Bafnet: A Soil Erosion Control Net Using Banana Pseudo-Stem Fibers

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***Abstract*— Soil erosion is a naturally occurring process that affects all landforms determined by four fundamental factors: soil characteristics, vegetative cover, topography, and climate. Various soil erosion control is processed to lessen and delay from happening using different parts of a plant. Hence, this study aimed to produce BafNet and compare it to Coconet in terms of water absorption capacity, tensile strength, and net efficiency or soil reduction efficiency. It was revealed that the banana pseudo-stem fiber (BPSF) rope could absorb more water than the coco fiber rope by 38.94%. Also, it is stronger than the coco fiber rope by 165.2 N and 5.85 MPa for a one-meter rope having a diameter of 6 mm. For torrential rain on a silty type of soil at a 30° slope, the results exhibited that BafNet is more efficient than the Coconet by 11.29%.**

Keywords— banana pseudo-stem fiber, erosion control net, soil erosion, soil reduction efficiency, tensile strength, water absorption capacity

I. Introduction

Soil erosion is a natural process and form of soil degradation when the upper layer of soil is displaced by the dynamic activity of erosive agents such as wind, water, and mass movement. It has been an increasingly recognized problem due to the expanding population and growing concern for food supply and water resources every year. This condition causes great destruction to soil characteristics and its properties and fertility, affecting countless numbers of individuals [1]. It also leads to a series of events, including the devastation of natural vegetation, the loss of prime lands for food production, and the opening of ecologically fragile lands. In the Philippines, about 45% of the arable lands have been moderately to severely eroded, causing the movement of subsistence farmers to marginal lands with the hope of meeting their daily food requirements. Approximately 5.2 M ha have been eroded severely, while 8.5 M ha are moderately eroded, resulting in a 30 - 50% reduction in soil productivity and water retention capacity [2].

Because of its natural process, its occurrence is unpredictable; therefore, recent studies have focused on preventive measures for this problem by providing erosion control measures. One of the current solutions for soil erosion problems is using degradable geosynthetics to prevent soil loss from the seedbed and vegetation establishment for sufficient site protection [3]. The most common temporary, degradable systems are erosion control netting (ECN), open weave meshes (ECM), and erosion control blankets (ECB). This provides a non-eroding environment, effective, affordable, and compatible with sustainable land management practices [4]. For example, the Coconet [5] and Baconet – Banana Fiber and Coconut Coir [6] are used in the Philippines as effective soil erosion control.

On the other hand, banana is one of the major agricultural products of the Philippines, producing 9.36 million metric tons on 447,889 ha, with Cavendish cultivars accounting for about 53% of total banana production, Saba (28%), and Lakatan (10%) in the year 2018. Among the regions, Cagayan Valley is one of the major producers of Saba or Cardava Bananas [7]. However, the banana pseudo-stem usually becomes biomass waste once the harvest time of banana fruit is finished [8]. Thus, many studies have been conducted on banana fibers to increase and promote an eco-friendly environment. Some of the products made from banana fibers are reinforcing materials, textiles, polymer matrices, packaging materials, tablecloths, handicrafts, and paper sheets.

Based on the different studies, banana pseudo-stem fibers (BPSF) are considered high-quality fiber in terms of their physical properties. Specifically, the BPSF has a good modulus of elasticity, tensile strength, stiffness, low density, and strong moisture absorption quality, making it a promising fiber material [8-11]. The study [8] also shows that the durability of BPSF can stay up to three months of storage. However, if the storage period of the fiber is longer than three months, its tensile strength is considerably decreased. Moreover, maximizing the use of other potential natural fiber resources such as BPSF can reduce agro-wastes left on the plantation. In addition, properly designed and installed soil erosion control can significantly reduce soil erosion. [12].

Although the combination of banana and coconut fibers [6] has been studied and used as slope protection, it is worthwhile to study the banana fiber as another soil erosion control material separately. The previous studies revealed different products made from banana fibers, but no one produced soil net using it. Therefore, this current study focused only on producing a soil net called BafNet fabricated from BPSF. The net was then subjected to a tensile strength test, water absorption capacity test, and surface run-off simulation to test its net/performance efficiency in mitigating soil erosion.

II. Related Works

Erosion control blankets are an increasingly popular eco-friendly solution to reclaim degraded lands, soil problems, and erosion-prone areas. Because of this, many studies were conducted for both foreign and local to test the potential usage of different materials as soil blankets. One of these is the Fibromat Erosion Control Blanket (FECB) [13], also known as the Paddy Straw Blanket, Palm Fiber Blanket, and Coconut Fiber Blanket, which is made up of natural agricultural straws and fibers that are stitched together with degradable thread to a double-layer photodegradable polypropylene netting. Upon installation, it lessens the soil erosion immediately up to 85%.

The study [14] revealed that it could significantly delay the initiation of surface runoff under simulated rainfall compared to control plots without geotextiles. Also, vegetation cover was an ideal solution to most problems with erosion on steep slopes. Moreover, a study of [15] about corn stalks as geotextile net showed effectiveness in mitigating soil erosion at 30° slope and 60°slope inclination under laboratory conditions. Sediment yield and soil loss efficiency were significantly reduced compared to plots without soil covering. Soil loss reduction efficiency ranged from 29-66.99% for 30° slopes and 72.67-78.19% for 60° slopes.

On the other hand, [12] considered essential factors for the sustainability of ECB, such as site inspection, preparation, and installation of blankets. Slope and aspects of contour embankments, depth and quality of soil covering the embankment, rockiness, potential for soil erosion and gulley formation, age of construction, and surrounding vegetation, should be taken care of during ecosystem development. The life of the blankets varies with the materials the conditions of the installed area and their application. Improper stapling or not using check slots leads to poor contact between the soil and blanket that will cause the water to flow under the blanket resulting in the ineffective installation of erosion blankets.

In the Philippines, the combination of banana fiber and coconut fiber (Baconet) studied by [6] tested their properties and behavior as soil erosion control. It was revealed that the physical properties of the Baconet are like the commercially available geotextile, Coconet 700 [5]. The test result indicates that Baconet is less flexible than Coconet and stronger in terms of tensile strength. The less flexibility of the Baconet may have a positive effect since the mesh openings will not become more significant as it ages, and the soil is less exposed to the action of raindrops.

III. Methods

A. *Acquiring Soil Samples*

The soil samples in Fig. 1 were acquired from an identified eroded area in Sitio Tueg, Bitag Grande, Baggao, Cagayan as per the Mines and Geo-Sciences Bureau (MGB) Rapid Geohazard Assessment last 2017 (Appendix A). After that, a request letter was prepared for soil testing at the Department of Public Works and Highways (DPHW) Laboratory and Testing Office.

Fig. 1. Accumulation of Soil Samples.

B. Collecting Banana Pseudo-Stems

The banana plantation was visited in Rizal, Cagayan, to ask permission from the owner to get some of the banana (Saba) trees that have been harvested. It was cut into one-meter lengths and transported to Tuguegarao City for preparation in Fig. 2. This process helped the owner reduce the agro-waste by converting it into more useful materials such as the net.

Fig. 2. Collection and preparation of Banana Pseudo-Stems.

C. Fabrication of BafNet

Fig. 3. Removing the impurities.

Fig. 4. Fiber Extraction.

The collected banana pseudo-stems in Fig. 3 were cleaned up to remove impurities before the extraction process. Banana Psuedo-Stem Fibers (BPSF) were separated from the stems by a water retting process, soaking it within a 24-hour duration. In Fig. 4, the fibers were extracted by scraping the soaked BPSF with a scraper tool to remove the remaining lignin and hemicellulose. Then, the fibers were collected and air-dried until the free water content was removed.

Fig. 5. Braiding of a single rope.

Fig. 6. The weaving of ropes.

After extracting the BPSF, a single rope was manually fabricated. Fig. 5 shows a single rope made by braiding two even lengths and sections of BPSF in the same direction. As the rope's tip approached, another pair of BPSF was joined to overlap the previous pair's tails and secure the connection between the ropes. This step was repeated until the desired length was achieved. After that, the BafNet was woven in the traditional open-weave design in Fig. 6 by intertwining the single rope at right angles to each other.

D. Soil Testing

Method C of AASHTO T 99 was performed to determine the moisture-density relationship of the soil using a mechanical compactor, as shown in Fig. 7. This laboratory test established the relationship between the dry density and the soil's moisture content to understand the soil's compaction properties better. When soil is compacted to a dense state, it increases shear strength, improves the stability of slopes of embankments, decreases future settlements, and reduces permeability.

Fig. 7. Mechanical Compactor.

Another test conducted for the soil samples focused on the Liquid Limit and Plastic Limit as defined in ASTM Standard D 4318. The moisture content required to close a distance of 12.7 mm along the bottom of the groove after 25 blows is the Liquid Limit. On the other hand, the moisture content at which the soil crumbles when rolled into 3.0 mm threads is known as Plastic Limit. Soil with a smaller diameter breaks due to wet soil, while a larger diameter soil breaks due to dry content. Fig. 8 shows the materials needed in this procedure.

Fig. 8. Liquid and Plastic Limit Test.

Fig. 9. Sieve Analysis.

The method described in ASTM C 136 and AASHTO T 27 covers the quantitative determination of the distribution particle sizes of soil was also tested. In Fig. 9, the soil was passed through a series of sieves, and the weight of soil retained in each sieve was determined and recorded. A gradation curve was drawn for each sample analyzed based on the percent finer weight.

E. BafNet Testing

Three tests were performed to identify the physical properties of BafNet in terms of water absorption capacity and a tensile test of the single rope made of fibers. These properties are essential in determining how much will the soil net uphold the soil from erosion.

The water absorption capacity of the fiber ropes was determined using the method described in ASTM D570 – 98. A laboratory balance scale was used to record the dry mass (m_{dry}) of a single fiber rope. Then, as illustrated in Fig. 10, it was submerged in water for 24 hours. Next, in Fig. 11, the fiber rope was pat dry with a clean cloth to record its wet mass (m_{wet}) [16]. Five BPSF ropes and five coco fiber rope samples with a length of 500 mm and a diameter of 6 mm were used in this process. The water absorption capacity (WAC) of the fiber rope was computed using formula (1).

$$WAC = \frac{m_{wet} - m_{dry}}{m_{dry}} * 100\% \qquad (1)$$

Fig. 10. BSPF ropes and coco fiber ropes soaked in water for 24 hours.

Fig. 11. BSPF ropes and coco fiber ropes are pat-dried with a clean cloth.

The tensile strength test was performed manually because the Universal Testing Machine (UTM) for fiber ropes is not accessible in the locality. Fig. 12 demonstrates a one-meter fiber rope carrying an empty bucket fastened to a horizontal rod 2 meters above the ground. Before the test, the mass of the empty bucket was recorded (m_{bucket}). Weights (sands) were gradually added to the bucket until the rope broke. The mass of the bucket with the weights (sands) was measured (m_{total}) at the breaking point. This method was applied to five BPSF ropes and five coco fiber rope samples. The tensile stress (σ) was computed using formula (2) wherein the net weight is computed using formula (3).

$$\sigma = \frac{net\ weigth}{cross{-}sectional\ area\ of\ the\ rope} \qquad (2)$$

$$net\ weight = (m_{total} - m_{bucket}) * 9.81 \qquad (3)$$

Fig. 12. A BSPF rope carrying a bucket.

Fig. 13. Showerheads and basins for rainfall intensity.

The measured time it took for the showerhead to fill up a 95 mm container with water was used to calculate the average rainfall intensity used in the soil run-off simulation. Fig. 13 shows five trials for each of the three showerheads. A surface run-off test was conducted on a soil testbed with a 30° slope to simulate a run-off scenario using water as the primary agent of weathering and erosion [17]. Three soil testbeds with 865mm (l) x 445mm (w) dimensions were created. In Fig. 14, soil bed A was the bare soil, soil bed B was the soil with Coconet, and soil bed C was the soil with BafNet. For the erosion control test, an artificial rainfall which was water coming from three shower heads (one for each soil testbed), was installed 1 foot above and perpendicular to the top of the soil testbed. For 25 minutes, the rainfall intensity remained constant.

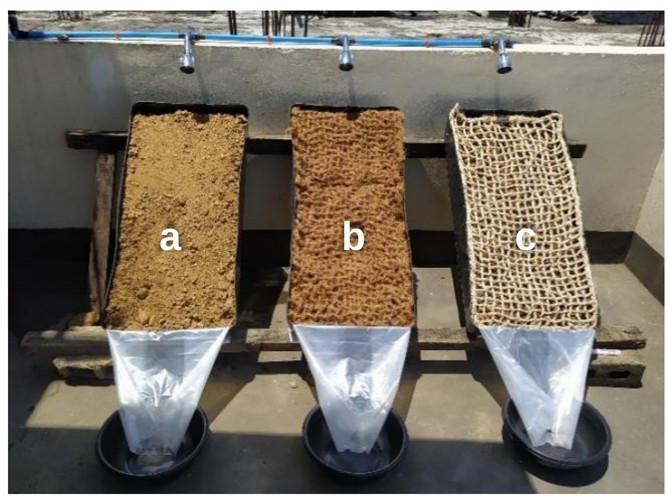

Fig. 14. Experimental Test Beds: (a) Bare Soil (b) with Coconet (c) with BafNet.

Surface run-off from the top of the soil was channeled to a catchment basin by a gutter (plastic) installed at the bottom of the slope. Every 5-minute interval, the volume of the run-off in the basins was measured [17].

Before being measured (m_{dry}), the collected sediments were filtered out with a canvas cloth and sun-dried. The sediment yield was evaluated as the rate of sediment removal from the watershed per unit area during a specified time and was calculated using the formula (4).

$$Sediment\ Yield = \frac{m_{dry}}{(surface\ area)(time)} \qquad (4)$$

The net efficiency (NE) of the BafNet and Coconet in mitigating soil erosion was evaluated using formula (5), where ($m_{dry\ \&\ covered}$) represents the dry weight of the sediments eroded from the soil net-covered slope and ($m_{dry\ \&\ uncovered}$) represents the dry weight of the sediments eroded from the bare soil-uncovered slope [17].

$$NE = \frac{m_{dry\ \&\ uncovered} - m_{dry\ \&\ covered}}{m_{dry\ \&\ uncovered}} * 100\% \qquad (2)$$

IV. Results and Discussion

Fig. 15 has a mesh opening size of 25mm x 25mm and dimensions of 825 mm (length) X 425 mm (width) to match the commercially available Coconet sample. For surface run-off simulation, the BafNet was then laid on an 865 mm (length) x 445 mm (width) soil testbed.

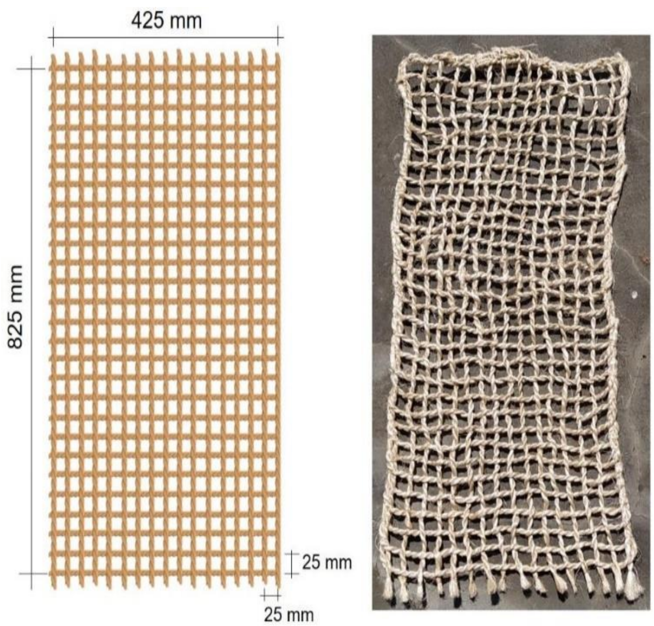

Fig. 15. The BafNet.

A. Properties of Soil Samples

Table I summarizes results obtained on soil samples from Sitio Tueg, Bitag Grande, and Baggao Cagayan conducted at DPWH Laboratory and Testing Office.

TABLE I. SUMMARY OF SOIL PROPERTIES

Property	Value
Liquid Limit (%)	0
Plastic Limit (%)	NP
Plasticity Index (%)	0
Group Index	0
Group Classification	A-2-4 or Silty Soil

The result signifies that the soil was identified as non-plastic, indicating that the soil cannot be rolled out down to 3.0 mm threads at any moisture content. Also, the soil was classified as Silty Soil with a maximum dry density of 1627 kg/m3 and an optimum moisture content of 14.8%. [12] Silty soils with vegetation improve soil stability by increasing the slope's factor of safety [9].

B. Properties of BafNet

The water absorption capacity of the Coco Fiber rope and BPSF rope in Table II was calculated and recorded using Formula 1.

The table above shows that the coco fiber rope and the BPSF rope have an average water absorption capacity of 220.84% and 259.78%, respectively. This implies that the BPSF rope can absorb more water than the coco fiber rope by 38.94%. This behavior was explained in the study of [18] that banana fibers are hydrophilic, resulting in a high-water absorption capacity.

TABLE II. SUMMARY OF SOIL PROPERTIES

Properties	Sample No.				
	1	2	3	4	5
Coconet, mdry (g)	4	3.9	4.8	4.5	5
Coconet, mwet (g)	14	13.1	14.5	13.6	15.7
BafNet, mdry (g)	8	7.2	7.5	8.1	7.7
BafNet, mwet (g)	28.5	26.4	27.8	28.2	27.5
Coconet (%)	250.00	235.90	202.08	202.22	214.00
BafNet (%)	256.25	266.67	270.67	248.15	257.14

Using Formula 2 and 3, the tensile strength test of the five samples of 6-mm diameter coco fiber ropes and BPSF ropes were calculated and recorded in Table III.

Sample No.	Coconet (N)	BafNet (N)	Coconet (MPa)	BafNet (MPa)
1	186.39	344.33	6.59	12.18
2	179.52	348.26	6.35	12.32
3	181.49	341.39	6.42	12.07
4	176.58	338.45	6.25	11.97
5	175.60	353.16	6.21	12.49

TABLE III. TENSILE STRENGTH TEST

The result shows that coco fiber rope could withstand a mean tensile load of 179.92 N and average tensile stress of 6.36 MPa, while the BPSF rope could withstand a mean tensile load of 345.12 N and average tensile stress of 12.21 MPa. This indicates that BPSF rope is stronger than the coco fiber rope by 47.91%. Furthermore, the BPSF rope is higher than 6-mm diameter bamboo rope [16] by 12.77%, having a mean tensile load of 428.68 N and average tensile stress of 10.65 MPa obtained from a universal testing machine.

TABLE IV. MASS OF SEDIMENTS

Rainfall Duration (minutes)	Bare Soil (grams)	Coconet (grams)	BafNet (grams)
10	786.3[illegible]	52.6[illegible]	11.[illegible]
15	1246.4[illegible]	107.4[illegible]	30.[illegible]
20	1483.6[illegible]	98.6[illegible]	14.[illegible]
25	986.5[illegible]	285.2[illegible]	8.[illegible]

The simulation's average rainfall intensity was 5307 mm/hr which falls under the category of torrential rain. According to

Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), more than 30 mm of rain is observed in 1 hour of torrential rain. Therefore, in low-lying areas, severe flooding is likely to occur. Surface run-off simulations were executed to compare erosion rates between bare and soil net-covered slopes. The first 5 minutes of the simulation were omitted to allow full saturation of the soil [17]. Table IV presents the mass of sediments carried away from the three testbeds during the simulation.

Table V summarizes the results of the sediment yield results from three testbeds. The results showed that the bare soil has an average of 10730.53 (g/m².hr), Coconet has an average sediment yield of 1120.66 (g/m².hr), and BafNet has an average of 165.25 (g/m².hr) during torrential rain on a silty type of soil at 30° slope. The Coconet accumulated 955.41 (g/m².hr) more sediment yield than the BafNet. The lower the sediment yield, the more controlled the soil erosion. Thus, soil erosion is most controlled in the BafNet.

Furthermore, soils with soil-net-cover consistently showed a significant reduction in sediment yield compared to the bare soil testbed. This is due to the water absorption property of the Coconet and BafNet, which lessens the impact of a raindrop on the soil surface layer. However, during the 25th minute of rainfall, the bare soil and soil with Coconet attained their maximum sediment yield of 6150.81 (g/m².hr) and 1778.22 (g/m².hr), respectively, which can be attributed to the scouring of the soil in testbed A and B. In contrast, the soil with BafNet reached the lowest sediment yield of 53.62 (g/m².hr) during that period.

TABLE V. SEDIMENT YIELD

Rainfall Duration (minutes)	Bare Soil (g/m²·hr)	Coconet (g/m²·hr)	BafNet (g/m²·hr)
10	12256.41	819.90	176.14
15	12952.13	1116.06	319.02
20	11562.77	768.46	112.23
25	6150.81	1778.22	53.62

Calculating the net efficiency or soil loss reduction efficiency using Formula (5) determines the effectiveness of soil net in reducing soil loss during run-off. The result of 5-minute interval rainfall is tabulated in Table VI.

TABLE VI. NET EFFICIENCY

Rainfall Duration (minutes)	Coconet (%)	BafNet (%)
10	93.31	98.56
15	91.38	97.54
20	93.35	99.03
25	71.09	99.13

For torrential rain on a silty type of soil at a 30° slope, the results exhibited that BafNet has an average of 98.57% reduction efficiency while Coconet has an average of 87.28%. The BafNet is more efficient than the Coconet by 11.29%. Moreover, the net efficiency of BafNet is higher than that of Jute and Coir Erosion Control Blankets, with a net efficiency of 66.99% for 30° slopes and 78.19% for 60° slopes [14], Bambusa Blumeana Fiber Mat with 74.70% for 60° slope [16], and Water Hyacinth Fiber Mat (WHFM) with 78.74% for 30° slope [17]. The present study confirmed the findings in [10] about BafNet being a feasible replacement for commercially available soil nets.

V. CONCLUSION

The net efficiency of the BafNet in mitigating soil erosion was investigated in this study in terms of water absorption capacity, tensile strength, and soil loss reduction efficiency using surface runoff simulation or rainfall simulation. First, BPSF rope absorbed more water than coco fiber rope. This indicates that the water absorption capacity of the BafNet reduced the damaging impact of raindrops, making it effective in mitigating surface erosion and subsequent slope failure. Second, BPSF rope had higher tensile strength than coco fiber rope. This means that BPSF rope is more flexible and could carry larger loadings. Third, the sediment yield analysis results showed that the BafNet prevented significant mass runoff from the topsoil during the simulation. It is more efficient than Coconet and even Jute and Coir Erosion Control Blankets, Water Hyacinth Fiber Mat, and Bambusa Blumeana Fiber Mat. Instead of synthetic geotextile, an effective and eco-friendly soil erosion control net can be made from Banana Pseudo-Stem Fibers (BPSF).

To further validate the results of this study, sediment runoff analysis on actual slopes is recommended. This study can also be modified by considering different factors such as the diameter of the rope, mesh openings, dimension of the soil net area, degree of inclination, and other soil types. Also, utilizing a tensile testing machine for natural fiber and applying an anchoring system is highly recommended.

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