Bambusa blumeana fiber as erosion control geotextile on steep slopes

S B Valle*, R D Albay and A M Montilla

1Civil Engineering Department, University of Batangas, Batangas City, 4200, Philippines

*Corresponding author: Siddhartha.valle@ub.edu.ph

Abstract. Accelerated erosion has been a threat on the agronomic productivity of arable lands, especially in the tropics with prevalent high-velocity winds and seasonal rainfalls. To prevent further soil degradation, geotextiles are installed as soil cover to provide interim protection until the soils are stabilized with vegetation as a long-term slope protection. This study examined the mechanical properties of a locally available fiber source to assess its viability as geotextile fabric for steep slopes. A woven natural geotextile was fabricated from the fibers of thorny bamboo (“kawayang tinik”). Ropes of 6-mm and 8-mm diameters were produced from the bamboo fibers, and subjected to tensile strength tests in accordance to ASTM D4268. Runoff simulations were carried out to compare the sediment yield between 60° slopes with and without geotextile netting. Sediment yield analysis showed significant reduction in topsoil erosion from the geotextile-covered slope. The bamboo geotextile performed effectively in mitigating slope failure in barren slopes.

1. Introduction

Soil degradation by accelerated erosion is of global interest due to its severe adverse impacts on environmental sustainability and agronomic productivity [1]. More than 10 million hectares per year of the world’s arable land has been lost to erosion, reducing the viable cropland for food production [2]. Erosion-caused food production losses have been seen as most critical in developing countries in the tropics and subtropics, including Southeast Asia, where erosion potential is high due to heavy rainfalls [3].

To promote vegetation growth and improve the shear resistance of soils against surface runoff and wind exposure, a self-propagating vegetal cover is found to be more suitable in steep slopes highly susceptible to erosion rather than more conventional methods such as bench terracing [4]. Slopes are covered with erosion control netting of geosynthetic material, providing a barrier over the soil to protect the seeds and the soil until the soils are stabilized with vegetal cover [5].

Geosynthetics is the umbrella term in civil, environmental and agricultural engineering pertaining to flexible, planar, polymeric fabrics applied for slope reinforcement and improved stability of structures such as earth fills. Forming the largest group are geotextiles, permeable geosynthetics comprised solely of textiles, which may either be natural or synthetic, woven or non-woven. Upon soil application, a geotextile netting functions as a filter, drainage and slope protection, allowing steeper cut slopes and less grading in hillside terrains.
Most synthetic geotextiles consist of a polymer from the polyolefin, polyester or polyamide family. While generally stable to microbial degradation and to acidic/alkaline conditions, polymers are subject to thermal oxidation and to photodegradation under ultraviolet radiation. Provide greater stability is provided through the incorporation of antioxidants and UV stabilizers [6, 7]. Over time, however, the polymers and their additives may degrade into microplastic particles, which under various conditions enhance leaching into soils, as additives are often not covalently bound to the polymer backbone [8]. Plant uptake of these particles may cause interference in the photosynthetic system, as in the case of algae.

The presence of non-biodegradable residues has drawn concerns over the environmental sustainability of polymer textile covers. To address these concerns, natural fibers have been utilized as substitutes to synthetic fibers in applications where low density, low cost, high strength and high modulus are required [9, 10]. Among the known natural fibers are jute, coir and palm [5, 11, 12, 13]. These fibers provide immediate erosion control, as they are readily available, making the geotextiles simple and cost-effective to manufacture. Natural geotextiles also significantly increase soil fertility thereby enhancing aboveground biomass production [14].

Due to their location within the Pacific Ring of Fire, the Philippine islands are of volcanic origin, creating a series of mountain slopes, interrupted by cultivated plains and terraces. Highland slopes are made vulnerable to erosion by monsoon rainfalls and tropical cyclones from adjacent Pacific Ocean. Geosynthetic technologies are being sought to reduce the construction of concrete slope protections, which tend to undermine the agricultural viability of land.

In line with the goals of sustainable development to utilize locally available resources, this study investigates the performance of geotextile netting, made from woven bamboo fiber, in mitigating slope erosion against rainfall runoff. Bamboo is one of the strongest and fastest-growing woody plants on earth, growing at a rate of up 4 cm in an hour. Bamboo belongs to a subfamily of flowering perennial evergreen plants in the grass family Poaceae. There are 62 identified bamboo species in the Philippines [15]. Annual bamboo production in the country is estimated to be about 39,200 to 52,700 hectares.

Fibers used in the production of the geotextile were obtained from one of the most abundant species of bamboo in the country, Bambusa blumeana, locally known as Kawayang Tinik (“thorny bamboo”) [15]. The UNDP-FAO Bamboo Research and Development Project (1987) listed B. blumeana as an economically important bamboo species, owing to its reliable mechanical performance. It is a natural composite material that has higher tensile strength than many alloys of steel, and also has higher compressive strength than many mixture of concrete and higher strength-to-weight ratio, making bamboo one of the most durable materials used in the construction industry.

Bamboo is a lingo-cellulosic composite, composed of fibers in vascular bundles, and matrices, thin walled cells around vascular bundles, vessels and sieve tubes in vascular bundles [16]. Due to their high flexibility, bamboo fibers are extensively used in the production of ropes and woven fabrics.

While most studies on geotextiles have demonstrated the effectiveness of natural fibers in reducing erosion and subsequent slope degradation on small or intermediate slope gradients (normally ≤ 30°), steeper slopes need immediate practical engineering solutions [17]. In this regard, this study performed surface runoff simulations to evaluate the efficiency of woven bamboo geotextile in reducing surface erosion on steep barren slopes.

2. Methodology

2.1. Preparation of bamboo cellulose

Fresh culms of kawayang tinik were collected from Bagalangit Mabini, Batangas. The stalks were split into strips then pounded to turn into pulps. Cellulose fibers were extracted from the pulps by hydrolysis alkalinization. The crushed bamboo pulps were soaked for three hours in an aqueous solution of 15-25% sodium hydroxide. Bamboo fibers were combed out from the culms. The fibers were then water-washed to remove excess NaOH, then air-dried for 24 hours. Upon drying, the bamboo fibers
were spun mechanically using an electric wheel rotating at 300 rpm to produce ropes in diameters of 6 mm and 8 mm.

2.2. Tensile strength test
The tensile strengths of the 6-mm and 8-mm ropes were assessed according to ASTM D4268 Rope Tensile Strength Test using a universal testing machine (UTM). The average normal strength of the 6-mm and 8-mm diameter ropes were compared to the natural breaking strength of Manila hemp set by the US Federal Specification TR-605B, Type M Class 1, Amendment 3.

2.3. Surface run-off analysis
A surface run-off test was performed to simulate a run-off scenario on a steep slope with water as the principal agent for erosion and weathering [18]. Soil control mats were weaved from the 6-mm diameter ropes. Each mat is produced as 1000-mm by 600-mm open-meshes with 5-cm square spacing.

Soil samples were prepared in two soil core test boxes with plane dimensions of 1000 mm in length and 600 mm in width, and a surface slope of 65°. Soil samples were assumed to be homogenous, with uniform distribution of fine-grained soils, silt and clay. Soil compaction was performed every 10-in depth.

The test boxes were placed side by side, with one of the test slopes fully covered with geotextile mat, while the other test slope was left barren. Water was introduced into the system through a perforated pipe hung horizontally 2 feet above the peak, running perpendicular to the slope.

Surface run-off from the test box flowed through a gutter placed at the bottom of the slope, which was directed to a bucket serving as the watershed catchment. The volume of the run-off collected in each bucket was measured every 10 minutes over the duration of an hour.

To determine the sediment concentration of the run-off, deposits were filtered by gravity using a canvas cloth. The dry weight, $m_{\text{dry}}$, of the sediments was taken after oven-drying the filter residue until its moisture content is at most 5%. The sediment concentration was computed as the ratio of the dry weight of the sediments in the runoff from the covered slope, $m_{\text{dry,covered}}$, to the volume of the covered slope runoff, $V$.

$$\text{Sediment Yield} = \frac{m_{\text{dry,covered}}}{\text{Surface Area} \times \text{Time}}$$  \hspace{1cm} (1)

The performance efficiency of the bamboo geotextile netting in mitigating erosion was evaluated as:

$$\text{Net efficiency} = \frac{m_{\text{dry,uncovered}} - m_{\text{dry,covered}}}{m_{\text{dry,uncovered}}} \%$$  \hspace{1cm} (2)

where $m_{\text{dry,uncovered}}$ is the dry weight of the sediments eroded from the uncovered slope.

3. Results and discussions

3.1. Tensile strength of bamboo fiber ropes
To evaluate their mechanical strength, bamboo rope samples were subjected to tensile tests. Figure 1 presents the result of tensile strength test on three samples of a 6-mm diameter bamboo fiber rope. The ropes were able to carry a mean load of 428.68 N at an average ultimate normal stress of 10.65 MPa. Rope elongation averaged 37.20 mm before the ultimate normal stress was reached. The factors of safety for all samples are above 1.0, with a mean of 2.14. This indicates that the average strength of the 6-mm bamboo rope is 2.14 times greater than the standard breaking strength of a commercial manila hemp. The US Federal Specification set a safe load for the 6-mm diameter manila hemp at 200 N.
Table 1. Tensile strength of 6-mm diameter bamboo rope samples.

| Sample | Load (N) | Elongation (mm) | Average Strength (MPa) | Ultimate Strength (MPa) | Rupture Strength (MPa) | Factor of Safety (MPa) |
|--------|----------|-----------------|------------------------|-------------------------|------------------------|------------------------|
| 1      | 512.76   | 41.50           | 10.20                  | 30.06                   | 30.06                  | 2.56                   |
| 2      | 410.87   | 33.86           | 14.53                  | 28.12                   | 13.27                  | 2.05                   |
| 3      | 362.40   | 36.25           | 7.21                   | 27.06                   | 12.56                  | 1.81                   |
| Mean   | 428.68   | 37.20           | 10.65                  | 28.41                   | 18.63                  | 2.14                   |

For the 8-mm diameter bamboo ropes, the Federal Specification requires a safe load of 330 N in manila hemp. Results of the tensile strength test show that the samples resisted loads up to 786.84 N.

Table 2. Tensile strength of 8-mm diameter bamboo rope samples.

| Sample | Load (N) | Elongation (mm) | Average Strength (MPa) | Ultimate Strength (MPa) | Rupture Strength (MPa) | Factor of Safety (MPa) |
|--------|----------|-----------------|------------------------|-------------------------|------------------------|------------------------|
| 1      | 878.97   | 37.86           | 17.49                  | 10.25                   | 3.58                   | 2.66                   |
| 2      | 778.52   | 35.34           | 27.54                  | 8.16                    | 3.68                   | 2.36                   |
| 3      | 703.02   | 23.90           | 24.86                  | 7.66                    | 3.38                   | 2.13                   |
| Mean   | 786.84   | 32.37           | 23.30                  | 8.67                    | 3.55                   | 2.38                   |
Ultimate strength reached around 8.67 MPa before declining to rupture limits of 3.55 MPa. The average rope elongation is at 32.37 mm. As with the 6-mm diameter ropes, all samples of 8-mm ropes yielded a factor of safety above 1.0, averaging at 2.38. This signifies that that the bamboo ropes were able to carry loads up to 2.38 times greater than the standard tensile strength requirement for manila hemp.

3.2. Sediment yield analysis
Rainfall simulations were performed to compare erosion rates between bare and geotextile-covered slopes. Sediment concentrations in runoffs from the two test slopes are recorded in Table 3.

| Test Slope      | Time Elapsed, in minutes |
|-----------------|--------------------------|
|                 | 10 | 20 | 30 | 40 | 50 | 60 |
| Uncovered (UTS) | 0.476 | 17.362 | 37.805 | 70.127 | Slope failure | Slope failure |
| Covered (CTS)   | 0.205 | 5.226 | 4.781 | 21.617 | 17.250 | 14.561 |
| %diff           | 56.93% | 69.90% | 87.45% | 69.17% | - | - |

Mass concentration in runoff from the uncovered test slope (UTS) increased dramatically as the soil gets more saturated over time. UTS mass flow was around 188.66 g/hr compared to 63.64 g/hr CTS mass flow. Faster rate of soil saturation in UTS resulted to weaker shear stresses between soil layers. Before the 40-minute mark was reached, UTS was fully saturated, and its bottom soil strata were loose. Surface runoff subsequently washed away the remaining sediments.

At t=40 min, UTS sediment yield was projected to be around 29.21 kg/sq-m, while CTS sediment yield was 68.92% lower at 9.08 kg/sq-m. Forty minutes under constant rainfall, the cumulative UTS mass runoff was 125.77 g/L. With the cumulative CTS mass concentration was 31.83 g/L, the bamboo geotextile was evaluated to have a net cover efficiency of 74.70%.

4. Conclusions
Tensile strength tests and surface runoff simulations were performed to assess the viability of bamboo fiber geotextile for erosion control netting on steep barren slopes. The tensile strengths of the bamboo fiber ropes passed the safe load standards for woven natural ropes based on the acceptable breaking strength of manila hemp.
Results of the sediment yield analysis showed that the bamboo geotextile prevented significant mass runoff from the topsoil during the rainfall simulations. The bamboo geotextile was effective in mitigating surface erosion and subsequent slope failure.

To validate the results of this study, sediment runoff analysis on actual slopes is recommended. A wide-width strip test should also be performed to cover the measurement of tensile strength and elongation of bamboo geotextile, including the assessment of the initial modulus, offset modules, secant modulus and breaking toughness.

Acknowledgement

This research was made possible through a grant from the University of Batangas Center for Publications, Research, Linkages and Liaison (UB-CPReLL).

References

[1] Lal R 2001 Soil Degradation by Erosion Land Degradation and Development 12 519–39
[2] Pimentel D 2006 Soil Erosion: A Food and Environmental Threat Environment, Development and Sustainability 8 119–37
[3] Labrière N, Locatelli B, Laumonier Y, Freycon V, and Bernoux M 2015 Soil erosion in the humid tropics: A systematic quantitative review Agriculture, Ecosystems & Environment 203 127–39
[4] Fattet M, Fu Y, Ghestem M, Foulonneau M, Nespoulous J, Le Bissonnais Y, et al 2011 Effects of vegetation type on soil resistance to erosion: Relationship between aggregate stability and shear strength CATENA 87 60–9
[5] Lekha K 2004 Field instrumentation and monitoring of soil erosion in coir geotextile stabilised slopes—A case study Geotextiles and Geomembranes 22 399–413
[6] Cooke T and Rebenfeld L 1988 Effect of chemical composition and physical structure of geotextiles on their durability Geotextiles and Geomembranes 7 7–22
[7] Rollin A, and Lombard G 1988 Mechanisms affecting long-term filtration behavior of geotextiles Geotextiles and Geomembranes 7 119–45
[8] Wiewel B and Lamoree M 2016 Geotextile composition, application and ecotoxicology—A review Journal of Hazardous Materials 317 640 - 55
[9] Tran L, Fuentes C, Truong Chi T, Nguyen Minh T, Van Vuure A and Verpoest I 2015 Investigation of microstructure and tensile properties of porous natural coir fibre for use in composite materials Industrial Crops and Products 65 437 - 45
[10] Defoirdt N, Biswas S, De Vriese L, Ngoc Tran L, Van Acker J, Ahsan Q, et al. 2010 Assessment of the tensile properties of coir, bamboo and jute fibre Composites Part A: Applied Science and Manufacturing 41 588 - 95
[11] Choudhary N 2013 Jute Geotextiles as Substitute to Synthetic Geotextiles Advanced Materials Research 821 85-9
[12] Davies K, Fullen M and Booth C 2006 A pilot project on the potential contribution of palm-mat geotextiles to soil conservation Earth Surfaces Processes and Landforms 31 561-9
[13] Bhattacharyya R, Fullen M, Davies K, and Booth C. 2009 Utilizing palm-leaf geotextile mats to conserve loamy sand soil in the United Kingdom Agriculture, Ecosystems & Environment, 130 50-8
[14] Bhattacharyya R, Yi Z, Yongmei L, Li T, Panomtaranichagul M, Peukrai S, et al 2012 Effects of biological geotextiles on aboveground biomass production in selected agro-ecosystems Field Crops Research 126 23-36
[15] Roxas C 1998 Bamboo research in the Philippines. International Plant Genetic Resources Institute, Kunming and Xishuanbanna, Yunnan, China
[16] Amada S, Ichikawa Y, Munekata T, Nagase Y and Kirigari N 1993 Proceedings of the 5th Bioengineering Div. Conference p. 62 Japan: Society of Mechanical Engineering
[17] Álvarez-Mozos J, Abad E, Giménez R, Campo M, Goñi M, Arive M, et al 2014 Evaluation of erosion control geotextiles on steep slopes. Part 1: Effects on runoff and soil loss *CATENA* 118 168-78

[18] Luo H, Zhao T, Dong M, Gao J, Peng X, Guo Y, et al 2013. Field studies on the effects of three geotextiles on runoff and erosion of road slope in Beijing, China *CATENA* 109 150-6