



Sociedade & Natureza

ISSN: 0103-1570

sociedadennatureza@ufu.br

Universidade Federal de Uberlândia

Brasil

Teixeira Guerra, Antonio José; Rodrigues Bezerra, José Fernando; Dias da Mota Lima, Luis; Silva Mendonça, Jane Karina; Teixeira Guerra, Tatiana; Buhmann, Christl; Garry Paterson, David; Pienaar, Gerry; Piet Nell, J.; Elvis Mulibana, Nthanyiseni; Van Deventer, Pieter Willem; Fullen, Michael Augustine

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Sociedade & Natureza, vol. 22, núm. 3, diciembre, 2010, pp. 431-446

Universidade Federal de Uberlândia

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LAND REHABILITATION WITH THE USE OF BIOLOGICAL GEOTEXTILES, IN TWO DIFFERENT COUNTRIES

Reabilitação de Solos com Uso de Geotêxteis Biodegradáveis em dois Países

Antonio José Teixeira Guerra

Department of Geography,
Federal University of Rio de Janeiro
Rio de Janeiro/RJ – Brazil
antoniotguerra@gmail.com

José Fernando Rodrigues Bezerra

Department of Geography,
Federal University of Rio de Janeiro,
School of Applied Sciences,
The University of Wolverhampton
Rio de Janeiro/RJ – Brazil /
Wolverhampton WV1 1SB - United Kingdom
fernangeo@yahoo.com.br

Luis Dias da Mota Lima

Department of Geography,
Federal University of Rio de Janeiro
Rio de Janeiro/RJ – Brazil
luizdmlagro@yahoo.com.br

Jane Karina Silva Mendonça

Secretaria de Estado do Planejamento e Orçamento,
Instituto Maranhense de Estudos Socioeconômicos
e Cartográficos (IMESC)
São Luis/ MA – Brasil
janeksm@yahoo.com.br

Tatiana Teixeira Guerra

Department of Geography,
Federal University of Rio de Janeiro
Rio de Janeiro/RJ – Brazil
tatianatguerra@gmail.com

Christl Buhmann

Agricultural Research Council-Institute for Soil,
Climate and Water
Private Bag X79
Pretoria 0001 – South Africa
cbuhmann@arc.agric.za

David Garry Paterson

Agricultural Research Council-Institute for Soil,
Climate and Water
Private Bag X79
Pretoria 0001 – South Africa
garry@arc.agric.za

Gerry Pienaar

Agricultural Research Council-Institute for Soil,
Climate and Water
Private Bag X79
Pretoria 0001 – South Africa
gerry.pienaar@daet.ecape.gov.za

J. Piet Nell

Agricultural Research Council-Institute for Soil,
Climate and Water
Private Bag X79
Pretoria 0001 – South Africa
garry@arc.agric.za

Nthanyiseni Elvis Mulibana

Agricultural Research Council-Institute for Soil,
Climate and Water
Private Bag X79
Pretoria 0001 – South Africa
garry@arc.agric.za

Pieter Willem Van Deventer

North West University,
School for Environmental Science and Development
Potchefstroom 2520 – South Africa
garry@arc.agric.za

Michael Augustine Fullen

School of Applied Sciences,
The University of Wolverhampton
Wolverhampton WV1 1SB – United Kingdom
m.fullen@wlv.ac.uk

Artigo recebido para publicação em 12/10/2010 e aceito para publicação em 09/11/2010

ABSTRACT: *This paper assesses the role of biological geotextiles on non-agricultural erosion environments, based on studies in the mine tailings Gauteng Province (South Africa) and urban area of São Luis City (Brazil). Gauteng Province (South Africa) has suffered immense problems related to sustainable rehabilitation of mine dumps. This is a huge challenge, as wastes are highly susceptible to both water and wind erosion. Establishing a grass cover to reduce erosion is the dominant reclamation method. Covering the slopes with biological geotextiles might constitute another option for mining companies to reduce erosion and aid natural re-vegetation. The objective of the waste part of this study was to determine the beneficial effect of palm mat cover on erosion control, using rainfall simulation. Results clearly illustrated that application of palm-mats more than halved the sediment load in runoff, thereby having the potential to effectively stabilize tailing dam slopes. Covering tailings with palm-mats did not reduce runoff or improve water infiltration, however. In São Luis City, biological geotextile mats were constructed from palm leaves which are an effective, sustainable and economically-viable soil conservation technique. At Sacavém Community biological geotextile mats were used in association with barriers of wooden stakes and the construction of terraces along contour lines. The aim is to minimize soil erosion, by intercepting rainfall, retarding runoff velocity and sediment loss.*

keywords: Biological geotextile. Sustainable development. Rehabilitation. Mine tailings. Buriti mats.

RESUMO: *O objetivo desse artigo é avaliar o papel dos geotêxteis biodegradáveis em áreas não-agrícolas, levando em consideração os estudos desenvolvidos na Província de Gauteng (África do Sul) e na área urbana do município de São Luis (Brasil). Nas últimas décadas, a Província de Gauteng vem sofrendo imensos problemas relacionados à reabilitação sustentável de áreas com rejeito de mineração. Este é um grande desafio, pois esses rejeitos são altamente suscetíveis à erosão, tanto pela água, como pelo vento. A proteção dessas superfícies por uma cobertura de gramíneas para reduzir a erosão é um método sugerido por parte dos pesquisadores. A utilização de geotêxteis biodegradáveis constitui outra solução para as companhias de mineração, para a diminuição da erosão superficial e auxílio para o processo de re-vegetação natural. Esse estudo teve como objetivo determinar os efeitos positivos da utilização de geotêxteis construídas com fibras de palmeiras no controle da erosão superficial, a partir do uso de um simulador de chuvas. Os resultados demonstraram claramente que a aplicação destas geotêxteis reduziu pela metade a carga de sedimentos no escoamento superficial, tendo também o potencial para estabilizar as encostas de rejeitos de mineração. A aplicação dos geotêxteis nos rejeitos não diminui o escoamento superficial, nem melhorou a infiltração da água no solo. Na cidade de São Luís, os geotêxteis biodegradáveis foram construídos a partir de folhas de palmáceas, que são eficientes, sustentáveis e economicamente viáveis, como uma técnica de conservação do solo. Na comunidade de Sacavém os geotêxteis foram usados em associação com paliçadas de madeira e foram feitos terraços, ao longo das curvas de nível. O objetivo foi o de minimizar a erosão do solo, a partir da interceptação da chuva, que retardou a velocidade do escoamento superficial e, conseqüentemente diminuiu a perda de sedimentos.*

Palavras-chave: Geotêxteis biodegradáveis. Desenvolvimento sustentável. Reabilitação. Rejeitos de mineração. Geotêxtil de Buriti.

INTRODUCTION

Soil degradation by erosion is one of the world's most serious environmental problems, causing extensive loss of cultivated and potentially productive soil and decreased crop yields (FULLEN; CATT, 2004; MORGAN, 2006). It has been estimated that some 4000 million tonnes of soil per year have been eroded from the continental USA since the 1930s (FULLEN; CATT, 2004). Major causes of water and wind erosion include deforestation, overgrazing and mismanagement of arable land. By removing vegetation cover the erosion-resisting capacity of the soil becomes disturbed. Most rehabilitation efforts on degraded lands involve different techniques which could be represented by traditional engineering or soil bioengineering.

Soil bioengineering has been recognized as a technique to provide slope stabilization and erosion control, taking into account both traditional engineering and biological principles, using living and dead vegetation, associated with construction materials. Normally, bioengineering projects are less costly than conventional engineering and they have been applied in different sites, such as stream bank stabilization, roadside slopes, river restoration, hillslopes, mine tailings and gully slopes. These different environments have distinct characteristics, but common locations include agricultural and non-agricultural (e. g. mine tailings and urban areas) sites.

For this paper we have considered two different situations, in terms of non-agricultural erosion, in order to contribute towards the assessment and rehabilitation of degraded areas. They include: mine tailing erosion in South Africa and urban gully monitoring and land rehabilitation in São Luís City, Brazil.

Mine wastes have been generated for a long period of human history, and mining activity has accelerated significantly during the 20th century. The mine wastes areas, such as tailing dams and dumps, represent a potential source of contamination to the environment, mainly when heavy metals and acid are released in large amounts (LEDIN; PEDERSEN, 1996).

Mining has been the backbone of the South African economy since the discovery of diamonds

and gold in the late 19th century. Intensive mining activities, however, not only fuel economic growth, can also have devastating environmental impacts. Large volumes of mine waste, such as tailings, have been generated in some areas and sustainable rehabilitation of mine dumps is a huge challenge.

Land degradation is attributed to both environmental and socio-economic conditions, including unauthorized and/or inefficient urban development and planning (SOBREIRA, 1989; GOUDIE, 1994; GUERRA, 2000; FULLEN, 2003). Soil erosion in urban areas is generally associated with irregular population settlement. Consequently, inappropriate land management, including poor maintenance of vegetal cover, is the principal cause of water erosion (CASAL *et al.*, 1999; VALENTIN *et al.*, 2008; MUNRO *et al.*, 2008). Vegetation cover is often undervalued in terms of its control over landscape incision (HOWARD, 1997; POESEN *et al.*, 2003).

São Luís, like many other Brazilian cities, has experienced rapid population growth in recent decades, which has created a series of socio-economic and environmental problems, including accelerated soil erosion. Sacavém is one of these communities where natural and human factors contribute to severe gully erosion (SATHLER *et al.*, 2005; GUERRA *et al.*, 2005; BEZERRA *et al.*, 2010). Rapid population and urban growth has intensified problems, compounded by poor planning and improper soil use.

Biological geotextiles are potentially excellent biodegradable and environmentally-friendly materials useful for soil conservation. The application of biological geotextiles, constructed from the palm leaves of *Hyphaene coriacea*. (Lala palm) and *Mauritia flexuosa* (Buriti), has been investigated at the Laboratory of Environmental Geomorphology and Land Degradation (Brazil) and The Agricultural Research Council-Institute for Soil, Climate and Water (South Africa). The integrated research programme BORASSUS is supported by the European Union under contract number INCO-CT-2005-510745 and was carried out from 2005-2009 with the participation of research groups from Europe (Belgium, Hungary, Lithuania and the United Kingdom), Africa (The Gambia and South Africa), South-East Asia (China, Thailand and Vietnam) and South America (Brazil). The overall

objective of the BORASSUS Project was to evaluate the long-term effectiveness of this technology in controlling soil erosion and their sustainability and economic viability in these countries.

The main objective of this paper is to analyse the role of biological geotextiles on non-agricultural environments, considering different methods and techniques applied on a mine tailing (South Africa) and an urban area (Sao Luis City, Maranhão State). It considers the principles of soil bioengineering related to the use of geotextiles using different methods.

STUDY AREAS

Gauteng Province (South Africa) and São Luís City (Brazil), were selected as case study locations for this research (Figure 1), as they were experiencing different land degradation problems, with the potential of remedial use of bioengineering techniques.

Gauteng (South Africa)

Gauteng is the smallest of South Africa's nine provinces, covering ~16,600 km² or 1.4% of the country. It has the second-largest population (9,525,571 in 2006), by far the highest population density and the highest per capita income level, contributing 33% to the national economy and a remarkable 10% to the GDP of the entire African continent. Gauteng is the most urbanized province with 97% of its population living in urban centres. Its capital, Johannesburg, is the largest city in South Africa and one of the world's youngest major cities, having been founded in 1886, and gold was discovered in the area (DEPARTMENT OF AGRICULTURE, CONSERVATION AND ENVIRONMENT, 2004).

Gauteng is a summer-rainfall area, characterized by hot summers and cold winters with frost. The mean annual precipitation varies from

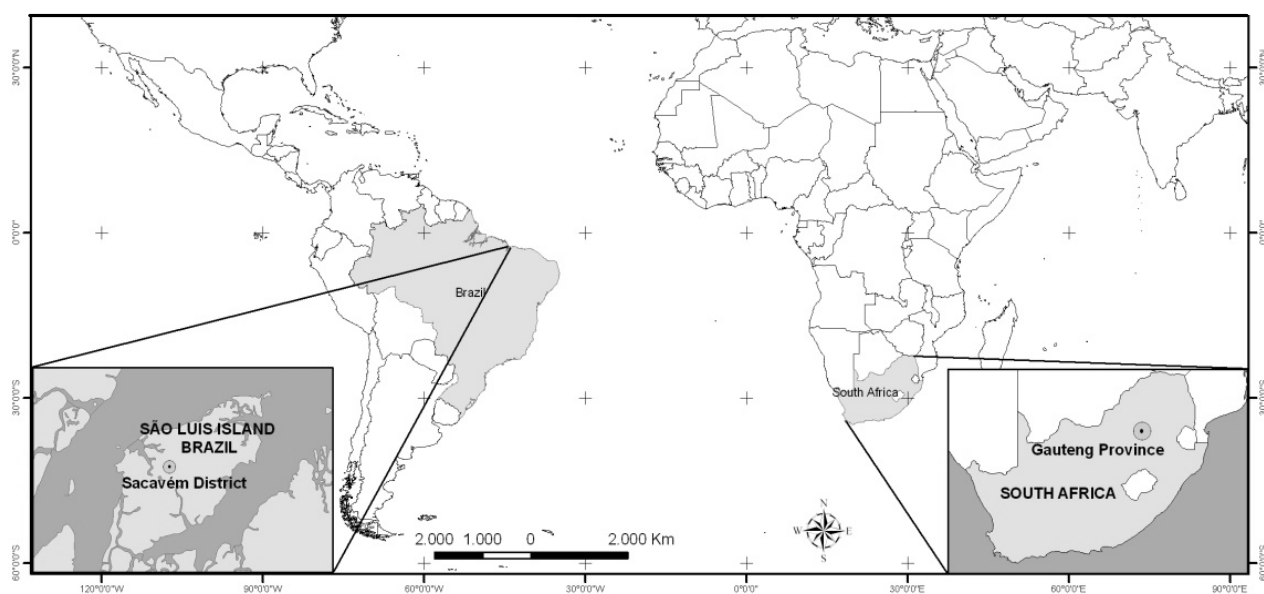


Figure 1: Sites used in this study.

574 to 900 mm, with an average of 672 mm. The mean annual temperature across the Province varies from ~15 to 19°C, with an average of 16.2°C, average minimum and maximum temperatures are 9.8 and 24.5°C, respectively (DEPARTMENT OF AGRICULTURE, CONSERVATION AND ENVIRONMENT, 2004).

Gauteng means “Place of Gold” in Sesotho and gold has been mined continuously since its discovery. These intensive mining activities, however, not only fuelled economic growth, but also had devastating environmental impacts. Large volumes of mine waste have been generated and tailing dams and dumps run as a continuous corridor from

Krugersdorp in the west part of Johannesburg and Soweto to Boksburg in the east and on to Springs (Figure 2). This waste belt is situated in a densely populated urban area.

São Luís City (Brazil)

The settlement of São Luís was established in 1612 and has evolved in distinct phases. Rapid urban



Figure 2: 'Mega-dump' of reprocessed gold tailings, south-east of Springs, Gauteng Province. Heavy rains in February 2008 led to landslides that denuded large parts of the previously vegetated slope.

growth was associated with industrialization in the second half of the 18th century. The local lithology is mainly Tertiary sandstones and, to a lesser extent, shales, argillites and siltstones, all of which belong to the Barreiras Formation (GUERRA *et al.*, 2004, 2005). Weathering on these rocks produces erodible soils, including lithosols, latosols, concretionary red/yellow clay soils and concretionary plinthosols (MARANHÃO, 1998). Thus, erodible soils and regolith are subject to high erosion rates, especially on steeper slopes subject to additional human interventions. Furthermore, although regional slopes are quite gentle, there is localized high relative relief. Secondary mixed forest and brushwood are the dominant vegetal cover adjacent to the urban gullies. The local climate is humid tropical, with average annual temperatures of 26°C, reaching higher values in October-December and lower from April-June (FONSECA, 1995). Rainfall distribution is irregular, marked by two very distinct seasons (rainy and dry). The highly seasonal

erosive rains incise a complex series of soil erosion landforms, mainly gullies.

MATERIALS AND METHODS

Materials and methods for this paper are divided into two topics, which relate to the study areas, where the effects of biological geotextiles on the stability of non- agricultural environments have been tested.

Gauteng Province (South Africa)

Rainfall simulation was selected as an investigative tool, as it provides a very reliable approach to obtaining interrill erodibility data for a range of representative conditions, such as slope angle, rainfall intensity and water composition (GABRIELS *et al.*, 2002). Laboratory experiments also enable a broad range of samples to be investigated. A particular

field site does not offer the range of waste and slope conditions that can be found elsewhere in the region or country. Experiments were conducted on 10 mine waste samples, first on the bare tailings and then on the same materials covered with biological geotextiles, manufactured from leaves of the *Hyphaene coriacea* (Lala palm). Material selection was based on the most common commodities mined in South Africa, namely gold, platinum, diamonds, coal, chromium, silica and vanadium (Table 1).

rain. The volumes percolating through the tailings were recorded at 2 min intervals during an event of 2 hours for each storm. Timed run-off samples were also collected at 2 min intervals, weighed, oven-dried at 105°C and re-weighed to determine runoff rate and sediment yield. Measurements were conducted in duplicate.

After the first run (Run 1) the samples were allowed to dry at room temperature for one week and were then subjected to the same treatment for a

Table 1: Locations and selected properties of mine wastes.

Location	Metal/mineral mined	Sand (%)	Silt (%)	Clay (%)	pH*	OC (%)	ESP	CBD Fe (%)	Dominant clay minerals (%)				
									Ka	Mi	Tc Py	Sm	Qz
Springs	Gold	67	29	2	3.9	0.09	2.4	0.16	5	23	0	0	59
Northam	Platinum	65	20	13	9.1	0.04	8.1	0.00	27	0	21	31	0
Cullinan	Diamond	85	9	3	9.9	0.08	2.9	0.04	0	0	15	85	0
Rustenburg	Chromium	91	6	3	8.9	0.01	1.2	0.02	4	0	13	80	2
Rustenburg	Platinum	83	11	5	8.7	0.02	19.7	0.08	7	0	27	0	15
Witbank	Coal	61	25	13	7.6	15.62	5.9	0.18	48	0	0	0	41
Rustenburg	Silica	9	56	25	6.0	0.27	3.3	0.49	43	27	0	0	28
Stilfontein1	Gold	48	38	12	2.7	0.05	9.6	0.51	1	15	39	0	37
Stilfontein2	Gold	45	44	11	7.6	0.03	12.2	0.08	0	30	22	0	44
Brits	Vanadium	92	6	0.3	9.1	0.07	9.1	0.31	39	0	0	0	27

pH*: pH, measured in water; OC: organic carbon content; ESP: exchangeable sodium percentage; CBD Fe: dithionite extractable iron; Kao: kaolinite; Mi: Mica; Tc: Talc; Py: Pyrophyllite; Sm: smectite; Qz: quartz; Fs: Felds [par; Ex.: exchangeable; *: cmol kg⁻¹; CEC: cation exchange capacity; Sand (2.0-0.106 mm); Silt (106-2 µm); Clay (<2 µm).

Some 50 kg of material was collected of each of the waste areas. Samples were dried at 40°C and gently ground to pass a 2 mm sieve. Selected textural, chemical and mineralogical parameters were determined using routine analytical methods (NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990).

For rainfall simulation, the samples were packed in 350 mm x 500 mm boxes, 20 cm deep over an 80 mm deep layer of coarse sand. The boxes were placed in the rainfall simulator on a 15° slope, water-saturated from the bottom and then subjected to high-energy rain until a steady final infiltration rate was observed. The median drop velocity was 6.02 m s⁻¹, the kinetic energy 18.1 J mm⁻¹ m⁻² and the rain intensity 45 mm h⁻¹ for 1.67 h. Distilled water (electrical conductivity value 1.0 mS m⁻¹) was used to simulate

second time (Run 2). Run 2 took seal/crust formation into account. The erosion variables surface runoff (RO) and sediment yield (SL) were determined, as described by Levy (1988), using a rainfall simulator model developed in Israel (MORIN *et al.*, 1967). Interrill erodibility EPP was determined according to Laflen *et al.* (1991). These erosion variables were determined for the bare tailings and repeated on the same materials, covered with palm-mats.

São Luis City (Brazil)

In Sacavém gully slopes was applied soil bioengineering techniques, considering biological geotextile constructed from Buriti palm. The aim was to minimize soil erosion, by intercepting rainfall, retarding runoff velocity and sediment loss. These

techniques included: 1. Buriti geotextiles in association with barriers of wooden stakes (Figure 3) and the construction of terraces along contour lines; 2. Analysis of sediment particle-size; and 3. Photo comparison of vegetation cover development.

The rehabilitation work used ~30 kg of grass seeds (*Brachiaria decumbens*) on the slopes in combination with geotextiles. The shrub Sabiá (*Mimosa*

caesalpiniae folia) was used on the higher parts of the gully, to protect the topsoil. The rehabilitated area was fertilized with 500 kg ha⁻¹ of NPK (4-14-8) and decomposing palm was added to topsoil, as a source of organic matter. The project employed 10 local men for six days, who conducted the work using hand-held tools (Figure 4). A tractor (type backhoe loader) was used for two days to construct the terraces (Figure 5).



Figure 3: Area 3 of the rehabilitated area, with work in progress. E, M and D were reshaped exclusively by manual labour, São Luís, Brazil. Source: LAGESOLOS, 2008.



Figure 4: Men working with hand-held tools, São Luís, Brazil. Source: LAGESOLOS, 2008.



Figure 5: Initial work in areas 4-8. Source: LAGESOLOS, 2008.

The rehabilitation work in Sacavém was divided into three areas, presented in Figures 4 and 5, because of local relief characteristics. Areas 1-3 (Figure 6) were constructed with men and tractors; areas 4-8 (Figure 6) were made in the higher parts with a tractor; and areas E, M and D (Figure 3) were reshaped exclusively by manual labour.

In Part 1 (Figure 6: areas 1-3) the team used biological geotextiles and organic matter from decomposing palms, seeds and inserted barriers of wooden stakes along contour lines. This area had formed due the concentration of runoff from the street above the gully (Figure 7).



Figure 6: Rehabilitated areas with cover of buriti geotextiles, Sacavém Community, São Luís, Brazil (Areas 1-3 were constructed with men and tractors; areas 4-8 were made in the higher parts with a tractor). Source: LAGESOLOS, 2008.



Figure 7: Continuous lines: areas rehabilitated with Buriti palm mats.

Hatched lines: the rehabilitated area in Sacavém Community, São Luís, Brazil. Source: LAGESOLOS, 2008.

Area 2 was mostly made by the tractor, to construct the terraces by reshaping the gullies. This part was formed by water flows collected from the street, and was totally modified by tractor work. Here there was evidence of active erosion, in the form of rills. After the tractor's work, the manual reshaping of slopes and the application of biological geotextiles was achieved manually.

Area 3 was made by men using Buriti biological geotextiles, organic matter from decomposing organic material (palm trees and leaves), wooden stakes and the planting of shrubs, as inaccessibility prevented tractor work. To reshape the internal part of the gully, we used techniques to minimize water flow energy, using many barriers of wooden stakes (Figure 3) and the application of biological geotextiles, grass seeds and organic matter from decomposing palm leaves. On the barriers, Sabiá bushes were planted to stabilize the topsoil. The rehabilitated area in Sacavém Community is ~2000 m² and ~800 m² is covered with Buriti biological geotextiles (Figure 7).

Studies were carried out in the laboratory using soil samples collected from Sacavém gully walls and from the gully floor to determine particle-

size distribution, using EMBRAPA (1997) protocols. Vegetation cover index was monitored and assessed on Sacavém rehabilitation site, using photographs and supervised classification tools available in Arcgis 9.3, which can perform pixel-based classification. The progress of vegetation cover was monitored weekly from March 2008 to May 2008. These photos were taken at the same point, using wood stakes on the rehabilitated slope.

RESULTS AND DISCUSSION

Gauteng Province (South Africa)

Over 200,000 ha of natural habitat have been degraded by mining activities in South Africa. Tailing dams are responsible for many of these environmental problems. Establishing a grass cover to reduce erosion is the dominant reclamation method. Chemical methods, such as lime, fertilizer and compost applications, are generally used (VAN DEVENTER; MARAIS, 2003). Covering the slopes with biological geotextiles might constitute another option for mining companies to reduce erosion and aid re-vegetation.

•Waste properties

The waste samples varied considerably with respect to their textural, chemical and mineralogical properties (Table 1). Most were sand-textured and the clay content was low. The pH ranged from 2.7-9.9, with seven samples being alkaline and three acidic. With the exception of the coal waste sample, organic carbon (OC) contents were low (<0.27%). Dithionite-extractable iron (CBD-Fe) contents were generally low, particularly in the tailings, and the exchangeable cation population was dominated by Ca. Exchangeable Na percentages (ESP) ranged from 1.2-19.7. Some clay fractions were dominated by kaolinite, smectite, mica, pyrophyllite or quartz. These results are characteristic of the broad range of South African mine wastes.

•Rainfall simulator results

Although experimental conditions under the rainfall were made as identical as possible, significant differences existed in the investigated erodibility variables (RO, SL, WEPP) (Table 2).

•Sediment load in runoff (SL)

SL in runoff (g) ranged from 0.5 to 699, with a mean of 248 for Run 1 and 223 for Run 2 (Table 2). Once the trays were covered with biological geotextiles, SL decreased considerably in all cases to a mean ~55% of bare treatment. This indicates that palm-mats have very beneficial effects on erosion reduction.

• Runoff (RO)

Runoff (cm³) ranged from 391 to 4295 with a mean of 2655 cm³ in Run 1 and almost identical values for Run 2. When the samples were covered with biological geotextiles, mean runoff values remained the same for Run 1 and slightly decreased for Run 2 (Table 2). This indicates that biological geotextiles do not always reduce runoff values. The following trends between selected waste parameters and interrill erodibility have been established: the silt percentage, commonly regarded as one of the most influential erosion-promoting parameters and featuring prominently in K equations, was also one of the most relevant erosion parameters in the present study. Clay content influenced RO, but not SL. The influence of texture became more pronounced when the tailings were covered with mats; quartz and mica were the dominant clay parameters governing interrill erodibility; the ESP, often associated with erosion, did not show any distinct relationship to SL; EPP increased with: a) increasing silt content; b) increasing quartz and mica proportions in the clay fraction and c) decreasing sand content and pH; the findings that materials which have their clay fractions dominated by quartz and/or mica are far more erodible than smectitic or kaolinitic ones and that a high ESP does not necessarily promote erosion are noteworthy.

Table 2: Minimum, maximum and mean (in brackets) values of selected erosion variables.

	Sediment load (g)	Runoff (cm ³)	WEPP# (kg.s.m-4)
Bare samples Run 1	0.5-699 (248)	391-4295 (2655)	0.06-6.53 (2.24)
Bare samples Run 2	6.5-551 (223)	419-4254 (2724)	0.06-5.15 (1.96)
Palm-mat cover Run 1	8.5-328 (122)	383-4497 (2658)	0.16-3.06 (1.34)
Palm-mat cover Run 2	4-244 (98)	386-4432 (2569)	0.03-2.27 (1.16)

EPP#: Erodibility according to the WEPP model. Source: Laflen *et al.*, 1991.

São Luis City (Brazil)

•Rehabilitation work

Due to the difficulties in diverting the flows, which would require more extensive engineering works, the channel was maintained, and the base of the slopes was strengthened to support the flows (Figure 7: arrow). In the upper part of this area, which had ~8° slope angle, contour lines were surveyed and barriers of wooden stakes were used to retard runoff velocity from adjacent vegetated slopes. Some slopes in this part had a 45° slope angle (Figure 6: part 3). However, this angle is considered too steep for the application of biological geotextiles.

In area 2, work was completed to reshape the gullies and construct the ~12 m high terraces using the gully material. Tractor work was impeded, because on the second terrace the tractor had difficulty in working, because the high sand content made the slope unstable. These terraces are crossed by a flow convergence area, which was formed by the men inserting sand bags, decomposing palm leaves and grass seeds, to form a vegetated channel after grass growth.

Most erodible materials tend to be silts and sands, which are non-cohesive and sufficiently small to be transported by the flow rates characteristic of rills (FULLEN and CATT, 2004). In the study area, soil textural analysis confirms the coarse texture (Ta-

Table 3: The texture of soil samples from Sacavém gully.

Samples	Sand (%)	Silt (%)	Clay (%)
1	96.67	2.23	1.10
2	68.46	23.04	8.50
3	83.25	9.25	7.50
4	92.85	2.75	4.40
5	94.76	2.14	3.10
6	96.60	1.60	1.80
7	94.15	1.05	1.80
8	78.97	10.53	10.50
9	94.12	3.38	2.50

Sand = 2000-50 µm, silt = 50-2 µm and clay = <2 µm.

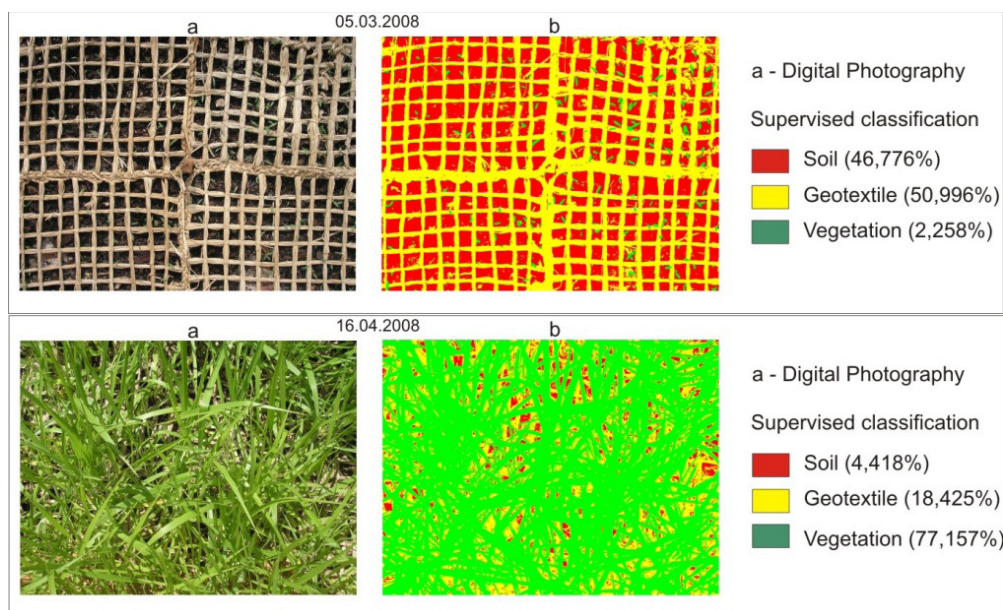


Figure 8: Photo comparison of vegetation cover developing in Sacavém community, São Luís, Brazil.

ble 3). The samples had high sand (68.46-96.67%) and fine sand (1.10-10.50%) contents and low silt (1.05-23.04%) and clay (5.00-26.98%) contents. Soil organic matter contents are low (~1% by weight) and are even less in the subsoil. These soil properties indicate high erodibility. Clay lenses were present at ~2.5 m depth (Figure 6: areas 4-8). Because of this, the tractor worked better than in the second sandier terrace. According to photo comparison data, in one month the vegetation had developed (Figures 8 and 9). Continued success requires continued high-quality maintenance, which is being achieved by local people, under project supervision.

For one month after the rehabilitation work São Luís City experienced intense and prolonged rains (Table 4), which presented attendant problems for the rehabilitation work. However, we again employed local people to work on site maintenance (Figure

10). This shows that we cannot assume that the entire rehabilitation process will be successful, especially when one is working in an erosive tropical climate. However, we have succeeded to date. The storm had a recurrence interval of ~60 years and, apart from some minor damage on parts of the rehabilitated area, there has been only some minor erosion, especially where some water convergence occurred. This evidence suggests the work will prove successful. The ongoing site development can be monitored via the LAGESOLOS (Laboratory of Environmental Geomorphology and Soil Degradation, Federal University of Rio de Janeiro) web site: <<http://www.lagesolos.ufrj.br>>.

Textural data show that the main component materials of the slopes at Sacavém gully are sands, with many samples being >90% sand (Table 3). Thus, the soils are highly erodible and, therefore, the use of biological geotextiles is very important to arrest the erosion process.



Figure 9: Grass development, one-month after rehabilitation, Sacavém community, SãoLuís, Brazil. Source: LAGESOLOS, 2008.

Table 4: Daily meteorological data from São Luís City (10/03/08-09/04/08).

Min. Temp. (°C)	Max. Temp. (°C)	Relative Humidity (%)	Rain (mm)	Date
23.3	30.8	76.0	5.0	10/03/2008
24.4	31.5	78.0	0.0	11/03/2008
24.2	30.4	78.0	0.0	12/03/2008
22.8	29.8	80.0	22.0	13/03/2008
23.2	26.4	91.0	8.6	14/03/2008
22.8	29.4	85.0	8.6	15/03/2008

22.9	28.4	70.0	83.0	16/03/2008
23.8	29.4	75.0	10.6	17/03/2008
23.0	26.3	82.0	28.6	18/03/2008
23.3	28.0	81.0	27.1	19/03/2008
22.9	30.3	71.0	0.4	20/03/2008
23.0	29.6	73.0	37.3	21/03/2008
23.2	29.2	77.0	0.0	22/03/2008
23.9	30.0	74.0	2.3	23/03/2008
23.9	27.6	80.0	37.6	24/03/2008
24.0	30.0	78.0	1.8	25/03/2008
23.4	29.4	84.0	34.6	26/03/2008
23.6	27.4	89.0	24.2	27/03/2008
23.2	30.0	74.0	38.6	28/03/2008
24.3	29.0	77.0	0.4	29/03/2008
23.4	27.6	95.0	10.6	30/03/2008
23.8	28.9	86.0	28.6	31/03/2008
23.6	28.7	87.0	102.2	01/04/2008
23.0	29.5	67.0	97.8	02/04/2008
22.7	29.4	74.0	29.6	03/04/2008
24.3	30.4	70.0	3.1	04/04/2008
24.2	26.2	90.0	0.0	05/04/2008
22.0	27.0	81.0	71.8	06/04/2008
23.3	31.2	68.0	3.7	07/04/2008
23.8	29.7	83.0	35.6	08/04/2008
23.8	31.2	77.0	0.0	09/04/2008
-	-	Σ	753.7	-



Figure 10: Maintenance work at the rehabilitated area one month after rehabilitation, Sacavém community, São Luís, Brazil. Source: LAGESOLOS, 2008.V

CONCLUSIONS

The conclusions for this paper take into account each presented study area. In this way, we can address the role of biological geotextiles on the stability of non-agricultural environments in two different countries. The objective was reached by a combination of field, experimental and laboratory studies, which suggest biological geotextiles constructed from palm leaves are an effective, sustainable and economically-viable soil conservation technique. It can be used to improve ecosystem management, decreasing deforestation, improving agroforestry and cost-effective applications in diverse environments.

Environmental and socio-economic rewards of biological geotextiles suggest they could be an effective and inexpensive soil conservation method, with enormous global potential. The postulated strategic impacts of biological geotextiles include promoting sustainable and environmentally-friendly palm-agriculture, which discourages deforestation, promoting both reforestation and agroforestry and the technique may be potentially profitable and thus augment the income of financially-deprived communities. Hence, construction of palm geotextiles could develop into a rural, labour-intensive industry, particularly encouraging the employment of socially-disadvantaged groups, such as women, disabled and elderly people (i.e. hand-work performed sitting down).

These techniques have been applied in different countries, with positive results from the use of biodegradable materials (e.g. vegetal fibres, wooden stakes and re-vegetation). These techniques stabilize the soil at low cost and improve the environment. Bioengineering involves the planned, strategic and phased application of selected materials, involving biodegradable materials, often in combination with 'hard engineering' structures constructed from stone, concrete and steel.

In Gauteng Province (South Africa), the results from rainfall simulator experiments clearly illustrate that application of palm-mats significantly decreased sediment load in runoff, thereby having the potential to effectively stabilize tailing dam slopes.

Covering tailings with biological geotextiles did not reduce runoff or improve water infiltration, however. Tailings that have their clay fraction dominated by quartz and are silt textured are particularly prone to erosion.

Accelerated erosion in Sacavém District (São Luís City) is enhanced by the action of intense rains, acting in combination with vegetation clearance and the erodible sandy soil texture. Intense human action, with inadequate soil use and irregular settlement, also plays a very important role in gully erosion. Only one month after the rehabilitation work, the area was exposed to intense erosive rains. Vegetation resisted erosion and the Buriti geotextiles seem to have achieved our main objective, that is, to stop soil erosion and rehabilitate the gullied area.

The main purpose of this study was to assess the effects of biological geotextiles on the stability of non-agricultural environments, considering different sites and methods. Although different techniques were used, the results indicate that positive effects of biological geotextiles can be achieved. First, biological geotextiles offer potential for sustainable development and soil conservation. Second, they can also be used for economic development, creating jobs and reducing poverty in poor rural and urban regions. Finally, the rehabilitation of degraded soils at these sites using biological geotextiles may help to recover stable conditions.

ACKNOWLEDGEMENTS

This research forms part of the BORASSUS Project 'The environmental and socio-economic contributions of palm-leaf geotextiles to sustainable development and soil conservation' (contract number: INCO-CT-2005-510745), funded by the European Commission (EC), Specific Targeted Research Projects (FP6-STREPs) for Developing Countries (INCO-DEV) Programme. This Project is dedicated to the memory of Dr Kathy Davies, who was the initiator and inspiration for palm-leaf geotextile research. We are grateful to Professor Mike Fullen (University of Wolverhampton) for having read the first version of this paper and having made useful suggestions.

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