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Development of Corn (*Zea mays* L.) Stalk Geotextile Net for Soil Erosion Mitigation

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***Abstract*—**This study aimed to introduce new natural fiber to be used in the production of geotextile net for mitigation of soil erosion. Fiber extraction from the stalks was the main challenge faced during the processing of stalks to ropes. Thus, an investigation on the extraction procedures of corn (*Zea mays* L.) stalk under biological and chemical retting was undertaken. Results indicated significant differences among percent fiber yield as affected by the retting methods used with values of 15.07%, 12.97%, 11.60%, and 9.01%, for dew, water, chemical (1 day after harvest and15 days after harvest), respectively, with the corresponding average extracting duration of 70, 82, 89, and 94 minutes. Physical characterization of the developed corn stalk geotextile net resulted to average mass per unit area of 806.25 g/m^2 and 241% water absorbing capacity. The effect of corn stalk geotextile net in mitigating soil erosion was evaluated in a laboratory experiment for 30^o and 60^o inclinations with three treatments: bare soil (A_1), corn stalk geotextile net (A_2) and combined cornstalk geotextile net and vegetation cover (A_3). Results revealed that treatment A_2 and A_3 significantly decreased sediment yield and an increase in terms of soil loss reduction efficiency. The cost of corn stalk geotextile net is Php 62.41 per square meter.

***Keywords*—**Corn stalk, natural geotextile, retting, soil erosion.

I. Introduction

SOIL erosion is widely recognized as a major environmental problem which threatens the most important and non-renewable reserve of human, the farmland. This problem is mainly initiated by the erosive forces like farm tillage, wind and water resulting to removal of top soil. Eroding of soil is dominantly triggered by intense rainfall and high velocity runoff to cultivated and steep areas. This condition causes great destruction not only to soil characteristics but also to its properties and fertility affecting numerous numbers of individuals.

In the Philippines, about 45% of the country's arable land suffers from moderate to severe soil erosion [1]. Reference [2] cited that an estimate of 623 MT of soil is lost annually from 28 million hectares of cultivated land in the country. Without immediate and appropriate protection, there will be severe soil loss that may lead to difficulty in establishing vegetation and possibly increase in sediment input to nearby rivers [3]. Hydroseeding, on the other hand, is a technique used to establish vegetation cover that can provide long-term protection against soil erosion. However, growth of vegetation is difficult during early stage since seeds or seedlings might be washed away by the erosive forces of rainfall and runoff [4]. During this situation, hydroseeding combined with bioengineering techniques is the best option to protect the plants from harsh environment.

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Geotextile has gained popularity in mitigating various types of soil erosion in different parts of the world. Like vegetation, it can reduce direct impact of raindrops; reduce runoff generation and soil detachment. But, despite these advancements, geotextile from naturally occurring fiber products has not received any significant consideration as researches were mostly focused on the production and utilization of synthetic geotextiles like polyolefin and polyester. Natural geotextile is also known to have a short life span, degrades easily [5], and has properties that limit its full utilization.

In an age of growing environmental awareness, biodegradation of natural geotextile as a result of microorganism's activity is of great advantage. This advantage leads to exploitation of different natural fiber resources which can be used as geotextile for a specific soil erosion problem. Expected degradation of these geotextiles eliminates the doubling effect when combined with the vegetation. Natural geotextile's advantages are biodegradability, ability to protect soil from splash erosion, capacity to absorb water, and aid for reduction to water loss through evaporation [5]. These are the indications that natural geotextiles have an edge over synthetic geotextile for slope stability application. In this premise, investigation of other potential natural fiber resources such as fiber from corn stalks can be done to reduce agro-wastes left on the field which can significantly reduce soil erosion when properly converted to geotextile net.

A. Statement of the Problem

Corn ranks second next to rice as the most important grain crop in the country. The volume of production of corn in the country for the year of 2014 has an output level of 7.75 million MT which is 5.1% above the 2013 output and is expected to rise up to 2.56 million hectares in 2015.

The province of Pangasinan has a total land area of 536,818 hectares, which represents almost 50% of the total area of the entire Region 1 and constitutes to about 1.8% of the total land area of the country. Report from [6] showed that Pangasinan has a total corn production of 289,607 MT for the cropping year 2012-2013 with an average yield of 5.63 tons/ha within the harvest area of 51,430 ha.

Since there is a massive production of this crop, there is also a high biomass production. The common practice of farmers is to leave the residues in the field and some are burnt which causes pollution. Corn residues are also left by the farmers on the ground immediately after harvesting to act as mulch material in conserving soil moisture for the next cropping season. The problem, however, is that corn stalks, without any prior physical alteration, may damage small machineries during land preparation. Also dried corn stalks when used as mulch can be easily blown by wind and be washed away through runoff. Lastly, huge quantities of corn stalks left in the field to decompose may lead to emergence of diseases among crops.

B. Objectives

The general objective of the study was to develop corn stalk geotextile net for erosion mitigation. Specifically, the study aimed to:

1. Determine the physical properties of the developed corn stalk geotextile net;
2. Evaluate the effect of developed corn stalk geotextile net and vegetation cover in sediment yield, sediment concentration and soil loss reduction efficiency; and,
3. Determine the cost of the developed corn stalk geotextile net.

C. Scope and Limitations of the Study

The study focused on the production of geotextile net derived from corn stalk. Experiments on fiber extraction were done which involved biological retting (dew and water) and chemical retting.

The effect of using corn stalk geotextile net as ground cover was evaluated under the following conditions: two different soil slopes (30^o and 60^o), 60-minute rainfall durations (data taken at 10-minute interval) and rainfall intensity of 75 mm/hr. Sandy loam type of soil was used. The variety of corn used throughout the experiment was NK 8860. The testing of physical properties of developed corn stalk geotextile net included only mass per unit area and water absorption. The hydroseeding mixture was limited only at single mixing ratio wherein Centrosema Pubescens and White Millet were the seeds used. The evaluation of the performance and efficiency of the man-operated twining machine was not included in the study.

D. Time and Place of the Study

The study was conducted from January to July, 2015. The development of corn stalk geotextile net and the evaluation of its physical properties were carried out at Sta. Maria, Pangasinan.

The fabrication of test boxes and frames was done at the Department of Public Ways and Highways (DPWH) Hydraulic Laboratory, Pasig, City. Evaluation of corn stalk geotextile net in mitigating soil erosion at different soil slopes and rainfall durations was also done at the DPWH Hydraulic Laboratory, Sta. Rosa, Pasig City.

II. Materials and Methods

A. Development of Corn Stalk Geotextile Net

In determining the retting method to be used, an experiment was first conducted. Treatments for this specific experiment were: T_1 – chemical retting (one day after stalk harvest), T_2 - chemical retting (15 days after stalk harvest), T_3 – dew retting and T_4– water retting. Manual stripping was done to separate fibers.

Production of single spline rope from corn stalk was made possible by using rope making machine. Cornstalk geotextile net weaving process follows the traditional open-weave pattern. This was done by interlacing the single-splined fiber ropes at right angle with each other manually. Mesh size opening used 25 mm x 25 mm (1 in. x 1 in.). The end part of each interlocking rope was tied with a brown yarn to avoid disengagement of each rope.

B. Vegetation Cover Preparation

The experiment employed hydroseeding to establish vegetation cover. Hydroseeding mixture ingredients were carefully weighed and then were mixed together in a container.

The slurry was manually applied at the top of soil surface (Fig. 1).

(a) ingredients (b) mixing (c) application

Fig. 1 Hydroseeding

Due to uneven application of the mixture, follow-up applications to cover weak spots were done as needed. Vegetation was allowed to establish for 21 days before subjecting to final simulation.

The installation of corn stalk geotextile net after hydroseeding application was done by anchoring the top and bottom edge of the net by small wire pegs to avoid slippage. After the geotextile net has been installed, test boxes were put outside the Hydraulic Laboratory, enabling the newly planted grass to get enough light and natural rainfall necessary for its growth.

C. Experimental Set-Up

A laboratory test was conducted to evaluate the physical characteristics and impact of corn stalk geotextile net in mitigating soil erosion. Rainfall simulator apparatus was owned and operated at Hydraulic Laboratory of the Project Management Office (PMO)-Flood Control and Sabo Engineering Center (FCSEC) of the Department of Public Works and Highways (DPWH), Pasig City, Philippines. The rainfall simulator was set to give a rainfall intensity of 75 mm/hr.

The effect of corn stalk geotextile net was evaluated in terms of sediment yield, sediment concentration and soil loss reduction efficiency. Various soil erosion covers as listed below were used as treatments: A_1 - bare soil (control); A_2 - 25 mm x 25 mm (1 in. x 1 in.) mesh size corn stalk geotextile net and A_3 - 25 mm x 25 mm (1 in. x 1 in.) mesh size corn stalk geotextile net combined with hydroseeding

The laboratory experiment was arranged in a Randomized Complete Block Design (RCBD), with three replications. The experiment was analyzed separately for the two angles of inclinations of test boxes (30^o and 60^o). Comparison among treatment means was done by using Duncan's Multiple Range Test (DMRT), at a 5% level of significance. Preparation of the experimental units under the bare soil, with corn stalk geotextile net and combined corn stalk geotextile net and vegetation is shown in Fig. 2. Rainfall simulation lasted for 60 minutes where data were taken at 10-minute interval.

(a) bare (b) with net (c) with vegetation

Fig. 2 Preparation of experimental units

1. Collection of Runoff Water and Sediment

During the rainfall simulation experiment, a readily available plastic container was put just below the test box for runoff water and sediments collection. The collected runoff water with sediments was weighed and allowed to stand overnight to let the visible sediments to settle down at the bottom part of the container. With the aid of silk cloth, sediments were separated by filtration method. Filtered sediments were air dried for five days to determine the sediment concentration, sediment yield and amount of soil erosion.

D. Evaluation of Corn Stalk Geotextile Net

1. Physical Characterization

The physical properties were limited to: mass/unit area and water absorption (WA). Technical specification of corn stalk geotextile net included number of twines crosswise and lengthwise, single and double spline rope diameters.

Mass/unit area is an important property that can directly measure fabric cost. It was determined by weighing samples in an accurate digital weighing scale.

Water absorption was computed through (2) as cited in [7]. Net weight refers to the weight of geotextile after the protruding fibers in the rope have been removed and the final weight refers to the weight of the net after soaking.

$$WA=\frac{WA_f\text{-}WA_i}{WA_f} \tag{1}$$

where WA is water absorption (%), WA_i is net weight (g) and WA_f is final weight (g)

2. Sediment Yield

This determines the mass of the sediment over its plot area with respect to time. This is the mass of the oven-dried sediment collected over the area of the soil test box and duration of simulation. It was estimated by using (2) cited in [8].

$$SY=\frac{S_m}{tA_b} \tag{2}$$

where SY is sediment yield ($g/m^2.hr$), S_m is mass of oven-dried sediment collected (g), A_b is area of soil test box (m^2) and t is duration of rain simulation (hr)

3. Soil Loss Reduction Efficiency

This determines how well a certain geotextile controls soil erosion. Computation was in accordance to (3), as given in [9], [10]:

$$SLRE=\frac{SY_b\text{-}SY_g}{SY_b} \tag{3}$$

where SLRE is soil loss reduction efficiency (%), SY_b is bare sediment yield ($g\ m^2$-hr) and SY_g is geotextile net sediment yield ($g\ m^2$-hr).

E. Cost of Developing Geotextile Net

The cost of development of corn stalk geotextile net is the sum of the cost acquired from the gathering of corn stalks from the field to the development of corn stalk geotextile net. These are the costs of harvesting of standing stover, transporting, loading and unloading, retting, fiber stripping and rope production including the cost of weaving the corn stalk geotextile net.

The total cost of development of corn stalk geotextile net will be computed by using (4):

$$GNC= T_c+ S_S+R_C+S_c+RD_c+W_c \tag{4}$$

where GNC is cost of corn stalk geotextile net (Php), TC is cost of harvesting, transporting, loading and unloading (Php), S_s is cost of stalk separation (Php), R_c is cost of retting (Php), S_c is cost of fiber stripping (Php), RD_c is cost of rope production (Php) and W_c is cost of weaving corn stalk geotextile net (Php).

The main factor that contributed to the initial cost of the developed cornstalk geotextile net is the duration of manual fiber extraction which may be reduced and compensated when development processes are fully mechanized.

III. Results and Discussions

A. Fiber Extraction

From the different retting methods used in the experiment, it was determined dew retting (T_3) had the highest mean fiber yield of 45 g from 300 g of dried corn stalks or about 15% of its dry weight and average extraction duration of 70 minutes.

B. Description of Corn Stalk Geotextile Net

Fig. 3 shows the developed corn stalk geotextile net and the physical specifications of the corn stalk geotextile net are presented in Table I.

Fig. 3 Corn stalk geotextile net

The average mass per unit area is 806.25 g/m^2. Mass per unit area of corn stalk geotextile net falls under heavy weight-type natural geotextile as classified in [11]. This specific physical property implies that corn stalk geotextile net is a suitable material for soil erosion mitigation.

TABLE I
PHYSICAL SPECIFICATION OF CORNSTALK GEOTEXTILE NET

PHYSICAL PROPERTY	AMOUNT
Mass per unit area, g/m^2	806.25
Water Absorption, %	241
Single spline rope diameter	5.22
Double spline rope diameter	10.89
No. of twine-crosswise	28
No. of twine-lengthwise	14

The test samples for water absorption were taken from the same specimen used in determining mass per unit area of cornstalk geotextile net. The change in weight before and after soaking was obtained using a weighing scale having an accuracy of +1 g. Results showed that the average water absorption of geotextile sample is 241% of its initial weight. Water absorbing ability of geotextile greatly influences the amount of runoff generated.

Natural geotextile has been demonstrated as a suitable material for use in various erosion control experiment because of its water absorbing capacity by reducing the volume of runoff. Reference [12] showed that natural fiber geotextile for erosion control has a lower runoff velocity which is due to high water absorbency. Also, its natural water absorbing capacity helps conserve soil moisture and anchor soil firmly (drapability).

C. Impact of Corn Stalk Geotextile Net on Soil Erosion Mitigation

Sediment yield seemed to increase with the decrease in the amount of surface cover at any given period of the rainfall simulation. For example, at 30^o inclination (Table II), the sediment yield recorded for 60-minute rainfall simulation with 10-minutes interval were 100.00, 134.37, 170.83, 215.62, 217.50 and 232.29 g/m^2-hr.

While sediment yield at 60^o slope (Table III), the sediment yield of 1212.50, 1418.75, 1437.50, 1431, 1465.50, and 1558.95 g/m^2-hr were obtained, respectively for rainfall duration of 10, 20, 30, 40, 50, and 60 minutes.

The amount of sediment yield obtained from the plots may be accounted to the ability of the surface cover to reduce the impact of falling water, thus, reducing the amount of splashed soil sediments. The result agrees with the study cited in [13] which stated that geotextile nets were good at reducing top soil detachment.

TABLE II
SEDIMENT YIELD MEANS AT 30^O SLOPE

RAINFALL DURATION	SURFACE COVER		
	Bare soil	Geotextile net	Combined geotextile net and vegetation
10	100.00^a	62.500^{ab}	0.00^b
20	134.37^a	65.62^{ab}	0.00^b
30	170.83^a	62.50^{ab}	0.00^b
40	215.62^a	64.06^b	0.00^b
50	217.50^a	72.50^b	0.00^b
60	232.29^a	69.79^b	0.00^b

In a row under each rainfall duration, means followed by a common letter are not significantly different at 5% level by DMRT.

TABLE III
SEDIMENT YIELD MEANS AT 60^O SLOPE

RAINFALL DURATION	SURFACE COVER		
	Bare soil	With geotextile net	Combined geotextile net and vegetation
10	1212.50^a	487.500^{ab}	0.00^a
20	1418.75^a	390.62^{ab}	0.00^b
30	1437.50^a	368.75^{ab}	0.00^b
40	1431.25$_a$	364.06^{ab}	0.00^b
50	1467.50^a	348.75^b	0.00^b
60	1448.95^a	307.29^b	0.00^b

In a row under each rainfall duration, means followed by a common letter are not significantly different at 5% level by DMRT.

Experimental units with combined corn stalk geotextile net and vegetation cover have 100% reduction efficiency for both 30^o and 60^o slope (Tables IV and V). Result revealed that the type of surface cover had significant effect on soil loss reduction efficiency. These values can be attributed to the ability of the surface covers to reduce the kinetic energy of flowing water thereby reducing its ability to transport soil particles.

TABLE IV
SOIL LOSS REDUCTION EFFICIENCY (%) MEANS AT 30^O SLOPE

RAINFALL DURATION	SURFACE COVER	
	With geotextile net	Combined Geotextile net and vegetation
10	29.36^b	100^a
20	38.04^b	100^a
30	54.45^b	100^a
40	58.62^b	100^a
50	62.07^b	100^a
60	66.98^b	100^a

In a row under each rainfall duration, means followed by a common letter are not significantly different at 5% level by DMRT.

TABLE V
SOIL LOSS REDUCTION EFFICIENCY (%) MEANS AT 60° SLOPE

RAINFALL DURATION	SURFACE COVER	
	With geotextile net	Combined Geotextile net and vegetation
10	57.68[b]	100[a]
20	72.67[b]	100[a]
30	71.79[b]	100[a]
40	73.34[b]	100[a]
50	75.34[b]	100[a]
60	78.18[b]	100[a]

In a row under each rainfall duration, means followed by a common letter are not significantly different at 5% level by DMRT.

D. Corn Stalk Geotextile Net Cost

From the assumptions and calculations, an estimate of 6,246.8 kg of stovers was produced per hectare of corn plantation. The amount of corn stalk per hectare reached up to 3,173.5 kg and 1,808.61 kg for wet and dry basis, respectively. From one (1) hectare of standing corn stover, 271.83 kg of stalk fiber could be obtained and converted into corn stalk geotextile net. Similarly, in order to produce 1 m x 1 m size corn stalk geotextile net with mesh opening of 2.54 cm x 2.54 cm, a total of 78 m double-spline ropes are needed with an equivalent weight of 806.26 g of stalk fiber.

Cost estimation for producing corn stalk geotextile net was determined by taking into account the following various cost:

1. cost of harvesting of standing stovers, transporting, loading and unloading;
2. cost of stalk separation;
3. cost of retting;
4. cost of fiber stripping;
5. cost of rope production; and,
6. cost of weaving the corn stalk geotextile net.

The estimated cost of developing geotextile net made from corn stalk fiber was placed at Php 62.41. When compared with commercially available geotextile net for erosion mitigation such as coco coir geotextile net, the cost of corn stalk net is higher by 4–52% depending on the diameter of the ropes used. The additional processes involved in developing corn stalk geotextile net such as stalk separation and retting, accounted for the relatively higher cost of the processed geotextile net.

IV. CONCLUSION

Based from the results, the following conclusions were derived:

Alteration of the physical structure of corn stalks should be done first before it can be converted into geotextile product for soil erosion mitigation. The processes in corn stalk geotextile net production involve retting, fiber extracting, rope making and net weaving.

Corn stalk geotextile net may be characterized in terms of such physical properties as mass per unit area and water absorbing capacity. Mass per unit area of the net (806.25 g/m^2) was affected by the mass of single and double spline ropes used in the production. Water absorbing capacity is about 241% of its initial weight.

The corn stalk geotextile nets that were developed were effective in mitigating soil erosion at 30° and 60° slope inclination under a laboratory condition. Soil loss reduction efficiency ranged from 29 - 66.99% for 30° slope and 72.67 - 78.19% for 60° slope.

The cost of developing corn stalk geotextile net was placed at Php 62.41 per m^2. A higher initial cost of the developed corn stalk geotextile net than the commercially available geotextile nets was attributed to the cost of fiber.

V. RECOMMENDATIONS

Results revealed that the developed corn stalk geotextile net has the potential to be used for soil erosion control. Sediment yield and soil loss efficiency were significantly reduced when compared with plots without soil covering. Other recommendations derived from the results of the experiments include:

- Developing and designing of decorticating and rope-making machines specifically for corn stalks to decrease the labor requirement, cost of producing geotextile net and fiber extraction duration.
- Validating the results of the laboratory experiment through field testing.

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REFERENCES

[1] D. Pimentel and M. Burgess, “Soil Erosion Threatens Food Production.” 2013.
[2] E. Sombrito. “Restoration of Soil Fertility and Sustenance in Agricultural Productivity”. Philippine Nuclear Research Institute. 2004.
[3] R.P. Morgan, and R. J. Rickson, “Slope Stabilization and Erosion Control: A Bioengineering Approach”. E and FN Spoon, London, United Kingdom. 2003.
[4] M.M. Cereno, FG. Tan, and F.A. Uy, “Combined Hydroseeding and Coconet Reinforcement for Soil Erosion Control, Soil Erosion Studies,” Dr. Danilo Godone (Ed.), ISBN: 978-953-307-710-9, InTech. 2011.
[5] M. Calkins, “Materials for Sustainable Sites: A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials,” John Wiley and Sons. 2008.
[6] Department of Agriculture Regional Field Unit 01. Annual Report. 2013
[7] G.A. Rosario, “Cement-bonded Particleboard from Cotton Stalk,” Unpublished Masteral Thesis. College of Engineering, Central Luzon State University, Science City of Munoz, Nueva Ecija. 1997.
[8] A.C. Junio, et al, “Performance Investigation of Banana Net as Slope Protection Against Soil Erosion” Unpublished Undergraduate Thesis. Department of Civil Engineering, College of Engineering, Technological University of the Philippines, Manila, Philippines. 2009.
[9] R. Bhattacharyya, K. Davies, M.A. Fullen, & C.A. Booth, C. A, “Utilizing Palm-leaf Geotextile Mat to conserve Loamy Sand Soil in United Kingdom”. 2008.
[10] R. Bhattacharyya, K. Davies, M.A. Fullen, & C.A. Booth, C. A. Utilization of Palm-mat Geotextiles to Conserve Agricultural Soils. 2009
[11] Commission Fund for Commodities (CFC), “A Report on the Comparative Advantages of Sisal, Coir and Jute Geotextile.” 2010.

[12] O. Ogbobe, K.S. Essien and A. Debayo. "A Study of Biodegradable Geotextiles Used for Erosion Control." Federal University of Technology, Owerri, Imo-State Nigeria. 1997.
[13] C.S. Llanto, et al. 2014, "Oil Palm (Elaeis guineensis Jacq.) Geotextile Net for Mitigating Hillslope Erosion and Runoff." Unpublished PhD Dissertation, Central Luzon State University, Science City of Muñoz, Nueva Ecija. March 2013.