1 BACKGROUND OF THE STUDY
Soil erosion occurs naturally in the environment due to elements like wind, water, and gravity. However, due to rapid expansion of human activities such as grazing, cutting down of trees and land conversion, soil erosion could occur at a much faster rate. The changes in the weather, wind velocity, and rainfall intensity also bring about an environment condition that could trigger soil erosion. Impacts of soil erosion could translate to substantial environmental and economic losses. As such, it is seen as a problem that should be provided with efficient and cost-effective solutions.

One common method to prevent soil erosion is the use of geotextiles. Geotextiles are permeable fabrics, synthetic or natural, that has the ability to reinforce slopes and control soil erosion. To effectively control soil erosion, geotextiles must be able to protect the soil from eroding elements like rainfall, runoff, and wind. It must also be able to trap suspended sediments in the water without hindering the water to pass through.

One type of geotextiles uses natural fibers. Natural materials can be as efficient as other synthetic materials, with less negative impacts on the environment. Natural fibers are also biodegradable and a good moisture retainer and soil enhancer. Being so, the fibers can be applied in combination with plants with good soil-retaining capability, thereby, adding to slope stability and enhancing aesthetics.

Among the natural materials used as a geotextile is coconut fiber. It is produced from coconut husks (Cocos Nucifera) which are waste materials in the coconut industry. The process of extracting fiber from coconut husk is called retting, wherein husks are submerged in water storage tanks for a period of time. In the process, water interacts with the fiber matrix to remove impurities (Vishnudas et al, 2006).

Coco fiber has the highest tensile strength among fibers and retains much of its tensile strength when wet (Vishnudas et al, 2006). Because of its high tensile and wet strength, cocomat can be used in very high flow velocity conditions. Fibers also have high durability and slow biodegradation. These properties are attributed to its high lignin content (Vishnudas et al, 2006).

Cocomat can be woven or nonwoven. Woven mats can be of different mesh sizes. In nonwoven mats, loose fibers are arranged randomly and then mechanically entangled by needle punching. Physically, woven and nonwoven mats differ in that more open area means more loose mesh and, therefore, lower density. Nonwoven mats are normally denser than woven mats.

There is an increase in the demand, both here and abroad, of cocomat not only for soil erosion control but for other purposes as well. Although the American Society for Testing and Materials (ASTM) has outlined the procedures for testing of geotextiles, technical properties of locally-produced cocomat that are relevant for soil erosion control are not sufficiently determined due to lack of testing equipment in the country. Also, there is a limited available quantitative result showing the degree to which cocomat reduces soil erosion and its slope suitability. Previous studies have also failed to show relationship between cocomat properties and soil erosion processes. Even if the results of the studies are available, the approaches, test conditions, and experimental designs are not standardized, thus making a meta-comparison impossible (Sutherland, 1998). Due to this, the marketability of locally-produced cocomat is not fully maximized.

2 OBJECTIVES
This study primarily aims to evaluate the effectiveness of cocomat in reducing soil erosion and determine the suitability of the chosen cocomat designs with the slope to
be reinforced. Furthermore, this aims to identify the technical properties of cocomat relevant for use in soil erosion control.

3 MATERIALS AND METHODS

1.1 Materials
The main materials used in the research are coco fiber geotextiles of different designs and the soil specimen, the soil boxes, and the artificial rainfall apparatus. The properties and characteristics of these materials are discussed subsequently.

3.1.1 Cocomats
The cocomat used in this study was supplied by the Soriano Multi-Purpose Fiber Corporation (SMPFC). Three cocomat designs were used: S400 (Fig. 1a), S700 (Fig. 1b), and the stitched fiber cocomat (SFC) (Fig. 1c).

Cocomat samples were brought to the Philippine Textile Research Institute (PTRI) for testing of thickness, mass per unit area and tensile strength. Ten specimens of each cocomat were cut using a sample cutter and subjected to testing. The thickness of each specimen was measured using SDL Digital Thickness Gauge M034A following ASTM 5199-01. The mass per unit area was obtained using a digital weighing scale. The tensile strength of the samples were obtained following ASTM D 5035-06 using Inston Tensile Strength Tester 5566 (CRE).

The results of the tests are shown in Table 1. SFC has the highest mass per unit area, making it the most expensive among the three designs. S700 and S400 are woven geotextiles, with S700 having smaller mesh sizes and higher mass per unit area compared to S400. In terms of cost, S400 is cheaper than S700.

<table>
<thead>
<tr>
<th>Property</th>
<th>S400</th>
<th>S700</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Brown</td>
<td>Brown</td>
<td>Brown</td>
</tr>
<tr>
<td>Mass per Unit Area (g/m²)</td>
<td>400</td>
<td>700</td>
<td>1790</td>
</tr>
<tr>
<td>Thickness, mm</td>
<td>8.17</td>
<td>8.08</td>
<td>17.81</td>
</tr>
<tr>
<td>Breaking Force, Newtons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine Direction</td>
<td>534</td>
<td>388</td>
<td>57</td>
</tr>
<tr>
<td>Cross-Machine Direction</td>
<td>366</td>
<td>427</td>
<td>30</td>
</tr>
<tr>
<td>Cost</td>
<td>Php45.00 per square meter</td>
<td>Php65.00 per square meter</td>
<td>Php105.00 per square meter</td>
</tr>
</tbody>
</table>

3.1.2 Soil
The soil used was obtained from the construction site of the University of the Philippines-Ayala North Science and Technology Park. The specimen was classified as ML under the Unified Soils Classification System (USCS). It has a natural optimum moisture content of 0.32 and a maximum dry density of 1.382 g/cm³.

3.2 Experimental Set-up
The experiment set-up is shown in Figure 2. The details of the set-up are discussed in the succeeding sections.

The soil boxes used were made of wood with an effective length of 1.5m, effective width of 1.0m, and effective height of 0.5m. The bottom of the boxes was perforated to allow the rain that percolated through the soil to pass through it.

The rainfall simulator, located inside the Hydraulics Laboratory of the Flood Control and Sabo Engineering Center of the Department of Public Works and Highway (DPWH) in Pasig City, is a fixed-type apparatus manufactured by Maruto Testing Equipment Incorporated. It has an effective rainfall area of 10.0m x 5.0m and effective rainfall height of 8.0m.
3.2.1 Experimental Procedure

The plot conditions are bare plot, plot with S400, plot with S700, and plot with SFC. Each condition was experimented for slopes of 30° and 40°, with five runs for every slope giving a total of 40 runs. The details of each step are discussed subsequently. The coomat and soil specimen used for one run were replaced with another coomat and specimen for the subsequent runs. Soil morphology was observed before the soil specimen was excavated from the soil plot.

The soil specimen is first placed on the soil box. Then, whenever applicable, coomat were laid on top of the soil. This comprised the soil plot (as shown in Figure 3). The soil plot is then placed on the stand, which can be adjusted to an inclination of 30˚ or 40˚, whichever the case may be. To avoid spills, a funnel is used to channel the water from the collection trough to the container.

3.2.2 Soil Specimen Preparation

Prior to the rainfall simulation, the soil specimen was made to pass through a 4-mm sieve. This was done to achieve uniform aggregate size distribution. The sieved soil was filled to the study plot to a height of 30cm. Soil was filled at every 10cm. and compacted using a 100N force dropped at a height of 20cm from the soil surface to achieve a bulk density of 1.35 ± .05 g/cm³. To reduce variability in compacting, the soil plots were pre-wetted by spraying approximately 5.0 liters of water over the plot area and then left to equilibrate overnight. Soil samples from the soil plot were oven-dried for 12 hours to determine the antecedent moisture content.

3.2.3 Installation of Cocomat

Before the soil boxes are placed on the stand configured to the desired slope, the surface of the soil plots were smoothed using a hand-held rake. Cocomat were carefully laid on top of the soil and pressed to make it in close contact with the soil. Aluminum rods were used to secure the contact between the two.

3.2.4 Rainfall Simulation

The control box of the rainfall simulator was adjusted to a discharge of 5.0 ± 0.05 m³/s corresponding to a rainfall intensity of 125.0 ± 10.0 mm/hr. The selection of the intensity was based on the intensity of the typhoon Milenyo, which devastated the Province of Albay on December 2006. The variability in the rainfall intensity occurred due to some fluctuations and calibration problems. Each simulation lasted for 50.0 minutes, with the runoff collected at 10-minute intervals to observe the temporal variation of erosion and runoff through time. To verify the adjusted intensity, four rain gauges were stationed near the four corners of the soil plots. Rainfall gauge measurements were taken after every 10.0 minutes.

3.2.5 Post-Rainfall Simulation Activities

Soil morphology was observed after every rainfall simulation. Part of this was to observe rill occurrences. Used coomat were discarded. Due to the limited volume of soil specimen, there was a need to reuse soil specimen. Used soil was excavated from the plot and sun-dried for one day. The sun-dried soil was used for subsequent experiments. Runoff was collected in a plastic container and then weighed.

The weight gives the total mass of runoff collected for a specific interval of collection. Filter cloths were used to separate the collected sediments from the water. Filtering of water was repeated until no more sediments of substantial dimension can be collected.

The collected sediments were then weighed and left for air-drying overnight. The air-dried sediments were again weighed.

2 RESULTS AND DISCUSSION

Filter Cloth

The data obtained from the experiment were runoff generation rate, rill occurrence, sediment concentration, sediment yield, and erosional effectiveness. Runoff generation rate was measured by subtracting the total volume of water collected from the total volume of input water and then dividing the difference by the total volume of input water. Rill occurrence was visually observed after every rainfall simulation.

Sediment concentration (in grams/liter), sediment yield (in grams/(square meter*hour), and erosional effectiveness were computed using the following formula:

$$SC = \frac{m_c}{V} \quad (1)$$

where $SC$ = sediment concentration in g/L

$m_c$ = mass of the sediments collected in grams

$V$ = volume of the water in liters

$$SY = \frac{m_c \times \frac{1}{A_p}}{t} \quad (2)$$

where $SY$ = sediment yield in g/m²h

$m_c$ = mass of the sediments collected in grams

$A_p$ = area of the plot in m²

$$Effectiveness = \frac{BSY - CSY}{BSY} \times 100\% \quad (3)$$

where $BSY$ = bulk soil yield
where BSY = bare sediment yield in g/m²h
CSY = cocomat sediment yield in g/m²h

4.1 Runoff Generation Rate

The runoff generation rates are computed and tabulated in Table 3. The data collected showed consistent results for the two slopes, with the bare plots generating the highest runoff followed by the SFC, then by S700 and S400.

Table 3. Runoff Generation Rates of Soil Plots

<table>
<thead>
<tr>
<th>Treatment</th>
<th>30°</th>
<th>40°</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC</td>
<td>0.33 ± 0.09</td>
<td>0.31 ± 0.00</td>
</tr>
<tr>
<td>S700</td>
<td>0.15 ± 0.11</td>
<td>0.06 ± 0.06</td>
</tr>
<tr>
<td>S400</td>
<td>0.27 ± 0.13</td>
<td>0.09 ± 0.02</td>
</tr>
<tr>
<td>Bare</td>
<td>0.47 ± 0.08</td>
<td>0.39 ± 0.06</td>
</tr>
</tbody>
</table>

At the first interval of runoff collection, the bare plot yielded less runoff. However, the runoff collected increased as the experiment progressed. This is because the infiltration capacity of the soil is gradually reached as the volume of rainfall increased. The water that can no longer infiltrate either moved as interflow or runoff, which caused the development of rill. The SFC generated consistent runoff rates for all collection intervals. Some part of the water infiltrated into the soil while some was absorbed by the SFC. For the S400 and S700 cocomat, the irregularity in the plot surface caused a head difference in the overland flow resulting to greater infiltration rate which yielded low runoff. But runoff generation increased as the soil reached its infiltration capacity.

4.2 Rill Occurrence

For the two soil plot slopes, rill occurrence was only visible on the bare plots. For the bare plots, rain dropped directly on the soil, causing soil particles to be detached and thrown into the air over a few centimeters. These detached particles were more prone to be eroded downslope. The infiltration capacity of the soil was also easily reached which consequently caused reduction in the infiltration rate. Due to this, more water moved downslope as runoff. Along its path to the outlet, runoff collected sediments. Note that the detached particles were easily dislodged by the runoff. As runoff increased and became more concentrated, it collected more sediments and gradually formed channels that further developed into rills.

For the soil plots reinforced with cocomat, direct throughfall was partially prevented. This resulted to the decrease in the transfer of the momentum from the raindrop to the soil particles which means that less energy is available to dislodge the particles. After removing the cocomat, it was observed that the soil beneath it followed the structure of the cocomat. More particles were eroded from the soil in between the ropes as compared to the soil directly under them.

Grain size distribution analysis – sieve analysis and hydrometer test - was also done to determine the size of the soil particles that were collected during the experiment. Sieve analysis was done for every soil sample that was collected every ten minutes. However, to perform the hydrometer test, the finest soil particles – that is, those that pass the #200 sieve -collected from every time interval were combined. This is because there is a required mass in order to perform the test. It was found out from the distribution curve analysis that there are 92.93% of sands in the collected soil sample and there are 7.06% of fines – that is, silts and clays. Also, fines were composed of 96.72% silts and 3.78% clays.

As the experiment progressed, the size of the soil particles that were collected decreased. The largest soil particle that was collected has a diameter of 4.75 mm and the smallest has a diameter of 0.0015 mm.

4.3 Sediment Concentration and Sediment Yield

The summary of the mean sediment concentration and mean sediment yield for plots at a slope of 30º is presented in Table 4. The input of “cannot be detected” on plots reinforced with SFC means that the amount of sediments collected for this condition was negligible compared to the sediments collected from other conditions.

The tables show that the experiments at 40º yielded higher values for both the sediment concentrations and sediment yields than those at 30º. Each treatment results differ from each other at both slopes, with the bare plots having higher values for both parameters followed by plots with S400 and then, plots with S700 and plots with SFC.

The graphs for sediment concentration for 30º experiments are shown in Figure 4.

Table 4. Mean Sediment Concentration and Mean Sediment Yield at 30º

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sediment Concentration (g/L)</th>
<th>Sediment Yield (g/m²h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC</td>
<td>Cannot be detected</td>
<td>Cannot be detected</td>
</tr>
<tr>
<td>S700</td>
<td>3.71 ± 2.14</td>
<td>126.40 ± 24.30</td>
</tr>
<tr>
<td>S400</td>
<td>4.56 ± 1.62</td>
<td>249.00 ± 32.31</td>
</tr>
<tr>
<td>Bare</td>
<td>35.67 ± 20.23</td>
<td>8665.60 ± 792.83</td>
</tr>
</tbody>
</table>

The summary of the mean sediment concentration and mean sediment yield for plots at a slope of 40º is presented in Table 5.

Table 5. Mean Sediment Concentration and Mean
Sediment Yield at 40°

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sediment Concentration (g/L)</th>
<th>Sediment Yield (g/m²h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC</td>
<td>0.55 ± 0.50</td>
<td>112.00 ± 26.81</td>
</tr>
<tr>
<td>S700</td>
<td>2.31 ± 1.26</td>
<td>209.00 ± 31.21</td>
</tr>
<tr>
<td>S400</td>
<td>11.36 ± 7.21</td>
<td>1930.40 ± 179.10</td>
</tr>
<tr>
<td>Bare</td>
<td>32.54 ± 22.58</td>
<td>9540.00 ± 851.15</td>
</tr>
</tbody>
</table>

The values for mean sediment yield for 30° and 40° experiments are also graphically shown in Figures 6 and 7 respectively.

![Mean Sediment Yield from Experiments at 30°](image)

**Figure 6. Mean sediment yield for each treatment versus the time interval of runoff collection for 30°**

It can also be seen from both graphs that the experiment for bare plot yielded very high values compared to the other three treatments.

For all treatments, sediment concentration peaked during the first ten minutes of the rainfall duration. This is because at the first drop of rainfall, the bond between the soil particles was still loose causing the soil particles at the top layer to be easily detached from the soil mass. However, as the experiment progressed, the soil became saturated causing the particles to bond. This bonding of soil particles was due to the soil’s clay content. Soil particles are harder to detach as the bond between them increases. This caused lower concentrations at the succeeding minutes. Also, soil saturation was followed gradually by the steady state of the overland flow, causing the concentrations to be almost constant for the last 40 minutes of rainfall.

The sediment yield is less in cocomat-reinforced plots than bare plots mainly because soil-cocomat interaction impedes the flow path of runoff. This means that overland flow is not permitted to attain high energies. The lesser the flow energy, the lesser the probability that the soil particle will be carried by overland flow. Experiments from 40° yielded higher values than 30° experiments. This is expected since the flow...
velocity of the water is greater at higher slopes thereby generating higher runoff and eventually, more sediment were transported by the water.

4.4 Erosional Effectiveness

The erosional effectiveness at 30º and 40º of the three cocomat are shown in Tables 6 and 7, respectively. The values were computed by subtracting the cocomat sediment yield from the bare sediment yield. The difference is divided by the bare sediment yield, and then multiplied by 100% (refer to equation 3).

For this parameter, a threshold value of 80% was used to assess the performance of each treatment as suitable or not suitable. This value was based on the suggestion of Sutherland (1998) that a higher value be used to define acceptability of cocomat performance.

For experiments at 30º, the effectiveness of all cocomat surpassed the threshold value. The negligible sediment yield from plots with SFC is interpreted as an indication that the design is 100% effective. There is an insignificant difference between the effectiveness of the cocomat designs. However, at 40º, the effectiveness of S400 only surpassed the threshold value for the first 30 minutes and fell below 80% in the succeeding minutes. It must also be noted that at this slope a substantial amount of sediment has been obtained from plots with SFC.

From Figure 8, it can be seen that all cocomat surpass the threshold value for 30º, while from Figure 9, the graph for S400 fell below the threshold value.

<table>
<thead>
<tr>
<th>Table 6. Erosional Effectiveness of Cocomat at 30º</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Bare Plot vs S400</td>
</tr>
<tr>
<td>Bare Plot vs S700</td>
</tr>
<tr>
<td>Bare Plot vs SFC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 7. Erosional Effectiveness of Cocomat at 40º</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Bare Plot vs S400</td>
</tr>
<tr>
<td>Bare Plot vs S700</td>
</tr>
<tr>
<td>Bare Plot vs SFC</td>
</tr>
</tbody>
</table>

Figure 8. Erosional Effectiveness of Cocomat at 30º

Figure 9. Erosional Effectiveness of the Cocomat at 40º

4.5 Replicability

To assess the replicability of the experiment, the standard deviation for of the sediment concentration and sediment yield were computed. It is observed that the values have a high range of variability, even though some of the experiment parameters were controlled. For bare plot conditions, the standard deviation for experiments at 30º is lower compared to the standard deviation at 40º.

The standard deviation values obtained on plots with S400 at 30º and at 40º are substantially lower than those obtained from bare plot conditions. However, the difference in the standard deviation values between the two S400 plot conditions is greater compared to those of the bare plot conditions.

Similarly, the standard deviation values obtained from plots with S700 are much lower compared to the values obtained from bare plot conditions. Conversely, these values have only a slight difference from those of plots with S400.

It can be said that the variability in the experiment is high. But, in general, the results show that soil erosion occur at the highest during the first few minutes of the experiment. Erosion diminished as time progressed due to lesser sediment available for transport. Generally, the standard deviation values for both sediment concentration and sediment yield are higher in 40º than in 30º and, among plot conditions on the same slopes, the standard deviation is

![Figure 8. Erosional Effectiveness of Cocomat at 30º](image)

![Figure 9. Erosional Effectiveness of the Cocomat at 40º](image)
highest in bare plot, followed by S400, then S700 and SFC. This also proves that soil erosion tends to be more stable when there is higher amount of cover material.

5. CONCLUSION

This study was able to present a laboratory-scale experiment to quantify soil erosion in two slopes using three types of cocomat designs. The effectivity of the three designs were shown for the two slopes, with the SFC having the least yield.

The analysis of experiment data also showed that all cocomat designs are effective at 30º slopes. However, at 40º, the effectiveness of S400 cocomat no longer surpasses the assigned threshold value. More so, the suitability of S400 in slopes between 30º -40º is still unknown since experiments for that range were not conducted. The effectiveness of S700 and SFC are still acceptable at 40º. Also, the performances of S700 and SFC for slopes higher than 40º still have to be tested.

6. RECOMMENDATIONS

Knowledge on the technical properties and performance of cocomat for soil erosion control is imperative to help clients decide on what cocomat design is suitable to a certain site condition. Although many similar studies have already been conducted to evaluate cocomat performance, a detailed and direct comparison cannot be done because the experiment set-up, procedure, and material properties are not similar. It is therefore recommended that further studies be conducted using other conditions of soil type, slope configuration, rainfall intensity and duration. The size of the soil plot should be increased so that overland flow can attain natural velocity. Appropriate equipment should also be used to help in quantifying parameters like tensiometer to measure soil water potential and capacitance probe to measure soil moisture content.

It would also be beneficial if results of studies in the Philippines are compiled. Although the data from these studies may not be directly compared, experimental procedure can be integrated to come up with the easiest and most economical way of testing the performance of the locally-produced cocomat.

It is also recommended that cocomat designs must be regularly tested to monitor if the standard specifications of the designs are maintained. Furthermore, it would be better to conduct studies comparing the effectiveness of the cocomat with other conventional soil erosion control products such as polyester geotextile, straw mulch, and straw blankets. In addition, cocomat with vegetation can also be evaluated.

ACKNOWLEDGMENT

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