CONCLUSIONS

A series of accelerated swelling tests were performed on pure as well as sand-amended, and water treatment residual (WTR)-mixed steel slag samples. The results can be summarized as follows:

•Pure steel slag specimens have fine particle contents between 10 and 12%. WTR amendment results in an increase in the fines content due to the fine-grained nature of WTR. Sandy soil included a larger amount of sand-sized particles compared with steel slag, which resulted in a finer grain-size distribution as compared to steel slag.

•Addition of water treatment residual (WTR) to steel slag decreased the $\gamma_{dry-max}$ and increased w_{opt} due to high fines content of the WTR. Addition of sand resulted in a lower $\gamma_{dry-max}$ due to lower specific gravity of sand particles compared with steel slag but no significant change in optimum content was observed.

•The results of the accelerated swelling (volumetric expansion) tests showed that both methodologies (sand amendment and WTR amendment) were very efficient in the prevention of significant expansion of the steel slag material. Mixing the steel slag material with 30% WTR by weight decreased the swelling (expansion) rate from 2.95% to approximately 1% for 2 year old steel slag.

ACKNOWLEDGEMENTS

The research reported in this paper was financially supported by the Federal Highway Administration (FHWA), Maryland State Highway Administration (MSHA) and Maryland Water Resources Research Center (MWRRC). Endorsement by SHA and MWRRC nor the steel slag supplier is not implied and should not be assumed.

REFERENCES

Andreas, L., Herrmann, I., Lidstrom-Larrsson, M., and Lagerkvist, A. (2005). Physical properties of steel slag to be reused in a landfill cover. Proceedings of Sardinia, Tenth International Waste Management and Landfill Symposium, Environmental Sanitary Engineering Centre, Cagliari, Italy, Oct. 3-7.

Barra, M., Ramonich, E.V., and Munoz, M.A. (2001). Stabilization of soils with steel slag and cement for application in rural and low traffic roads. Proceedings of the Beneficial Use of Recycled Materials in Transportation Application, 423-432.

Dayioglu, A.Y., Aydilek, A.H. and Cetin, B. (2014). Swelling Potential and pH of Coated Steel Slags, Journal of the Transportation Research Board, 2401, 52-57.

Deniz, D., Tutumluer, E., and Popovics, J. (2009). Expansive characteristics of reclaimed asphalt pavement (RAP) used as base materials. Research Report ICT-09-055, Illinois Center for Transportation.

Deniz, D., Tutumluer, E., and Popovics, J. (2010). Evaluation of expansive characteristics of reclaimed asphalt pavement and virgin aggregate used as base materials. Transportation Research Record 2167, 10-17.

Evans, A.C. (2006). Compaction control of large-sized granular solis/aggregates: the vibrating hammer method of compaction and time domain reflectometry, M.Sc. Thesis, Purdue University, West Lafayette, Indiana.

Geiseler, J. (1996). Use of steel works slag in Europe. Waste Management 16(1-3), 59-63.

Golestani, B. (2015). Sustainable Material Solution for Flexible Pavements; Performance Evaluation and Impact Assessment of Utilizing Multiple Recycled Materials in HMA, PhD Thesis, University of Central Florida, FL.

Lee, A.R. (1974). Blastfurnace and steel slag: production, properties and uses. Edward Arnold Ltd,. London.

Noureldin, A. S. and McDaniel, R. S. (1990). Evaluation of surface mixtures of steel slag and asphalt. Transportation Research Record 1269, 133-149.

Ozkok E., Davis, A.P., and Aydilek, A.H. (2015). Treatment Methods for Mitigation of High Alkalinity in Leachates of Aged Steel Slag, *Journal of Environmental Engineering*, ASCE, 141(9), 1-9.

Rohde, L., Nunez, W. P., and Ceratti, J. A. P. (2003). Electric arc furnace steel slag base material for low-volume roads. Transportation Research Record 1819, 201-207.

Sorlini, S., Sanzeni, A., and Luca, R. (2012). Reuse of steel slag in bituminous paving mixtures. Journal of Hazardous Materials, 209- 210, 84–91.

Verhasselt, A. and Choquet, F. (1989). Steel slags as unbound aggregate in road construction: problems and recommendations. Proceedings of International Symposium on Unbound Aggregates in Roads, London, 204–211.

Wang, G. (2010). Determination of the expansion force of coarse steel slag aggregate. Construction and Building Materials, 24, 1961–1966.

Yildirim, I. Z. and Prezzi, M. (2009). Use of steel slag in subgrade applications. FHWA/IN/JTRP-2009/32 Final Report, West Lafayette, Indiana.

Use of Jute as a Sustainable Alternative for PP in Geotextile Tubes

Z. B. Kiffle[1]; S. E. Steele[2]; S. K. Bhatia, Ph.D., M.ASCE[3]; and J. L. Smith, Ph.D., P.E., A.M.ASCE[4]

[1]Ph.D. Candidate, Dept. of Civil and Environmental Engineering, Syracuse Univ., 151 Link Hall, Syracuse, NY. E-mail: zkiffle@syr.edu
[2]Research Assistant, Dept. of Civil and Environmental Engineering, Syracuse Univ., 151 Link Hall, Syracuse, NY. E-mail: sesteele@syr.edu
[3]Professor, Dept. of Civil and Environmental Engineering, Syracuse Univ., 151 Link Hall, Syracuse, NY. E-mail: skbhatia@esf.edu
[4]Geotechnical Engineer, John P. Stopen Engineering LLP, 450 South Salina St, Syracuse, NY. E-mail: jlsmith19@outlook.com

Abstract

Geotextile tubes have been used extensively to contain and dewater high water content materials. Geotextile tubes are typically manufactured from polypropylene (PP), a high embodied energy polymer, because of their relatively high tensile and seam strength properties that are often necessary to withstand the stresses that can develop in a geotextile tube during filling, and to maintain geotextile tube shape after filling. There are applications where lower-strength jute geotextiles could be used to manufacture smaller, more sustainable geotextile tubes for use in sensitive environmental applications, such as in wetland or shoreline rehabilitation applications. This paper presents the results of a laboratory study that compares the filtration performance of PP versus jute geotextiles for use as geotextile tubes, demonstrating the potential use of jute in geotextile tubes. Second, the paper presents a life cycle analysis that compares commercially available PP geotextile tubes to jute geotextile tubes. Overall, jute shows great promise for use in geotextile tubes.

INTRODUCTION

Geotextile tubes have been used extensively to contain and dewater high water content materials. Although they provide designers and engineers with a cost-effective means for containing and dewatering materials, geotextile tubes are typically manufactured from polypropylene (PP), a high embodied energy polymer. PP geotextiles are used because of their relatively high tensile and seam strength properties, in comparison to other fiber types, that are often necessary to withstand the circumferential and longitudinal tensile stresses that can develop in a geotextile tube during filling, and to maintain geotextile tube shape after filling. PP accounts for more than 90% of the synthetic fibers used in geotextile tubes.

There are applications where lower-strength materials, such as coconut, jute, or cotton natural fiber geotextiles, could be used to manufacture smaller, more sustainable geotextile tubes for use in sensitive environmental applications, such as in wetland or shoreline rehabilitation applications. Jute geotextiles have been successfully used for surface erosion control, construction of embankments, drainage, temporary reinforcement, and dewatering of dredged sediments. However, due to their biodegradable nature, they may not be effective for reusing them.

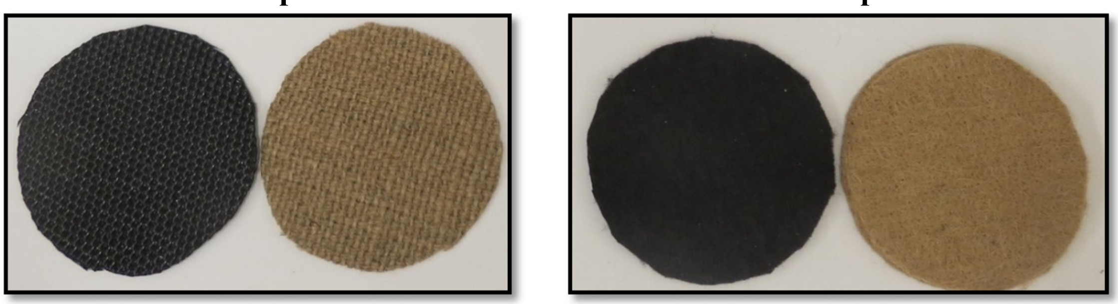
A case study on the application of biodegradable geotextile tubes as a submerged breakwater was discussed by Gaffney (2004). The project was a coastal restoration on Dog River, Alabama on which the previously constructed riprap was found to be ineffective in terms of facilitating vegetation, partly due to boat wake energy. To address the issue, geotextile tubes manufactured from coir, jute, and cotton were used. The 12-m long and 4-m circumference biodegradable geotextile tubes, placed 6 m offshore, helped absorbed the boat wake energy and allowed for the establishment of vegetation. The geotextile tubes were hydraulically filled with sand slurry which provided sound stability against the wave energy.

PERFORMANCE COMPARISON

In the evaluation of jute geotextile as a possible alternative to PP geotextile for dewatering projects, conducting performance tests is important. Some of the common methods for performance evaluation are small-scale laboratory tests, pilot-scale tests, and full-scale tests (Satyamurthy, 2011). Among the small-scale laboratory tests, the Pressure Filtration Test (PFT) was found to be quick and economical. Therefore, the PFT was used as the basis for the performance comparison between jute and PP geotextiles.

Geotextiles. For the study, four geotextiles were selected which fall into two groups: woven geotextiles (Group 1) and nonwoven geotextiles (Group 2). Each group was composed of jute and PP geotextiles (see Figure 1). The groupings were based on their comparable pore-size distribution (PSD) which is a governing factor for the sediment retention and dewatering behavior of the geotextiles.

Group 1 **Group 2**



W-1 **W-2** **NW-1** **NW-2**

Figure 1. Geotextiles used in this study.

Sediment. The sediment used for the testing, "Tully Coarse", was obtained from a local aggregate site (Clark Aggregates, Tully, NY). According to the Unified Soil Classification System (USCS) (ASTM D2487), the sediment is classified as clayey sand (SC). The sediment contains 41% fines and has low plasticity.

Experimental Results. Physical, mechanical, and hydraulic properties of the geotextiles are given in Table 1. In general, the jute geotextiles were 2 to 3 times thicker and 1.5 to 4 times heavier than the woven and nonwoven PP geotextiles, respectively. The reason for higher thickness of jute geotextile to increase its weak tensile strength. Even so, the woven jute geotextiles had tensile strengths that were only 20% of the PP geotextile tensile strengths. This was not observed for the nonwoven geotextiles, where the tensile strength of both the jute and PP nonwoven geotextiles were low in comparison to the PP woven geotextile.

Table 1. Basic geotextile properties.

Group	Geotextile	Thickness (mm)	Mass/Area (g/m^2)	Tensile Strength		Bubble Point Pore Size (microns)
				Woven CD (kN/m)	Nonwoven (kN/m)	
1	W-1 (PP)	1.04	585	109.4	---	265-330
	W-2 (Jute)	2.10	845	19.8	---	240-365
2	NW-1 (PP)	2.90	339	---	1.2	133-158
	NW-2 (Jute)	7.00	1297	---	3.5	133-145

Note: CD = Cross Machine Direction

Pore-Size Distribution. A Capillary Flow Porometer, Geo PorePro (Model No. GPP-1001A), was used to measure the pore-size distribution (PSD) of the geotextiles. The PSDs were measured based on ASTM D6767. For each geotextile, five tests were conducted to evaluate the reproducibility of the testing. The average PSD for each geotextile is shown in Figure 2. The larger opening sizes were similar for the woven jute and woven PP geotextiles (Figure 2a). The PSDs were similar for both the nonwoven jute and nonwoven PP geotextiles (Figure 2b).

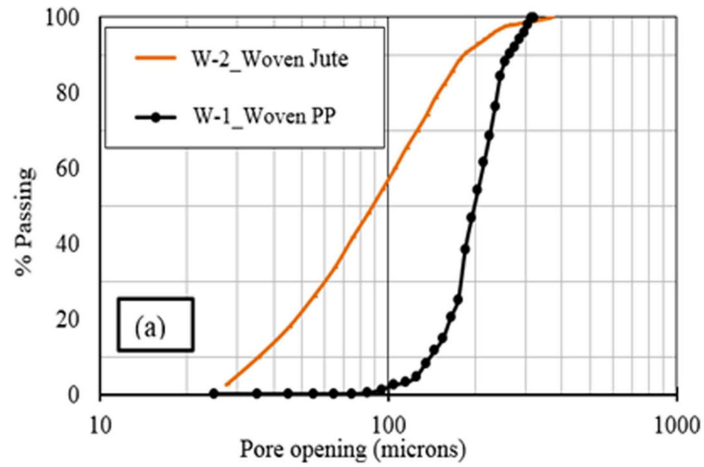
One basic factor that influences the PSD of jute geotextiles is their water absorbing capacity. Before testing, the jute geotextiles were soaked in water for about five minutes to saturate them. It was observed that soaking the jute geotextiles for longer periods created more open structures.

Pressure Filtration Test (PFT). The Pressure Filtration Test (PFT) simulates the retention and dewatering performance of geotextiles under pressure. Details of the PFT setup are provided by Khachan, et al. (2011, 2013, 2014).

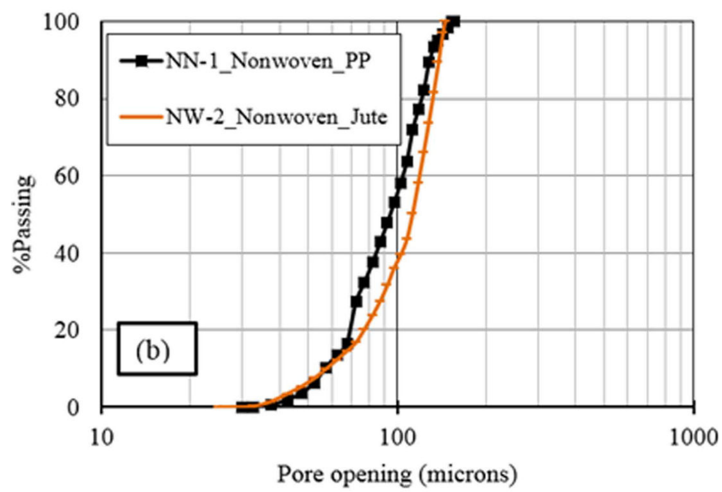
In this test, 500ml of slurry was well mixed and conditioned with an optimum dose of synthetic polymer (cationic flocculant and anionic coagulant). The percent solids of the slurry was 15% for Group 1 and 10% for Group 2. The lower slurry concentration was used for the nonwoven geotextiles to take into account their tighter pore structures.

During the test, a constant external pressure of 21 kPa was applied until the free water drained out completely. The applied pressure was based on field stresses at the base of geotextile tubes in dewatering projects (Khachan, et al., 2014). The results of PFT was evaluated using the parameters such as dewatering rate, percent solids of filter cake and filter cake height and effluent quality.

(a) Group 1 – Woven Geotextiles. Three PFT tests were conducted for each Group 1 woven geotextile. The average results are shown in Figure 3(a). The woven jute geotextile exhibited a fairly similar dewatering rate to the woven PP geotextile. The jute geotextile also had marginally better performance when dewatering 90% of the total effluent collected (about 400ml). Figure 3(b) shows the filter cakes of both geotextiles. The geotextiles had comparable filter cake heights and percent solids at the end of the tests. The PFT with jute geotextile produced a filter cake of slightly higher percent solids and height than the PP geotextile. The relative faster dewatering rate can be attributed to the tendency of jute geotextile pores to increase in size while under pressure.



(a) Group 1: Woven geotextiles



(a) Group 2: Nonwoven geotextiles

Figure 2. Pore-size distribution results.

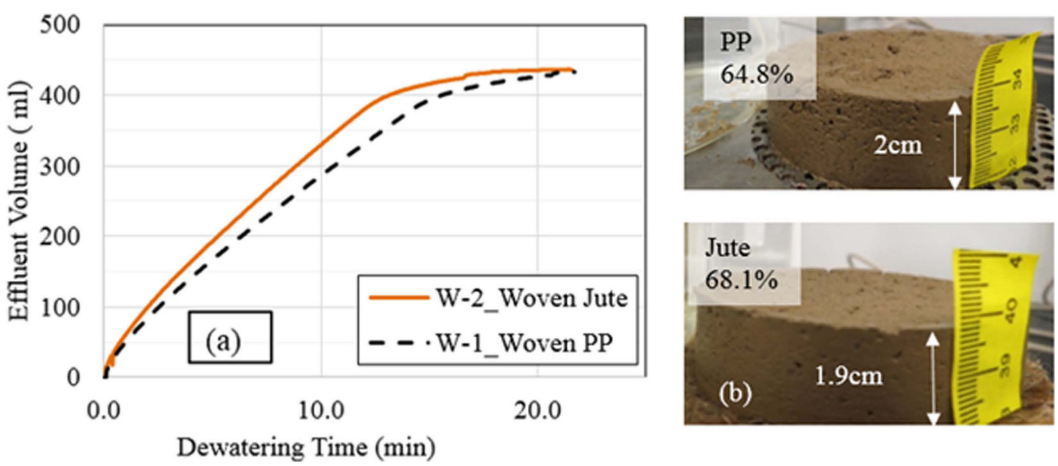


Figure 3. Dewatering performance of woven geotextiles: (a) dewatering rate; (b) filter cake properties.

(b) Group 2 – Nonwoven Geotextiles. Even though the Group 2 PSDs were similar in appearance, the dewatering rate of the jute geotextile was about 15% higher than that of the PP geotextile (see Figure 4). The dewatering time was also decreased with the jute geotextile. The filter cake percent solids of the jute geotextile was 1% less with a 15% thicker filter cake than the PP geotextile. The swollen filter cake formed when using the jute geotextile was due to the absorption of water during the test.

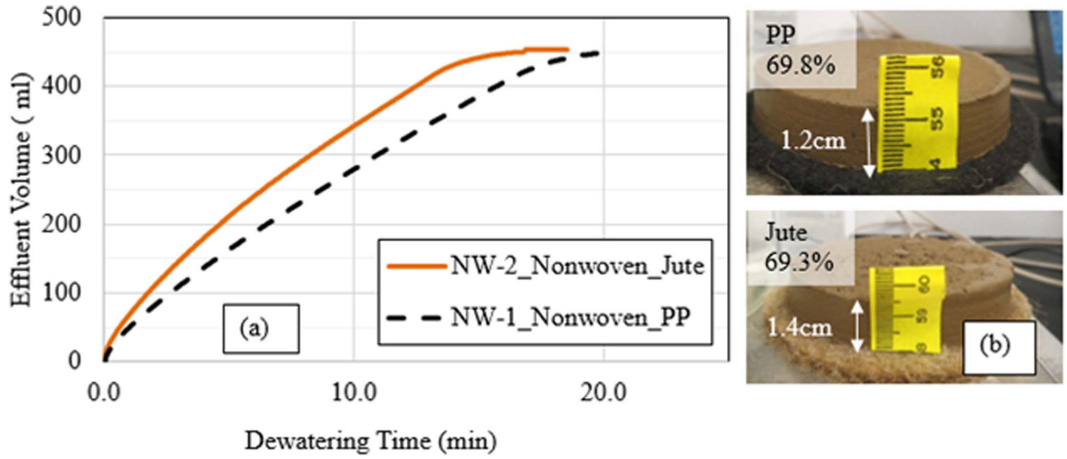


Figure 4: Dewatering performance of nonwoven geotextiles: (a) dewatering rate; (b) filter cake properties

Overall, the jute geotextiles demonstrated that they are capable of performing in geotextile tube dewatering projects. There are still concerns regarding their relatively low tensile strengths in comparison to PP geotextiles, which limits their use to small-scale projects. Also, the production quality of jute geotextiles is not as highly controlled as for PP geotextiles; imperfections in the production may lead to failure.

From the perspective of cost, jute geotextile fabrics is relatively cheaper as compared pp fabrics. However, in the making of tubes from the fabrics, there are additional production costs. Also, for the same dewatering projects, more jute geotextiles tubes is required to accommodate their less tensile strength, which allows smaller tube diameter. In contrast, less number of large diameter PP geotextile tubes can be used as their tensile strength is much higher than the jute geotextile tubes. Currently, there are no official jute geotextile tubes providers which makes it difficult to compare with pp geotextile tubes quantitatively.

SUSTAINABILITY COMPARISON

Generally, any product (like geotextile tubes) will move through four main stages in the duration of its useful life: (1) raw materials acquisition, (2) manufacturing, (3) transportation, and (4) waste management. In the following sections, commercially available jute and PP geotextiles are discussed relative to their life cycles and the environmental impacts. The focus of the comparison is on raw material acquisition, manufacturing processes, and on disposal.

Polypropylene Geotextile Tubes. Polypropylene is the product of a crude oil distillate (the naphtha cracker) via polymerization of its propylene monomer. As such, PP is generated from a non-renewable resource that relies heavily on petroleum-based resources which may become increasingly scarce. PP is considered a thermoplastic which has a high recycle and incineration potential. However, current practices of recycling and incineration only include a small portion of the total PP produced (Timpson, 2015).

Several companies produce geotextile tubes, one of the leading producers is TenCate Geosynthetics Americas (TenCate). TenCate has developed an internal assessment of carbon footprint for geotextile tubes in comparison to mechanical dewatering so as to make an effort toward environmentally conscious designs and practices. TenCate is a vertical manufacturer, controlling every stage of PP geotextile tube manufacturing. The manufacturing stage begins with an import of PP pellets to the site (raw materials acquisition). Pellets are then extruded into yarn, woven into a geotextile, and sewn together to form a TenCate geotextile tube, called Geotube®. Geotextile tubes move to different facilities for different stages of production. Since most of the facilities are fairly close together, environmental impacts of transportation at this stage are very small.

During the use phase, little-to-no energy is required. Each geotextile tube is packaged for deployment and requires little more than correct placement on site and assurance that the geotextile tubes are filled to design height to avoid rupture. After job completion, some geotextile tubes remain on site, with their initial location becoming their final resting place. Soil covers are often placed on top of the filled geotextiles tubes for stability. In some cases, the contents of the geotextile tube will be used for fill in other locations, or incinerated for their energy value. In many cases, geotextile tubes are sent to a landfill.

Using the TenCate carbon footprint software, the carbon breakdown for PP geotextile tubes is summarized in Table 2. As shown, the production of raw PP, extrusion of yarn, and weaving generates 2.6 KgCO_2/kg of product; the manufacturing stage of geotextile tube production produces 1.6 KgCO_2/kg of fiber product; and the total transportation carbon costs are 0.1 kgCO_2/kg of product. Overall, the total carbon investment is 4.3 kgCO_2/kg of product.

Table 2. TenCate Geotube® polypropylene carbon breakdown

Process	Value (KgCO_2/kg)
Raw materials production	2.6
Manufacturing	1.6
Transport	0.1
Total	4.3

Typically, there are about 18 ounces of PP per square yard of geotextile tube and a standard tube size of 667 square yards, yielding 340.4 Kg of product and a carbon investment of 1463.6 kgCO_2 for a single standard geotextile tube. The extent of packaging, however, is not considered in the carbon deficit.

Potting and Blok (1995) present different results for the carbon investment involved in PP production. They evaluated the environmental impacts of different types of floor coverings. PP production from raw materials required 64.7MJ/kg and the extrusion process required 0.45 kWh/kg, for a total of 9.71 KgCO2/kg total. This value in nearly 4 times higher than TenCate's measurement of 2.6 KgCO2/kg. Harding et al (2007) found that the entire process of production for PP releases 3.53 KgCO2/kg.

Jute Geotextile Tubes. There is no evidence that geotextile tubes have been produced exclusively out of jute fibers. Gaffney et al. (2003) developed a geotextile tube product that partially used jute fibers to manufacture geotextile tube casings. These geotextile tubes were designed to biodegrade after a number of years but the intention was to use them as breakwaters, not for dewatering. The design was successful for two different case studies and provides evidence that natural fibers can be used for geotextile tube technologies.

As there is no industry standard for jute geotextile tubes, carbon footprint analyses must make reasonable assumptions when moving through the stages of the useful life of jute geotextile tubes. It is necessary to start the analysis with the raw materials acquisition of jute fibers. Cultivating and processing jute is relatively elaborate and variable (Khastagir, 2015). Jute is grown in many locations worldwide; however, the majority is grown in India and Bangladesh.

Jute is usually grown in a 120-day period. During this time, one hectare of jute typically absorbs close to 15MT of CO_2 (-5kgCO2/kg) and releases 11MT of O_2, effectively sequestering carbon and maintaining a negative global warming potential (Abdullah, 2010). Abudullah (2010) also states that that the use of fertilizers for jute agriculture is very slim and “can be considered insignificant”, because organic manure is applied in most cases. In a study by PricewaterhouseCoopers (2006), controlling for anthropogenic contributions of insecticides and methane emissions, it was found that one hectare of land yielding 3 tons of jute will produce -1.5 KgCO2/kg.

Rahaman and Bala (2009) compare the Bangladesh system to the Indian system in terms of total CO_2 fixation based on information gathered from the Institute of Environmental Economics. The authors found that, in total per hectare, the Bangladesh jute cultivation system fixes 5768.81 kg of CO_2 compared to the 6409 kg fixed in the conventional Indian Jute cultivation system. This translates to -2.14 KgCO2/kg for the Indian System, assuming the 3 tons per hectare given by PricewaterhouseCooper and verified by Khastagir who claimed a just slightly higher value of 3.1 tons.

The next part of the life cycle to consider is manufacturing. Nonwoven geotextiles produced from jute have somewhat different manufacturing processes than woven geotextiles do. Jute geotextile manufacturing requires several steps; raw jute bale opeing, selection and sorting, chopping, spreading, softening, pilling, 1st carding, 2nd carding, and packaging. Woven jute geotextiles require the additional steps of: 1st drawing, 2nd drawing, 3rd drawing, spinning, winding, spool production, beaming, weaving, and rot resistent treatment. Nonwoven jute geotextiles require only garneting and needle-punching (Khastagir, 2015). The carbon values were not found for each of the steps in manufacturing of woven and nonwoven jute geotextile. PricewaterhouseCoopers (2006) life cycle analysis indicates for the production of 483 nos of finished bales of jute , the grams of CO2 equivalents produced is higher for nonwoven than woven jute, at 612.14 and 120.72, respectively. Converting those numbers to a per kg basis, there is a very small difference and is considered to be negligible. Nonwoven jute geotextiles produce 6.12E-07 KgCO2/kg while woven jute geotextiles produce a slightly smaller 4.98 E-07 KgCO2/kg.

The National Jute Board states that over 50% of all jute is produced in West Bengal, India. Therefore, this analysis assumes jute production and geotextile manufacturing from West Bengal. Jute geotextile would then be shipped to the United States to be manufactured into geotextile tubes. For comparison purposes, it was assumed that the geotextile tubes would be produced at the same location where most of the PP geotextile tubes are produced, TenCate’s manufacturing center in Georgia. Similary, the carbon impact of sewing the geotextiles into tubes was assumed to be the same for both jute and PP geotextile tubes, 1.6KgCO_2/kg of fiber product.

Transportation of jute geotextiles was assumed to be made via cargo ship from the Haldia Port in India, as it is the closest to West Bengal. It is further assumed that this cargo ship will end at the Savannah, Georgia port because it is the closest port to the TenCate manufacturing facility in Pendergrass, Georgia. It is not known exactly where the jute manufacturing facility will be located in West Bengal so an assumption was made to double the distance from Savannah to Pendergrass (250 miles) to cover transportation to Haldia. Lescot (2012) quoted from EcoInvent data that 7.79 g/ton/km of carbon equivalents was produced for maritime shipping. Walsh and Bows (2012) have slightly different values ranging from the baseline of 6.87gCO_2/ton/km to 10.13gCO_2/ton/km in practice. Mithraratne (2011) found that for trucks between 7.5 and 15 tons that 0.082 kg CO_2 was produced per vehicle km. The additional 0.1CO_2 in TenCate geotextile tubes was not added because only the final seaming would be required and would not need to be shipped to multiple locations on site. The transportation to site is not considered in this study since it is assumed to be similar for both jute and PP geotextile tubes. The carbon investment involved in jute geotextile tube production is summarized in Table 3.

Table 3. Jute geotextile tube carbon breakdown

Process	Value (KgCO_2/kg)
Raw materials production	-1.5 to -5
Manufacturing	1.6
Transport	.14 to .21
Total	-3.26 to .31

CONCLUSION

As non-renewable sources are depleted and the environmental effects associated with oil-based products become more apparent, the scientific and industry communities alike are searching for more sustainable options. This research finds that jute geotextile tubes have far less of a global warming potential than the industry standard of PP geotextile tubes. The carbon footprint values used were obtained from one of leading producers of geotextile tubes. Even though their carbon footprint values were lower than other evidence found in the literature, the jute alternative was still considered to generate significantly less carbon overall. This fact can be attributed to the ability for jute to sequester carbon during the cultivation stage of its life cycle. The disposal phase of the life cycle was not considered in depth in this study. However, considering that most geotextile tubes are left on site or brought to a landfill, this stage would garner further carbon benefits for jute geotextile tubes as they are biodegradable and PP tubes are not.

ACKNOWLEDGEMENTS

This study was supported by National Science Foundation (NSF) Grant No. CMMI 1100131. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We would like to thank Mr. Chris Timpson Technical Services Manager for the