil Analysis: Part 1. Physical and mineralogical methods*, 2nd Edition. Klute, A. (Ed.), ASA-SSSA, Madison, WI, USA. pp. 443-461.
- [20] Schoonover, J. E., & Crim, J. F. (2015). *An Introduction to Soil Concepts and the Role of Soils in Watershed Management*. *Journal of Contemporary Water Research & Education*, 154(1), 21–47. doi:10.1111/j.1936-704x.2015.03186.x