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15. Supplementary Notes

16. Abstract

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PRODUCTION AND EVALUATION OF SUGAR CANE FIBER GEOTEXTILES

REPORT 2: FIELD TESTING

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LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER

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ABSTRACT

Prior research involved the production and laboratory testing of sugar cane fiber geotextiles for soil erosion control. Comparative preliminary studies were conducted on test slopes to determine slope stability, in horticulture plots to determine grass propagation characteristics, and in the laboratory to characterize physical properties. Based upon satisfactory laboratory and germination results, a field test was designed to determine product performance in a natural environment. A field test was conducted in cooperation with the Louisiana Transportation Research Center (LTRC) and the Louisiana Department of Transportation and Development (DOTD) to compare the sugar cane fiber mats with commercially available natural fiber geotextiles of wood, coconut, and straw. Field test results indicate that protection provided for the seed bed during the vegetative establishment period and slope stabilization were satisfactory among all products. Further work will include a continuous process for sugar cane fiber mat formation and a spray-on application using bagasse fibers. Standardized product specifications need to be developed.

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IMPLEMENTATION STATEMENT

Often a geotextile is required only for a short time until vegetation is established. A suitable natural fiber geotextile can perform this function temporarily and will biodegrade as vegetation grows to permanently control soil movement and erosion loss. Emphasis is placed on the sugar cane by-product indigenous to Louisiana because of the economic benefits it can contribute. This non-woven geotextile made from fibers of sugar cane rind or bagasse slurry could be produced in local sugar mills and provide an economic benefit to both the transportation system construction industry and to the sugar cane industry. A side benefit is the conversion of what is essentially an agricultural waste by-product, currently used for boiler feed, to a useful value-added product. Due to the availability of raw materials and the natural adhesion of fibers, a low cost biodegradable geotextile without stitching or net reinforcement and including appropriate physical properties of controlling erosion would be available.

Based upon satisfactory results from laboratory tests and the field study, an application for the sugar cane fiber geotextile will be submitted for review to be included in the DOTD Qualified Products List (QPL). A continuous reactor manufacturing process that will include a procedure for roll production is being developed. It is estimated that the sugar cane fiber geotextile will be commercially available by the spring of 1998.

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INTRODUCTION

Fibers from sugar cane rind formed into a non-woven mat were investigated as a biodegradable geotextile for soil erosion control in order to provide a competitive natural fiber product from essentially agricultural waste. A process for production of sugar cane fiber mats based on appropriate fiber length and lignin removal and the comparison of the performance properties of these mats with other natural fiber geotextiles in a laboratory setting were accomplished in prior research [*1*].

Research objectives included determining the extraction parameters that produce fiber bundles from sugar cane rind. It was determined that sugar cane rind in a sodium hydroxide solution of 0.05 normality with mechanical action followed by steam explosion yielded fiber bundles appropriate for non-woven mat formation. For the blanket erosion control mat formation, the fiber bundles that result from the chemical and mechanical treatment were subsequently washed to remove excess sodium hydroxide and liberated lignin. Non-woven blanket mats were formed from these bundles by being suspended in water, deposited on a screen, de-watered and dried. This blanket form was produced in one square yard mats since facilities were not available for continuous blanket production.

Properties of commercially available natural fiber geotextile mats of wood, coconut, and straw were compared with those of the newly developed product from sugar cane fibers. Characterization of the geotextile mats included weight, thickness, strength, water permittivity, water resistance, biodegradability, light penetration, and flammability. Appropriate geotextile requirements of physical compatibility, ease of installation, slope protection and stabilization, germination, propagation, and cost effectiveness were investigated. Specifically, American Society for Testing and Materials (ASTM) and American Association of Textile Chemists and Colorists (AATCC) test methods were used to compare physical, mechanical, hydraulic, and environmental properties identified as being necessary for controlling erosion of the natural fiber geotextiles. A commercial wood fiber geotextile served as a benchmark for evaluations because it was assumed that the wood mat possessed minimum product specification requirements to control erosion.

The methodology was based on standard ASTM and AATCC test methods adapted for this research or as a guide in developing appropriate testing procedures. The opacities of the geotextiles were measured on a Digital Drape Tester with the pedestal removed. This adaptation of the Drapemeter has a digital voltmeter connected to photovoltaic cells in the base of the tester that enable a direct readout of the relative amount of light energy incident upon the specimens [2]. Until the recent formation of the LTRC New Products Evaluation Committee, John Oglesby, P.E. LTRC Engineer Supervisor, was the official evaluator for product testing. Evaluations of products on test sites were based on germination growth at the end of a growing season and the absence of the washing away of product or soil. Products were evaluated for basic erosion control usage under no extreme conditions. Products were either accepted or rejected based on the above mentioned factors plus the evaluator's own knowledge and past experience with product materials.

Laboratory results comparing sugar cane fiber and other natural fiber geotextiles are presented in Table 1. The sugar cane fiber mat was an entanglement of fibers with the lignin content providing a natural adhesive. This material fully biodegrades and acts as a mulch after the mat begins to decompose and vegetation has started. Other natural mats were the coconut geotextile that had polypropylene nets on both sides and was stitched with polyester thread, the straw fiber mat that had a lightweight photodegradable polypropylene net on one side and was stitched with cotton thread, and the wood that had a photodegradable extruded plastic mesh on one side. The nets and mesh are described by the manufacturers as being photodegradable, and the strength of the nets is reflected in test results presented in Table 1.

Wood mats were denser than the other geotextiles, and the sugar cane mats were second highest in weight measurements. The wood mats were significantly thicker than the other products. Variation in thickness was high because of the fiber unevenness in the mats. The sugar cane fiber mats can be made in a wide range of thicknesses depending on the application and the desired physical properties. The higher values of strength for the coconut, wood, and straw were because of the net covering on the mats. The strength of the sugar cane fiber mat was attributed solely to fiber entanglement.

Density of the geotextile is an important variable affecting water flow rate. All products were capable of being measured at the .5-in (12.7-mm) head. Neither wood nor straw were able to be tested at higher head levels, because the water flowed through the mats too quickly to obtain an accurate time. The permittivity value was normalized (specific value) to account for weight variance of the products. A post-ANOVA test showed that the sugar cane fiber mat had a significantly lower flow rate than coconut and straw. The wood geotextile was not significantly different from any product.

Table 1
Properties of Natural Fiber Geotextiles

PROPERTY; TEST METHOD	SUGAR CANE (mean)	WOOD (mean)	COCONUT (mean)	STRAW (mean)
weight (g/m^2); ASTM D 3776	416.01	487.86	247.34	209.75
thickness (mm); ASTM D 1777	3.503	6.064	2.328	2.571
strength (N); ASTM D 1682	9.4	43.3 (net)	109.2 (nets)	32.1 (net)
water permittivity (s^{-1}); ASTM D 4491	0.040	0.105	0.124	0.131
water resistance (%); AATCC 42-1989	98.78	115.80	106.79	127.49
biodegradability-retained tensile strength (%); AATCC 30-1988	28	82 (net)	58 (nets)	96 (net)
light penetration (%); DIGITAL DRAPE TESTER	37.8	63.6	50.6	58.5
flammability (sec); ASTM D 1230	31.7	23.8	19.2	22.2

Resistance to penetration of water impact was measured. The sugar cane fiber mat had significantly higher water resistance than the other products.

The soil burial test determined the susceptibility of textile materials to mildew and rot. T-test statistical analyses comparing sample means were conducted to determine the differences between the breaking strength of pre- and post-burial specimens. Significant differences were found in all products except straw nets. This test more appropriately measured the biodegradability of the sugar cane fiber specimens but measured the netting alone for the other products.

All products were significantly different in the transmission of light. Wood transmitted the most light and sugar cane fiber mats the least. Although the cane fiber mats were visually similar to the other products, the light penetration was lower and the density relatively higher than the wood and straw mats.

Flammability was determined on a 45° angle tester with a specially built specimen holder. The time required for the flame to proceed up the specimen, a distance of 5-in (127 mm), was recorded. Every wood specimen burned the maximum length. Propagation was augmented by the protruding curled wood fibers. Over half of the sugar cane fiber, coconut, and straw specimens ignited, had flame propagation, and the flame traveled between 1.8-4.75-in (45-121 mm) before self extinguishing. Burning times ranged from 9 to 58 seconds, and often the underside of these geotextiles remained unburned. The sugar cane fiber mats had longer burning times, and 70 percent of the cane fiber specimens self extinguished prior to burning the stop cord. Sugar cane fiber mats burned completely when fibers protruded and enabled the flame to spread upward across the surface of the mat.

A field test was conducted in summer 1995 in cooperation with LTRC and DOTD to compare the cane fiber erosion control mats with the currently available natural fiber geotextiles of coconut, straw, and wood. This study investigated mats formed from sugar cane rind fibers as a biodegradable non-woven geotextile for soil erosion control. The field study was a comparison of grass propagation and slope protection of approximately 400 sq yds (334 sq m) of sugar cane fiber mats and commercial geotextile products of coconut, straw, and wood.

Purpose of the Study

The purpose of the field test was to design and perform a rigorous program of controlled testing that provided the most realistic physical conditions related to natural roadside environment. A primary concern in field testing is to determine the product's effectiveness in retaining sediment of the slope and promoting vegetative cover in one growing season. Tests are typically conducted at an indoor lab using very small samples, which do not adequately describe field performance. To address this problem, LTRC selected a site with shallow erosion problems on which to conduct the study.

Objectives

Field test objectives were:

1. to compare temporary geotextile products for use in soil erosion control by measuring vegetative growth among products and slope positions during one growing season and
2. to assess the performance provided for the seed bed during the vegetative establishment period and slope protection according to LTRC evaluations.

Scope

The project consisted of a comparison of products selected by the research team and approved by LTRC. This test was representative of a select few commercially available products made from different materials. Test results are a relative index of tested products compared to the wood geotextile, the benchmark product.

MATERIALS AND METHODS

Materials

A total of approximately 400 sq yds (334 sq m) of sugar cane fiber mats and geotextiles of coconut, straw, and wood were tested. The wood rolls were 8 ft (2.44 m) wide; the straw and coconut rolls were 6.5 ft (1.98 m) wide; and the sugar cane fiber mats were 3 ft (.91 m) wide. Table 2 lists the products and their specifications. The test included two additional products that LTRC evaluated. One of the additional products was Soil Guard®, a hydromulch, bonded fiber matrix by Weyerhaeuser. The other was a woven coconut netting.

Table 2
Products and Specifications

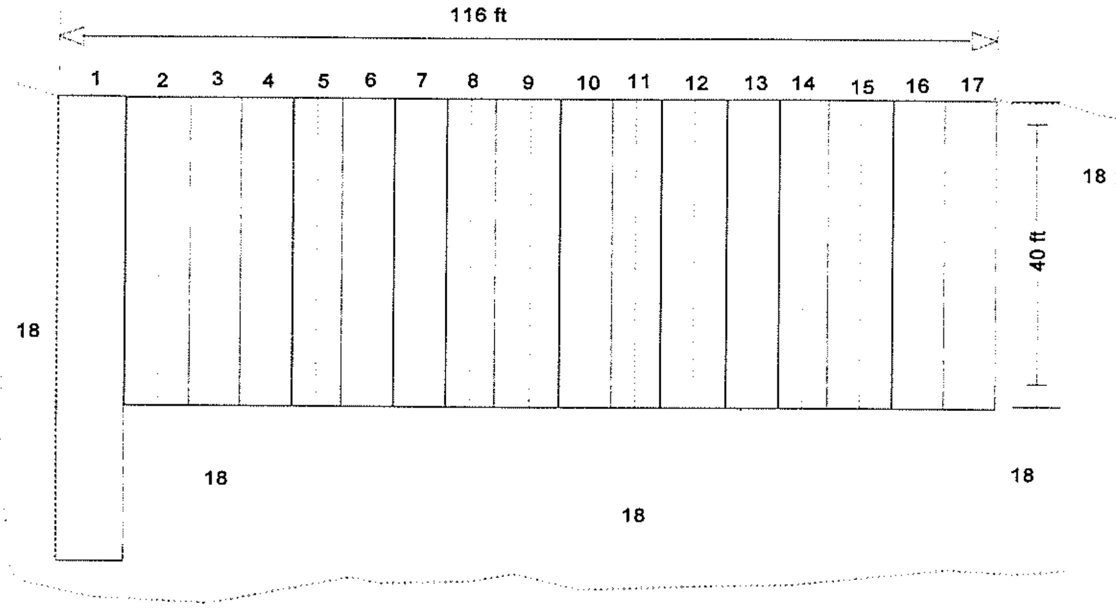
Company	Product	Roll Length	Coverage/Roll	$ Cost
North American Green	C125 coconut	83.5 ft (25.45 m)	60 yd^2 (50.17 m^2)	1.60/yd^2 (1.34/m^2)
North American Green	S150 straw	83.5 ft (25.45 m)	60 yd^2 (50.17 m^2)	0.55/yd^2 (0.46/m^2)
American Excelsior	Curlex Wood Blanket	180 ft (54.86 m)	80 yd^2 (66.89 m^2)	0.51/yd^2 (0.43/m^2)
Louisiana State University	Sugar Cane Fiber	not yet available	1 yd^2 (0.84 m^2)	0.34/yd^2 (0.29/m^2)
Soil Guard	Bonded fiber matrix	(hydro-mulch)	3000 lbs/acre (334.02 g/m^2) application rate	0.83/yd^2 (0.69/m^2)
RoLanka	BioD-Mat 70 Woven coconut mat	166 ft (139 m)	122 yd^2 (102 m^2)	2.00/yd^2 (1.67/m^2)

The cost estimate is of product only; it does not include installation costs. The sugar cane fiber cost analysis is detailed in Appendix A.

Methods

The test site was located in Baton Rouge, Louisiana, on the I-12 Millerville Road interchange over the east quadrant entrance ramp to I-12. The slope of the site was approximately 30°. Common Bermuda grass, a warm-season grass, was used because it is a common perennial sod in the southern part of the United States. Peak growing season is generally spring to early fall. Significant environmental factors that influence growth and development of grass species include: shade tolerance, cold tolerance, drought tolerance, heat tolerance, salinity tolerance, and tolerance to acidic soils [*3*]. Common Bermuda grass has a low shade tolerance, medium cold tolerance, medium-high drought tolerance, high heat tolerance, high salinity tendency, and medium tolerance to acid soils. It has a fairly low maintenance requirement and survives on little water and fertilizer. Bermuda grass is a standard option for DOTD as listed in Section 717 Seeding Specifications [*4*].

The research design included a layout of product and plot assignments that yielded data appropriate for statistical analyses. It was determined that each product and its three replicates would be arranged in a rotating fashion after the initial order of the four test products was determined randomly. Each product assignment was staked with the appropriate lane number. Figure 1 shows the final layout.



Woven Yarn Coconut	:	1				Straw	:	4	7	10	17
Wood	:	2	9	12	15	Sugar Cane	:	5	8	11	14
Coconut	:	3	6	13	16	Soil Guard	:				18

Figure 1
Plot Assignment

The site was prepared by DOTD crew members. The current erosion problems were filled in with a mixture of soil and river sand soil and then compacted and leveled out to an appropriate density as specified by Section 203.10 Plastic Soil Blanket description [5]. The soil on the 1:2 slope was analyzed by LTRC and has approximately the following gradation and particle size [DOTD 407 procedure]: 1.8 percent gravel 4, 0.2 percent gravel 10, 1.4 percent sand 40, 4.9 percent sand 200, 56.1 percent silt, 35.6 percent clay, 18.4 percent moisture, and 6 percent organic [DOTD 413 procedure]. The Atterberg limits [DOTD 428 procedure] were: liquid limit 37, plastic limit 16, and plasticity index 21. The established vegetation was removed along with the topsoil. The root mass was not totally removed. Fresh common Bermuda grass, with 8-8-8 fertilizer, was sown at a rate of 30 pounds/acre (13.6 kg/4074 m^2). Manual or supplemental irrigation was not conducted during the testing period.

The project coincided with the mowing season (May through September), therefore a letter was sent to the City Parish instructing DOTD not to mow until Spring of 1996. The research area was labeled with "Do Not Mow - Erosion Test" stakes.

Measurements were taken weekly for a minimum of three months to obtain an acceptable indication of vegetative coverage. There was a total of 12 measurements. To determine grass establishment, a 2 ft^2 (0.61 m^2) wooden frame was constructed with twine dividing the inside area into 81 cells or sections measuring 2.67 in^2 (0.07 m^2). Measurement was a visual assessment of each cell to determine if vegetative growth was visible within its boundaries. This technique is common to horticultural researchers. Grass growth measurements were initiated four weeks after product installation and conducted weekly throughout the growing season. Each test section of mats was randomly measured lengthwise five different times to obtain an average measurement per lane. The slope site was divided into five horizontal sections to reflect any differences in the slope from top to bottom. Measurements were labeled "top," "intermediate A," "middle," "intermediate B," and "bottom."

DISCUSSION OF RESULTS

The products were installed on May 17, 1995, and representatives from North American Green and American Excelsior assisted in the installment of their respective products. The roll products were installed according to the installation guide of slope applications. The blankets were anchored in a trench at the top of the slope, the trench was backfilled and compacted after stapling, and the blankets were rolled down the slope. The edges of parallel blankets were stapled using 8 in (20.3 cm) staples with approximately 2 in (5.1 cm) overlap and 1.2 staples per sq yd (1 staple per sq m). The sugar cane fiber mats were installed using the same overlap and staple rate. Soil Guard was applied the following morning by a crew certified for hydromulch applications, and the test site received over 3 in (7.6 cm) of rain that evening. The once visible seams and overlap of the sugar cane fiber mats were no longer visible after the rainfall; the cane mats formed a solid roll similar to that of other products. The Soil Guard's first application was not successful, because it did not receive the company recommended 48-hour drying period. That product was re-applied on June 8 under the following conditions for the protection of the mats:

1. application near and adjacent to roll products was done by hand-held hose,
2. overlap did not exceed one foot,
3. hose application was completed prior to cannon application, and
4. re-application was supervised by LTRC.

The sugar cane fiber mats performed as well as the commercial products and exhibited equivalent grass propagation and slope protection. Sugar cane fiber mats were superior in conformation to the slope even after heavy rains. Because of the long fiber entanglements, short fiber matting, and the retained lignin acting as an adhesive, the sugar cane mats did not need stitching to maintain their shape and bulk properties and were able to better conform to the slope. In the case of the commercial stitched mats, related bridging caused undercutting and small channel formation. The synthetic stitching did not biodegrade and interfered with mowing. Also, the woven coconut netting shrank after the first rainstorm. After the netting dried, there were gaps where the rolls overlapped, and the product was taut and did not touch the ground between staples.

Field test results indicated that sugar cane fiber mats, along with the other test products, allowed grass from planted seed to germinate. The mats maintained the integrity of a non-woven mat, and the fibers did not wash away during heavy rains. The products passed LTRC's criteria for germination and slope stabilization.

Analysis-of-variance (ANOVA) was conducted to determine if there were statistical differences among vegetative growth means with a common variance. A multiple comparison procedure known as Duncan's New Multiple Range Test was used to detect inequalities among the means of the treatment groups. The products were evaluated for effectiveness in promoting vegetative cover in one growing season.

Tables 3, 4, and 5 show vegetative growth by product and position on slope. Table 3 includes all variables for the entire test period; Tables 4 and 5 do not contain results for some of the slope positions due to an accidental partial mow of the test products on August 16, 1995.

Table 3
Vegetative Growth

PRODUCT	NUMBER OF MEASUREMENTS	MEAN PERCENT COVERAGE	DUNCAN GROUP[a]
Soil Guard	60	84	A
Straw	240	84	A
Wood	240	81	AB
Woven Coconut	60	78	BC
Sugar Cane	240	74	C
Coconut	240	68	D

[a] Means with the same letter are not significantly different at the 0.05 level.

Table 3 has two measurement positions deleted, and the Duncan group indicates that the vegetative growth coverage for the wood geotextile is not statistically significantly different from Soil Guard, straw and the woven coconut products. The sugar cane fiber mat is not significantly different from the woven coconut product, and the coconut geotextile is significantly different from all products.

Table 4
Vegetative Growth, Positions Intermediate B and Bottom Deleted

PRODUCT	NUMBER OF MEASUREMENTS	MEAN PERCENT COVERAGE	DUNCAN GROUP[a]
Straw	144	88	A
Soil Guard	36	86	AB
Wood	144	84	AB
Woven Coconut	36	81	B
Sugar Cane	144	80	B
Coconut	144	73	C

[a] Means with the same letter are not significantly different at the 0.05 level.

Table 4 indicates that the wood geotextile is only significantly different from the coconut product. Straw had the highest percent coverage and is significantly different from the woven coconut, sugar cane fiber, and coconut products.

Table 5
Vegetative Growth, Measurement Periods 10-12 Deleted

PRODUCT	NUMBER OF MEASUREMENTS	MEAN PERCENT COVERAGE	DUNCAN GROUP[a]
Soil Guard	45	81	A
Straw	180	80	A
Wood	180	78	AB
Woven Coconut	45	74	BC
Sugar Cane	180	69	C
Coconut	180	63	D

[a] Means with the same letter are not significantly different at the 0.05 level.

Table 5 does not include the last two measurement periods and indicates that the vegetative coverage of the wood product is not significantly different from the Soil Guard, straw or woven coconut geotextiles. The sugar cane fiber geotextile is not significantly different from the woven coconut, and the coconut mat is significantly different from all products.

A possible reason for sugar cane fiber and coconut geotextiles having slightly lower germination measurements than the straw and wood is mat opacity. Low sunlight exposure affects Bermuda grass growth to the extent that growth is stunted by the grass's own shadow if allowed to grow too high. This shading problem is called "light exclusion." This results when obstacles to light penetration occur directly on the turf. The effects of shading on the turfgrass microenvironment include moderation of diurnal and seasonal temperature fluctuations, restricted air movement, and increased relative humidity. As reported earlier in this study, the sugar cane and coconut fiber mats had lower light penetration in laboratory tests than did the straw and wood fiber products. The sugar cane fiber mats were visually similar to the other products, however, weight and thickness (which affect opacity) can be altered by amount of fiber used per square foot of mat. Soil Guard's high growth may be caused by the double seeding and fertilizing from the two applications.

Tables 6, 7, and 8 show the effect of position for all products. Table 6 includes all measurements; Tables 7 and 8 exclude certain measures or parts of measurements due to the partial mow.

Table 6
Vegetative Growth by Slope Position

POSITION	NUMBER OF MEASUREMENTS	MEAN PERCENT COVERAGE	DUNCAN GROUP[a]
Top	216	83	A
Intermediate A	216	83	A
Middle	216	79	A
Intermediate B	216	73	B
Bottom	216	68	C

[a] Means with the same letter are not significantly different at the 0.05 level.

Vegetative growth by slope position for the top, intermediate A, and middle are not significantly different as seen in Table 6. Intermediate B and bottom growth measurements are significantly different from all positions including each other.

Table 7
Vegetative Growth by Slope Position, Positions Intermediate B and Bottom Deleted

POSITION	NUMBER OF MEASUREMENTS	MEAN PERCENT COVERAGE	DUNCAN GROUP[a]
Top	216	83	A
Intermediate A	216	83	A
Middle	216	79	A

[a] Means with the same letter are not significantly different at the 0.05 level.

The partial mow affected all products across the intermediate B and bottom positions. Table 7 excludes all intermediate B and bottom positions and indicates that the remaining positions are not significantly different from each other.

Table 8
Vegetative Growth by Slope Position, Measurement Periods 10-12 Deleted

POSITION	NUMBER OF MEASUREMENTS	MEAN PERCENT COVERAGE	DUNCAN GROUP[a]
Top	162	79	A
Intermediate A	162	79	A
Middle	162	75	A
Intermediate B	162	67	B
Bottom	162	63	B

[a] Means with the same letter are not significantly different at the 0.05 level.

Table 8 excludes measurement periods 10-12, because the partial mow occurred prior to measurement 10. Vegetative growth differences are not statistically significant between positions intermediate B and bottom, however, both are significantly different than top, intermediate A, and middle positions.

Lower grass growth on the bottom portion of the slope may be due to drainage differences. Water is the most important requirement for turfgrass growth and survival [*6*]. However, too much water (i.e., seed submersion) can affect Bermuda grass establishment. After product installation, the test site received over 3- in (7.6 cm) of rain. Wet conditions may have persisted due to the natural runoff of the slope. Also the majority of the slope repairs were conducted in the intermediate A and middle positions. The addition of the river sand soil may have contributed to better drainage in these areas. Growth measurements were consistently lower on slope positions intermediate B and bottom throughout the testing period. Standing water and/or wetter conditions may have contributed to a lower germination establishment rate.

CONCLUSIONS

This study indicates that there are statistically significant vegetative growth differences among products and the location of a product on a slope. The materials have different physical properties, and it has been observed, in laboratory tests as well as this field study, that germination growth varies among products. The wood fiber geotextile was suitable to use as a benchmark product. Its performance was very satisfactory and vegetative growth differences from the highest growth yielding product fell within the range of experimental error. It is possible to manufacture a sugar cane fiber geotextile with no netting, good germination promotion, conformation to the slope, and easy installation, with the opacity characteristics of the wood fiber geotextile but at half the cost or less.

Due to the shrinkage of the coconut netting, it was determined that a non-woven mat provided better slope conformation and possible slope protection. However, protection provided for the seed bed during the vegetative establishment period and overall slope protection were satisfactory among all products. The most critical characteristic appears to be opacity, which permits/restricts rain and sunlight penetration. The acceptable performance level in fostering the establishment of a suitable vegetative cover was determined by an LTRC evaluation. The commercial products tested in this study were approved for the Louisiana Qualified Products List (QPL) due to the satisfactory vegetative growth on this site. Only products on the QPL can be used for state projects. Since natural fiber geotextiles are not selected on the basis of standard specifications and guidelines, product and installation costs will continue to be a primary factor in determining product usage.

RECOMMENDATIONS

A continuous process will be developed for sugar cane fiber mat formation. This non-woven mat will be available for similar geotextile applications of wood, straw, and coconut products. Lower manufacturing costs will make the sugar cane fiber product more competitive.

A spray-on application using a hydromulcher is being investigated for mat application and the use of bagasse fibers. This would be useful in applying products to steep slopes and can be used in conjunction with blanket products to seal edges or be applied at bottoms of slopes. For example, Soil Guard was successfully applied below the roll products in this study.

There is a need to establish appropriate guidelines to evaluate different natural fiber geotextiles. This is necessary to ensure proper product selection for different applications.

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APPENDIX A

Production Cost of Commercial Geotextile Fibers made from Bagasse Using Continuous Reactor Process

(A) Assumptions

Daily Production 15 tons/day

Plant depreciation over 5 years

Abbreviations:

Ton = t ; Pound = lb ; Liter = l ; yard = yd

Year = y ; Month = m ; Week = w ; Day = d ; Hour = hr

(B) Production Data

Daily Production	15 t/d
Number of working weeks	50 w/y
Number of working days = 50 (w/y) X 5(d/w) = 250 (d/y)	
Number of working hours	24 hrs (3 shifts)
1 yd^2 of bagasse mat @ 5/16" weigh about 1 pound Bagasse	
Usable bagasse % raw	50 %
Cost of raw bagasse	$17 /t
Annual Production = 15(t/d) X 250(d/y) = 3,750 t/y	
	= 3,750 t/y X 2000(lb/t)
	= 7.5 X 10^6 lb/y
	= 7.5 X 10^6 yd^2/y
Hourly rate of production	15(t/d) X 2000(lb/t) X 1/24(hrs/d)
	= 1250 lb/hr
Weight ratio of throughput	
Bagasse: Solution	= 1:4 = 20% bagasse
Reactor holding capacity	= 1250 (lb/hr)/0.20
	= 6250 lb/hr= 3,000 liter

© **Capital Cost**

Reactor cost including package boiler	$150,000
Mat formation system including hot air drying conveyor	$ 75,000
Baling and wrapping system	$ 50,000
Bagasse handling system	$ 50,000
Bagasse screening system	$ 25,000
Subtotal	$350,000

Annual depreciation = $350,000/5 years = $70,000

(D) Operating Cost

Material :

(I) *Bagasse* :

Mass of raw bagasse	= 3,750 (t/y) X 2	= 7,500 t/y
Cost of bagasse	= 7,500(t/y) X $17/t	= *$ 127,500*

(ii) *Alkaline* :

Rate of fiber production	= 1,250 lb/hr		
Bagasse : Solution	= 1 : 4 = 20% bagasse		
Rate of solution usage	= 1,250(lb/hr) X 4		= 5,000 lb/hr
	= 2,250 kg/hr		= 2,250 l/hr
Concentration of NaOH in solution	= 0.1 N	= 0.1 X 40 gm/l	= 4 gm/l
Rate of alkaline usage	= 2,250(l/hr) X 4(gm/l)		
	= 9,000 gm/l		= 9 kg/hr
Annual consumption	= 9(kg/hr) X 24(hr/d) X 250(d/y)		
	= 54,000 kg/y		= 54 t/y
Annual cost of alkaline	= 54(t/y) X $ 250/t		= *$ 13,500*

(iii) *Manpower* :

- 3 supervisors = 3 X $4,500/m X 12(m/y) = $162,000
- 15 workers =15 X $2,500/m X 12(m/y) = $450,000

Subtotal = *$612,000*

(iv) *Maintenance* :

Maintenance assumed @ 10% of capital cost

Annual maintenance cost = 0.10 X $350,000 *=$ 35,000*

(E) Summary

Capital cost annual depreciation	
$ 350,000 /5 years	= $ 70,000
Operating cost	
Cost of bagasse	= $127,500
Cost of alkaline	= $ 13,500
Manpower	= $612,000
maintenance cost	= $ 35,000
Subtotal	= $788,000

Annual operating cost	= $ 788,500
Total annual production cost	= $ 858,000

Manufacturing Production cost per unit area

(Square yard @ 5/16" thickness)

($858,000/y)/(7.5X10^6 yd^2/y) =$ 0.12

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