Beneficial effect of palm geotextiles on inter-rill erosion in South African soils and mine dam tailings: a rainfall simulator study

D.G. Paterson[1#*], C. Bühmann[2], G.M.E. Pienaar[2] and R.O. Barnard[1]

[1] Department of Plant Production and Soil Science, University of Pretoria
[2] Agricultural Research Council-Institute for Soil, Climate and Water,
Private Bag X79, Pretoria 0001, South Africa
#Current address: Agricultural Research Council-Institute for Soil, Climate and Water, Private Bag X79, Pretoria 0001

1 August 2011

Geotextiles are reported to be highly effective and economically viable erosion control products. The objective of this study was to test this hypothesis by determining the extent of differences in erosion-related variables between bare soils and mine tailings and those covered with palm mats, via rainfall simulation. Erosion parameters studied included runoff (RO), sediment load in the runoff (SL), percentage of stable aggregates (SA), final infiltration rate (FI) and inter-rill erodibility (K_i). Thirty samples, representative of South African soils and mine tailings, were investigated. The soils varied considerably with respect to their textural, chemical and mineralogical properties in line with soil taxonomy, annual precipitation and geological substrate. Tailing sample selection was based on the dominant type of mine. Erosion parameters varied greatly within, but to a much lower extent between, the two different types of material. Several significant correlations were obtained. Sediment load had the best correlation with kaolinite content and with fine sand content, while for runoff, the best correlation was with organic carbon content. When the samples were covered with palm mats, final infiltration rate, stable aggregate and inter-rill erodibility values were similar to those of bare materials and the amount of runoff was slightly higher. Sediment load, however, was reduced by ±65%. These results document the suitability of palm geotextiles for soil conservation.

Keywords: Inter-rill erodibility, rainfall simulator, soil and water conservation, palm leaf mats.

* To whom correspondence should be addressed (E-mail: Garry@arc.agric.za)

Introduction

Many regions of the world are characterized by relatively long dry seasons followed by shorter, wetter rainy seasons, often with high intensity precipitation events, inducing high runoff and increased erosion rates. South Africa comprises an area of just over 122 million ha and approximately 80% of the country falls into the above category, so that erosion is potentially a major problem with wide-ranging social and economic consequences. Across South Africa, annual soil loss through erosion is estimated to exceed 300 million tons (Roberts, 1983) and it has been estimated that the rate of soil erosion per person of the population is as high as 20 times the world average (d'Huyvetter, 1985). It has been determined that removal of vegetation in parts of the Karoo can lead to a 10-fold increase in runoff (Boardman *et al.,* 2003). On-site effects of this removal of topsoil are related predominantly to the loss of organic matter and plant nutrients, which for much of the highveld area of South Africa averages 3 kg nitrogen, 2.4 kg phosphorus and 33 kg potassium per ha per annum (van der Merwe, 1995). Off-site effects are associated with the siltation of reservoirs on which South Africa is strongly dependent, due to the average annual rainfall across the country of only 454 mm (ARC-ISCW, 2008).

All types of erosion are evident in South Africa: sheet, rill and gully erosion as well as landslides. The landscape is often truncated by deep and wide gullies. Many areas, especially parts of the Eastern Cape and Limpopo Provinces, are extensively denuded. Between 1969 and 1990 there has been a progressive deterioration from sheet through rill to gully erosion, as assessed from a chronological analysis of aerial photographs and field evidence (le Roux *et al.*, 2006). Erosion is particularly severe in overgrazed, overpopulated regions, including the fields of subsistence farmers in the rural areas of the former homelands (d'Huyvetter, 1985; le Roux *et al.*, 2006).

Erosion in South Africa is not restricted to sediments and soils, but is also a major problem in tailings dams. South Africa mines 55 different minerals from over 713 mines and quarries and exports mineral commodities to 87 countries. Though mining fuels economic growth, the activities of the industry have a major negative impact on the environment, much of which is associated with the approximately 270 tailings dams (Rosner *et al.*, 2001). Tailings often have very poor physical and chemical properties resulting in a very high degree of water and wind erosion. The rehabilitation of tailings and other mine discard is particularly problematic as their pH may be very high or very low (van Rensburg *et al.*, 2004). Many tailings are silt-textured and organic carbon may be severely lacking or absent (Van Deventer, 1997).

Complex surface engineering problems are often solved in much of the industrialized world by using geotextiles, which may or not be biodegradable to a certain degree. Their initial application efficiently and economically reduces erosion and allows sufficient time for plant communities to stabilize engineered slopes. Two organic products, manufactured from jute and coconut fibre, are marketed in South Africa at present. These geotextiles are imported from Asia, mainly India and Sri Lanka, and approximately 175 000 m^2 are utilized annually by engineering companies (Maccaferri, 2011). A significant benefit, therefore, would be to develop an effective geotextile product that could be produced locally, providing the largely unskilled labour force with a means of employment.

A completely organic product for surface bioengineering, which shows considerable potential to reduce erosion, favours re-vegetation and is economical, has recently been reported (Booth *et al.*, 2005; Guerra *et al.*, 2005; Davies *et al.*, 2006; Fullen *et al.*, 2006). This geotextile is manufactured from palm leaves and its production might improve the socio-economic foundation for sustainable development in developing countries or regions, especially given the widespread weaving skills present in many communities. Available studies, however, have not quantified the effectiveness of such palm mats in reducing rates of inter-rill erosion.

Rainfall simulation has been selected as an investigative tool as it is reported to be a very reliable approach of obtaining information on inter-rill erodibility for a range of conditions, such as slope angle, rainfall intensity and water composition (Schiettecatte *et al.*, 2002). The technique has also been used to test the influence of a variety of soil factors on erosion, including crusting (Smith, 1990), clay mineralogy and cations (Levy, 1988), a range of organic mulches (Smets *et al.*, 2008) and the effects of grazing (Kato *et al.*, 2009). Rainfall simulation experiments also allow many different soils to be investigated simultaneously, as a particular field site does not offer the range of soil and slope conditions that can be found elsewhere in the region or country. The objective of this study was therefore to determine differences in erosion variables between bare soils and palm mat covered soils and mine dam tailings.

Material and methods

Mat manufacturing

Palm mats were manufactured from leaves of the Lala palm (*Hyperhene coriacea*), harvested in northern KwaZulu-Natal, by stripping the thick central spine, which gives the leaf its fan-like appearance. Using a 0.5 x 0.5 m wooden template, the leaf fronds were woven into a grid pattern, vertically and horizontally, using knots at approximate 50 mm intervals (Figure 1). Selected chemical parameters of the mats were determined using routine analytical methods (Non-Affiliated Soil Analysis Work Committee, 1990).

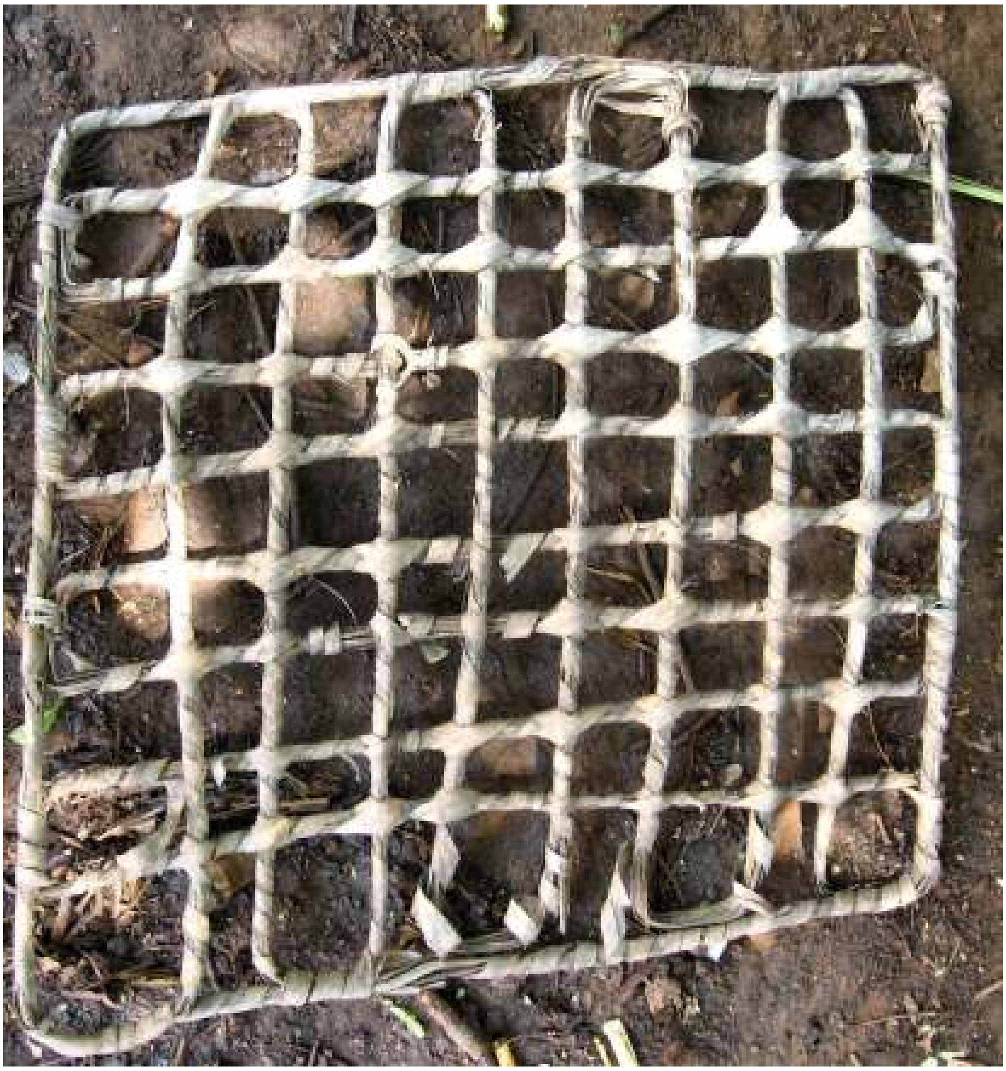

Figure 1 Example of palm mat (approximately 0.5 x 0.5 m).

Table 1 Soil sampling sites

Soil	Location	Longitude (E)	Latitude (S)	AP[a] (mm)	Slope angle	Altitude (m)	Parent material	Soil Classification	
								SA[b]	WRB[c]
S1	Bergville	29°21’59”	28°48’53”	898	5%	1316	Colluvium	Kroonstad	Gleyic Planosol
S2	Towoomba	28°19’26”	24°54’55”	628	<1%	1102	Basalt	Arcadia	Haplic Vertisol
S3	Towoomba	28°19’29”	24°54’54”	628	<1%	1102	Basalt	Shortlands	Rhodic Nitisol
S4	Lusikisiki	29°34’45”	31°16’10”	983	6%	680	Shale (Ecca)	Cartref	Haplic Cambisol
S5	Marico	26°24’00”	25°34’18”	415	2%	1105	Colluvium	Valsrivier	Calcic Planosol
S6	Long Tom	30°34’38”	25°06’48”	904	5%	2078	Shale (Pta)	Inanda	Humic Ferralsol
S7	Eshowe	31°13’15”	28°55’20”	681	15%	556	Sandstone	Inhoek	Mollic Fluvisol
S8	Musina	30°25’01”	22°20’33”	347	6%	481	Gniess	Addo	Calcaric Cambisol
S9	□elmas	28°49’35”	26°14’27”	861	1%	1590	Shale	Avalon	Acric Plinthosol
S10	Badplaas	30°47’34”	25°47’27”	1037	5%	1452	Gneiss	Griffin	Acric Ferralsol
S11	Rietgat	27°55’22”	24°57’02”	555	1%	1071	Granite	Glencoe	Petric Plinthosol
S12	Aliwal Nth.	26°45’59”	30°38’38”	519	2%	1311	Mudstone	Sterkspruit	Haplic Solonetz
S13	Rouxville	26°33’36”	30°32’22”	464	3%	1386	Colluvium	Valsrivier	Luvic Planosol
S14	Witsieshoek	28°52’54”	28°24’35”	668	7%	1654	Mudstone	Valsrivier	Luvic Planosol
S15	Pietersburg	29°20’14”	23°56’57”	540	3%	1320	Granite	Hutton	Eutric Ferralsol
S16	Ladysmith	29°37’01”	28°23’37”	819	3%	1218	Sandstone	Tukulu	Haplic Cambisol
S17	Rietrivier	24°21’17”	28°55’26”	369	2%	1039	Colluvium	Augrabies	Calcaric Cambisol
S18	Brandvlei	21°11’05”	30°20’32”	171	3%	928	Shale (Ecca)	Augrabies	Calcaric Cambisol
S19	Tankwa	19°38’55”	32°21’24”	72	1%	304	Tillite	Glenrosa	Leptic Cambisol
S20	Malmesbury	18°49’33”	33°21’35”	379	10%	372	Shale	Shortlands	Rhodic Nitisol

[a] AP – Annual Precipitation

[b] Soil Classification Working Group (1991)

[c] IUSS Working Group WRB (2006)

Table 2 Tailings sampling sites

Site	Location	Element mined	Longitude (E)	Latitude (S)	AP^a(mm)	Slope angle	Altitude (m)	Parent material
T1	Springs	Gold	28°26’57”	26°15’26”	681	18°	1580	Conglomerate, Witwatersrand
T2	Northam	Platinum	27°21’27”	24°47’52”	624	18°	1017	Pyroxenite, Bushveld Complex
T3	Cullinan	Diamond	28°32’11”	25°36’33”	760	18°	1312	Kimberlite
T4	Rustenburg	Chrome	Confidential		619	18°	1156	Pyroxenite, Bushveld Complex
T5	Rustenburg	Platinum	Confidential		619	23°	1149	Pyroxenite, Bushveld Complex
T6	Witbank	Coal	Confidential		891	<1°	1617	Shale, Karoo (Vryheid Formation)
T7	Rustenburg	Silica	Confidential		619	<1°	1270	Quartzite, Magaliesberg Formation
T8	Stilfontein (acidic)	Gold	Confidential		560	23°	1365	Conglomerate, Witwatersrand
T9	Stilfontein	Gold	Confidential		560	23°	1359	Conglomerate, Witwatersrand
T10	Brits	Vanadium	27°34’39”	25°34’15”	650	<1°	1885	Magnetite, Namaqualand Suite

[a] AP – Annual Precipitation

Rainfall simulator tests

Rainfall simulator tests were carried out on twenty South African soils (originating in eight of the provinces in South Africa) and ten mine dam tailings (the locations of some sites are governed by confidentiality). The soils cover a range of South African conditions, reflecting different parent materials (e.g. Archaean granites, Karoo sedimentary rocks, Jurassic basalt) and climatic zones (annual precipitation ranges from 72 mm to 1 037 mm). Half of the soils were selected on the basis of their soil taxonomic properties, while the remainder were identified from field evidence as being potentially highly erodible. Details of the soil sampling sites are given in Table 1.

Mine tailings were selected based on the element or mineral mined, namely gold, platinum, diamonds, chromium, silicon and vanadium, with sampling sites occurring throughout the mining belt of the South African Highveld (Table 2).

About 50 kg of material was collected for each of the soils and tailings. In the case of soils, only the upper 100-150 mm was sampled. All samples were dried at 40°C and gently ground to pass a 2 mm sieve. Selected parameters were determined using routine analytical methods (Non-Affiliated Soil Analysis Work Committee, 1990). These included particle size, CBD (citrate-bicarbonate-dithionate) Fe, Al, and Mn, exchangeable cations and organic carbon. Modulus of rupture, electrical conductivity, SAR (sodium adsorption ratio) and resistance were done for selected samples.

For the rainfall simulation procedure, the samples were packed in 350 x 500 mm boxes, with a 200 mm deep layer of soil placed over a 80 mm layer of coarse sand and gravel. Four boxes were placed in the rotating rainfall simulator at a slope of 15^o. The soil was first saturated by suction from the bottom and then subjected to high-energy rain until a steady final infiltration rate was observed.

Distilled water with an electrical conductivity value of 1.0 mS m^{-1} was used to simulate rain. 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. The volumes percolating through the soil were recorded at 2 min intervals during an event of 2 h for each storm. Timed runoff samples were collected at 2 min intervals during the 2 h event, weighed, oven-dried at 105°C and re-weighed to determine runoff rate, sediment concentration and sediment yield. Measurements were carried out in duplicate, so that two soils could be assessed for each run of the rainfall simulator. After the first run (run 1) the soils were allowed to dry at room temperature and were then subjected to the same treatment for a second time (run 2). Run 2 therefore took crust formation into account. Water infiltration, percentage of stable aggregates, surface runoff and sediment yield were determined as described by Levy (1988), using a rainfall simulator originally developed in Israel (Morin *et al.*, 1967). Inter-rill erodibility was determined according to Kinnell (1993).

Erosion variables such as runoff (RO), sediment load in the runoff (SL), final infiltration rate (FI), percentage of stable aggregates (SA) and inter-rill erodibility (K*i*) (Kinnell, 1993) were determined for the bare soils and tailings as well as for the same material covered with palm mats.

Results

Selected physical and chemical properties of the palm mats indicate their suitability as mulch. The mats add 1.3 kg of dry organic matter to each m^2 of soil (Table 3) and the mesh (Figure 1) covers approximately 40% of the soil surface, allowing space for vegetation to emerge. Furthermore, they have a water retention capacity of 1.8 litres kg^{-1} m^{-2}. The N, K, S and P percentages are high, while the Al content is low. The palm mats have, generally speaking, the ideal chemical composition of an organic mulch. They are also able to absorb more than their own mass of water, have a low sodium content and a favourable C/N ratio.

Table 3 Selected characteristics of palm mats

□W	SCF	WR	C/N	Ash	N							
g m^{-2}	%	g m^{-2}	ratio	%	%	Na *	K*	Mn *	C *	Al*	S*	P*
1332	40	1850	46.0	3.7	1.08	781	11700	1810	1810	50	1474	1463

□W: dry weight; SCF: soil cover factor; WR: water retention; *: mg kg^{-1}.

Soil and tailing properties

The soils and tailings varied considerably with respect to their textural, chemical and mineralogical properties (Table 4). Some soils were very sandy, while others were clay-textured. The pH ranged from acid to alkaline. Some of the clay fractions were dominated by kaolinite while others contained high percentages of smectite, mica or quartz. The organic carbon (OC) content was generally low, particularly in the tailing materials. The exchangeable cation population was dominated by Ca and the Na content was low, as was the percentage of secondary Fe minerals. The samples therefore reflected the wide range of soils and mine tailings present in South Africa.

Table 4 Range in selected soil and tailing properties (average values in brackets)

Parameter	Soils	Tailings	Parameter	Soils	Tailings
Sand (%)	10-81 (52)	9-92 (65)	OC (%)	0.05-3.65 (1.16)	0.01-0.27 (0.07)
Silt (%)	7-56 (23)	9-56 (25)	Na*	0.06-0.72 (0.25)	0.1-0.61 (0.28)
Clay (%)	5-52 (23)	0.3-25 (9)	K*	0.04-1.31 (0.52)	0.02-1.69 (0.24)
pH (H_2O)	4.9-8.9 (6.7)	2.7-9.9 (7.3)	Mg*	0.07-10.52 (2.93)	0.18- 3.05 (1.28)
Kao. (%)	0-68 (22)	0-48 (17)	Ca*	0.04-35.75 (9.41)	0.38-22.42 (6.42)
Sme. (%)	0-90 (14)	0-85 (20)	CEC*	2.37-45.86 (14.38)	1.31-18.41 (6.0)
Mica (%)	0-45 (22)	0-30 (10)	CB□-Fe (%)	0.22-4.86 (1.39)	0.002- 0.49 (0.18)
Quartz (%)	0-93 (38)	0-59 (25)	CB□-Al (%)	0.06-1.76 (0.39)	0.002-0.13 (0.036)

OC = organic carbon; CB□ = dithionite extractable; Kao. = kaolinite;
Sme. = smectite; * = cmol kg^{-1}; CEC = Cation Exchange Capacity.

Rainfall simulator results

Major differences existed in the range of erodibility parameters within the various soils and tailing materials but only minor variations in the average values and in the range between the two different materials. In Table 5, values for FI, SA and K*i* are presented only for the bare soils, as these figures are calculated from measured RO and SL data and reflect soil characteristics. Applications of palm mats will change RO and SL and, accordingly, will lead to different FI, SA and K*i* values, though these soil characteristics remain unchanged.

Runoff and sediment load

The runoff values for the soils ranged from 2 415 – 4 044 cm^3 with an average of 3 152 cm^3 in run 1, with very similar values for run 2 (Table 5). Some of the tailings, however, showed much lower runoff rates (ranging from 391 – 4 295 cm^3).

When the samples were covered with palm mats, average runoff values for the soils increased from 3 152 to 3 592 cm^3 for the first run with similar increases for the second run. In the tailings, too, the amount of runoff increased by approximately 500 cm^3 (Figure 2).

The amount of eroded soil in the runoff ranged from 29 to 615 g, (average 294 g) and similar values for tailing samples in run 1 (Figure 3). In the second run, values for both materials were lower (Table 5). Once the trays were covered with palm mats, SL decreased considerably in all cases. This reflects the beneficial effect that palm mats have on retaining sediment on the soil surface, leading to erosion reduction. The extent of reduction was independent of the sediment load of the uncovered soils and both the least and most highly erodible soils had their sediment load reduced by a similar percentage.

Table 5 Range in erodibility characteristics (average values in brackets)

Parameter		Run	Soils	Tailings
RO	**bare**	1	2415 - 4044 (3154)	391 - 4295 (2596)
		2	2220 - 3963 (3141)	419 - 4184 (2544)
	palm	1	2803 - 4140 (3592)	383 - 4497 (3046)
		2	2853 - 4372 (3640)	331 - 4432 (2697)
SL	**bare**	1	29 - 615 (294)	0 - 699 (178)
		2	28 - 491 (249)	0 - 551 (100)
	palm	1	42 - 369 (118)	6 - 328 (178)
		2	26 - 296 (110)	4 - 244 (78)
FI; bare		1	0 - 15.59 (7.01)	1.11 - 37.85 (14.97)
		2	0.89 - 20.04 (7.70)	1.34 - 37.85 (14.4)
SA; bare		1	6.24 - 17.95 (9.95)	1.83 - 40.0 (17.17)
		2	1.60 - 23.14 (10.25)	2.77 - 40.48 (17.02)
K*i*; bare		1	1.20 - 17.89 (9.39)	0 - 17.13 (5.42)
		2	1.33 - 21.19 (7.96)	1.43 - 15.04 (5.26)

RO = runoff (cm^3); SL = sediment load in the runoff (g); FI = final infiltration rate ($mm\ h^{-1}$); SA = percentage of stable aggregates; K*i* = inter-rill erodibility ($kg\ m^{-3}\ s^{-1}$) according to Kinnell (1993); bare = bare materials; palm = materials covered with palm mats; 1 = first simulation run; 2 = second simulation run.

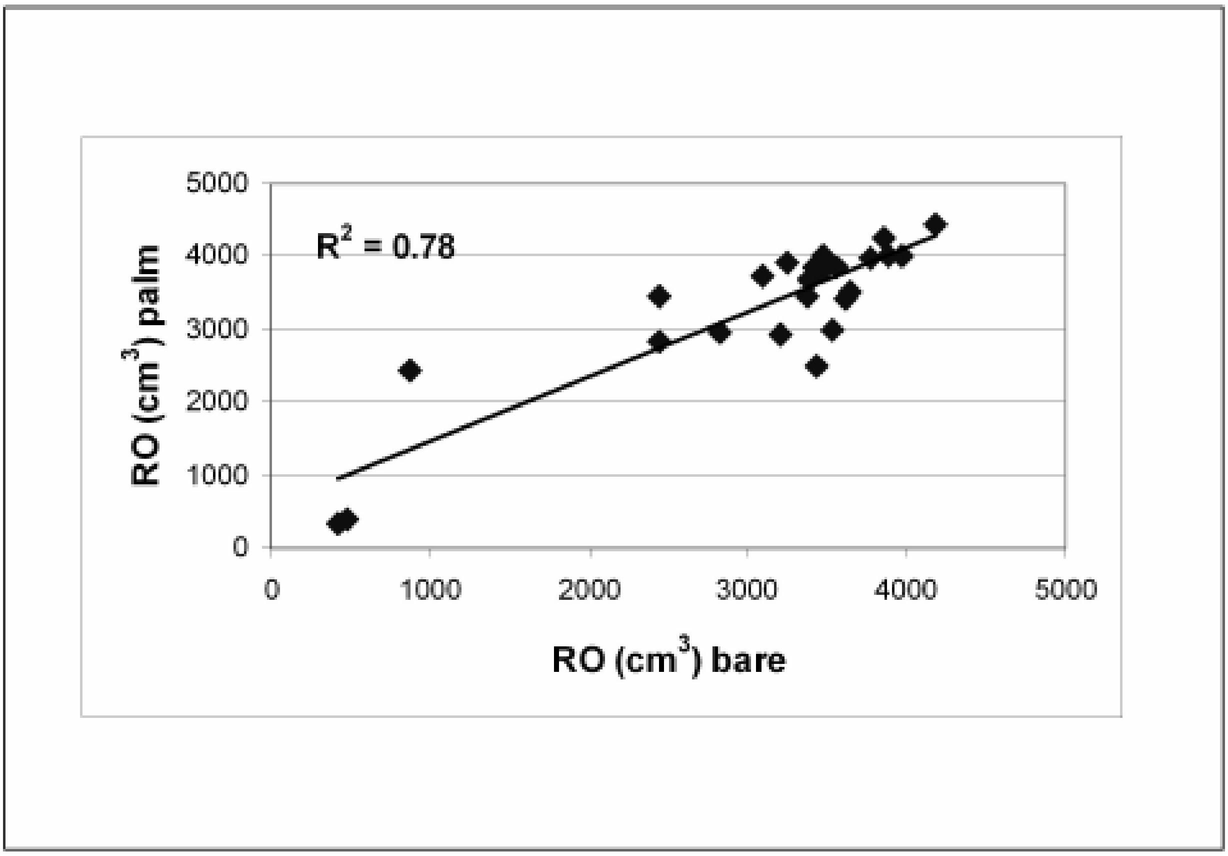

Figure 2 Relationship between runoff from the bare soils (RO bare) and that from the same soils, covered with palm mats (RO palm, run 2) ($P < 0.05$).

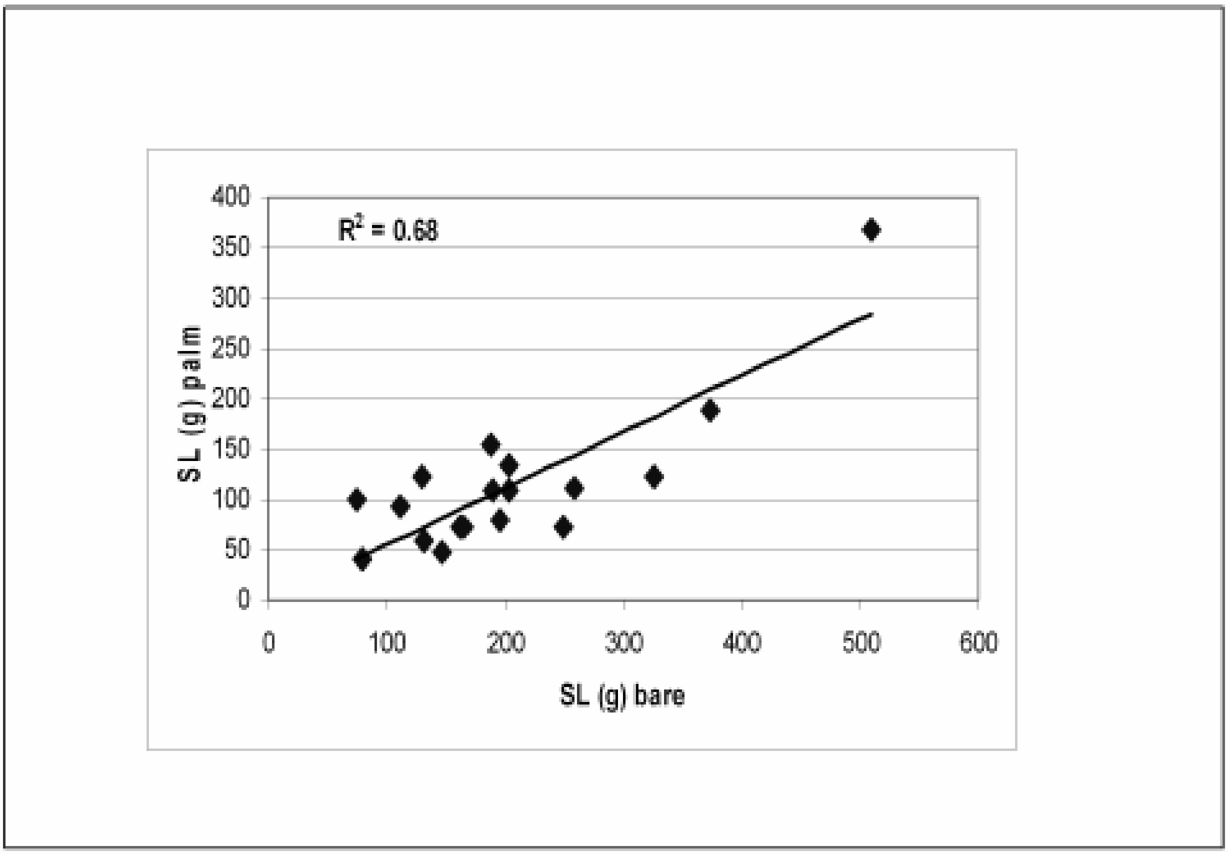

Figure 3 Relationship between the sediment load in the runoff from the bare soil and from a soil, covered with palm mats (run 1) ($P < 0.05$).

Final infiltration rates

The relationship between water infiltration and erodibility is far from straightforward. Development of a surface seal may increase surface runoff but may well stabilize a soil against erosion (Bradford *et al.,* 1987), although re-vegetation will be more difficult. The contact of the soil with water (aging) improves aggregate stability (Rapp, 1998) and therefore reduces erodibility. This discrepancy is reflected in the present study where most soils showed a decrease in FI although others remained unchanged and a few showed an increase.

In the first run (Table 5), FI differed markedly between soils and tailings, the former between 0 and 15.59 (average 7.01) mm h^{-1}, the latter between 1.11 and 37.85 (average 14.97) mm h^{-1}. In run 2, FI increased by a small margin to an average of 7.70 mm h^{-1} in the soils but decreased slightly to 14.4 mm h^{-1} in the tailings. After the second run, infiltration curves and FI values were almost identical to those of the first run for the two most stable samples. In the other soils, infiltration rates showed a decrease or increase. Generally, infiltration rates decreased at a significantly earlier stage in the erosion-prone soils, indicating a much earlier onset of infiltration problems.

Percentage of stable aggregates

A high SA percentage reportedly greatly reduces soil erodibility (Barthes *et al.,* 2000). The samples of the present study displayed a considerable degree of variation in SA. Results from run 1 (Table 5) showed that SA ranged from 6.24% to 17.95% (average 9.95%) in the soils and from 1.83% to 40% (average 17.17%) in the tailings. Raindrop action and soil dispersion during run 1 hardly reduced SA percentages, as values for the second run were very similar to those of the first run. This pattern of observed changes reflects the influence of crust formation (decrease in FI) and aging (increase in aggregate stability), with different processes being obviously dominant in different soils.

Inter-rill erodibility

The two different groups of materials varied within a similar range, as far as inter-rill erodibility (Kinnell, 1993) is concerned (Table 5), but average values were lower for the generally coarser-textured tailings. Values for the soils varied between 1.20 and 17.89 kg m^{-3} s^{-1} (average 9.39) in the first run and between 1.33 and 21.19 kg m^{-3} s^{-1} (average 7.96) in the second run, the tailings also falling within this range, so that the tailings and soils would seem to share similar inter-rill erodibility characteristics.

Soil properties

A range of soil properties that may have a significant relationship with either runoff or sediment load was selected and the relationship between them was studied. These results, using the R^2 values, are shown in Table 6, with the correlations with relatively better values are shown in **bold**.

Table 6 Correlation coefficients (R^2) of selected soil properties as related to run-off and sediment load

	Sediment Load (g)				**Runoff (cm^3)**			
	Run 1		**Run 2**		**Run 1**		**Run 2**	
SOIL PARAMETER	**Bare**	**Palm**	**Bare**	**Palm**	**Bare**	**Palm**	**Bare**	**Palm**
Kaolinite	**- 0.33**	- 0.03	**- 0.24**	**- 0.22**	- 0.15	- 0.06	- 0.11	- 0.02
Swelling Clay	0.02	0.01	<0.01	<0.01	<0.01	- 0.07	0.09	- 0.12
Mica	0.03	- 0.01	0.02	0.08	0.07	0.08	0.17	0.05
Fine sand	**0.22**	**0.34**	**0.20**	**0.37**	- 0.05	0.05	- 0.04	0.01
Very fine sand	0.17	**0.22**	0.18	**0.35**	0.03	0.09	0.11	0.03
Total sand	<0.01	**0.27**	**0.22**	**0.43**	- 0.09	<0.01	<0.01	<0.01
Coarse silt	- 0.01	<0.01	**- 0.25**	- 0.02	0.11	0.02	<0.01	0.05
Fine silt	- 0.03	**- 0.21**	- 0.06	- 0.19	0.14	0.04	<0.01	0.04
Total silt	- 0.03	- 0.11	<0.01	- 0.14	0.17	0.04	0.17	0.06
Clay	- 0.19	**- 0.22**	- 0.12	**- 0.40**	<0.01	- 0.06	- 0.01	- 0.05
Exch. Na	<0.01	- 0.09	0.03	- 0.06	0.10	<0.01	0.15	<0.01
Na/CEC	0.10	0.03	0.14	0.12	0.04	0.02	**0.24**	0.03
CEC	- 0.04	- 0.11	- 0.03	**- 0.23**	0.02	- 0.06	< 0.01	- 0.09
Org. Carbon	- 0.08	- 0.03	- 0.03	**- 0.20**	- 0.04	**- 0.28**	- 0.06	**- 0.22**
CBD-Fe	- 0.06	<0.01	<0.01	<0.01	**- 0.20**	<0.01	- 0.15	0.01
CBD-Al	- 0.09	<0.01	- 0.04	- 0.03	- 0.09	<0.01	- 0.12	0.03
pH (H_2O)	0.02	- 0.04	<0.01	<0.01	**0.22**	0.08	**0.21**	0.02

Sediment load was better correlated with the various soil factors than runoff, and especially so with the fine sand content, and negatively correlated with the kaolinite content. The addition of the palm mats gave a generally good negative correlation with organic carbon.

Discussion

Geotextiles, such as palm mats, have been shown to effectively reduce erosion (Sutherland, 1998a & b). The results from these rainfall simulator experiments supported this, by indicating that the application of palm mats consistently decreased the sediment load in the runoff. The extent of reduction was independent of the sediment load of the uncovered soils and both the least erodible and most highly erodible soils had their sediment load reduced by a similar percentage. The palm mats did not significantly improve water infiltration, however, and even led to slightly increased runoff volumes. However, this could well be a result of difficulty in maintaining consistent soil/mat contact given the size of the soil containers used in the rainfall simulator. Similar findings of inconsistency have been reported from experiments carried out in Belgium (Smets *et al.,* 2008), albeit using slightly larger surfaces (approximately 2 m^2). It is anticipated that this discrepancy will be negated by using larger field plots.

Conclusions

Mats constructed from leaves of the Lala palm reduced the sediment load in the runoff by approximately two-thirds. Palm mats, accordingly, have potential for use in South Africa as a biotechnical soil conservation method effectively conserving soil on sloping lands which may be agricultural land or engineered slopes like road embankments or dam walls, coupled with their ability to act as a mulch through progressive decomposition. The mats, however, do not always decrease runoff volumes.

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' (INCO-CT-2005-510745), funded by the European Commission (EC), Specific Targeted Research Projects (FP6 - STREPs) for Developing Countries (INCO-DEV) Programme. The support is gratefully acknowledged.

Thanks to Anastasia Kgapane, William Mashabane and Martiens Mmamadisha of ARC-ISCW for their assistance with various procedures.

References

ARC-ISCW, 2008. Climate Information System. Agricultural Research Council-Institute for Soil, Climate and Water, Pretoria.

BARTHES, B., AZONTONDE, A., BOLI, B.Z., PRAT, C. & ROOSE, E., 2000. Field-scale run-off and erosion in relation to topsoil aggregate stability in three tropical regions (Benin, Cameroon and Mexico). *Eur. J. Soil Sci.* 51, 485-495.

BOARDMAN, J., PARSONS, A.J., HOLMES, P.J, HOLLAND, R. & WASHINGTON, R., 2003. Development of badlands and gullies in the Sneeuberg, Great Karoo, South Africa. *Catena* 50, 165-184.

BOOTH, C.A., DAVIES, K. & FULLEN, M.A., 2005. Environmental and socio-economic contributions of palm-leaf geotextiles to sustainable development and soil conservation. p. 649-658. *In:* Ecosystems and Sustainable Development. V.E. Tiezzi, C.A. Brebbia, S.E. Jorgensen & D. Almorza Aomar, (eds.). WIT Press, Southampton, UK.

BRADFORD, J.M., FERRIS, J.E. & REMLEY, P.A., 1987. Inter-rill soil erosion processes: I. Effect of surface sealing on infiltration, runoff and soil splash detachment. *Soil Sci. Soc. Am. J.* 51, 1566-1571.

DAVIES, K., FULLEN, M.A. & BOOTH, C.A., 2006. A pilot project on the potential contribution of palm-mat geotextiles to soil conservation. *Earth Surf. Processes & Landforms* 31, 561-569.

D'HUYVETTER, J.H.H., 1985. Determination of threshold slope percentages for the identification and delineation of arable land in Ciskei. M.Sc.(Agric.) dissertation, University of Fort Hare.

FULLEN, M.A., BOOTH, C.A., SARSBY, R.W., DAVIES, K., BHATTACHARYYA, R., POESEN, J., SMETS, T., KERTESZ, A., TOTH, A., SZALAI, Z., JAKAB, A. KOZMA, K., JANKAUSKAS, B., JANKAUSKIENE, A., BÜHMANN, C., PATERSON, D.G., GUERRA, A.J.T., MENDONÇA, J.K.S., ZHENG YI, LI LONGMEI, PANOMTARACHICHIGUL, M., DAO CHAU THU, TRAN HUU CUONG, TRUONG THI TOAN, JONSYN-ELLIS, F., CORKHILL, C., MULHOLLAND, B., & DEARLOVE, M., 2006. The potential contribution of palm mat geotextiles to soil conservation and sustainable development. p. 303-306. *In:* Soil and Water Conservation under Changing Land Use. J.A. Martinez-Casasnovas, L. Pia Sentis, M.C.R. Martin & J.C.B. Solanes (eds.). Universitat de Lleida Press, Lleida, Spain.

GUERRA, A.J.T., MARCAL, M., POLIVANOV, H., SATHLER, R., MENDONÇA, J.K.S., BEZERRA, F., FURTADO, M., LIMA, N., SOUZA, U., FEITOSA, A., DAVIES, K., FULLEN, M.A. & BOOTH, C.A., 2005. Environmental management and health risks of soil erosion gullies in Säo Luis, Brazil and their potential remediation using palm-leaf geotextiles. p. 459-467. *In:* Environmental Health Risk III. C.A. Brebbia, V. Popov & D. Fclyzieva (eds.). WIT Press, Southampton, UK.

IUSS WORKING GROUP WRB, 2006. World Resource Base for Soil Resources, 2nd edn. World Soil Resources Report No. 103. FAO, Rome.

KATO, H., ONDA, Y., TANAKA, Y. & ASANO, M., 2009. Field measurement of infiltration rate using an oscillating nozzle rainfall simulator in the cold, semi-arid grassland of Mongolia. *Catena* 76, 173-181.

KINNELL, P.I.A., 1993. Runoff as a factor influencing experimentally determined inter-rill erodibilities. *Aust. J. Soil Res.* 31, 333-342.

LE ROUX, J.J., MORGENTHAL, T.L., MALHERBE, J., SMITH, H.J., WEEPENER, H.L. & NEWBY, T.S., 2006. Improving spatial soil erosion indicators in South Africa. Report No. GW/A/2006/51. ARC-Institute for Soil, Climate and Water, Pretoria.

LEVY, G.J., 1988. The effects of clay mineralogy and exchangeable cations on some of the hydraulic properties of soils. Ph.D. Thesis, University of Pretoria, Pretoria, South Africa.

MACCAFERRI, 2011. Technical Data Sheet ZAF/TDS/BIOJUTE, *www.maccaferri.co.za* (accessed July 2011). Maccaferri, Pinetown, KZN, South Africa.

MORIN, J., GOLDBERG, S. & SEGINER, I., 1967. A rainfall simulator with a rotating disc. *Trans. ASAE.* 10, 74-79.

NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of standard soil testing methods for advisory purposes. Soil Science Society Southern Africa, Pretoria, South Africa.

RAPP, I., 1998. Effects of soil properties and experimental conditions on the rill erodibilities of selected soils. Ph.D. Thesis, University of Pretoria, Pretoria, South Africa.

ROBERTS, P.J.T., 1983. Development of a master plan for sediment research. Internal Report, Water Research Commission, Pretoria.

ROSNER, T., BOER, R., REYNEKE, R., AUCAMP, P. & VERMAAK, J., 2001. A preliminary assessment of pollution contained in the saturated and unsaturated zone beneath reclaimed gold-mine residue deposits. Water Research Commission Report No. 797/1/01.

SCHIETTECATTE, W., VERBIST, K., JIN, K., GABRIELS, R., HARTMANN, R., CAI, D. & CORNELIS, W., 2002. Sediment load in runoff from small plots: laboratory and field simulation tests on Chinese loess soils. p.155-159. *In:* Proc. 12th Int. Soil Cons. Org. Conf. Vol. 2. 26-31 May 2002, Beijing. Tshinghua University press, Beijing.

SMETS, T., POESEN, J. AND KNAPEN, A., 2008. Spatial-scale effects on the effectiveness of organic mulches in reducing soil erosion by water. *Earth Sci. Rev.* 89, 1-12.

SMITH, H.J.C., 1990. The crusting of red soils as affected by parent material, rainfall, cultivation and sodicity. M.Sc. Thesis, University of Pretoria, Pretoria, South Africa.

SOIL CLASSIFICATION WORKING GROUP, 1991. Soil classification. A taxonomic system for South Africa. ARC-Institute for Soil, Climate and Water, Pretoria.

SUTHERLAND, R.A., 1998a. Rolled erosion control systems for hillslope surface protection: a critical review, synthesis and analysis of available data. I. Background and formative years. *Land Degr. Dev.* 9, 465-486.

SUTHERLAND, R.A., 1998b. Rolled erosion control systems for hillslope surface protection: a critical review, synthesis and analysis of available data. II. The post-1990 period. *Land Degr. Dev.* 9, 487-511.

VAN DER MERWE, A.J., 1995. Wise land use: the basis for sustainable growth and development in South Africa. p. 2-8 *In:* M.C. de Villiers (ed.). Proc. ARC-ISCW "Wise Land Use" Symposium. Sigma Press, Pretoria.

VAN DEVENTER, P.W., 1997. Rehabilitation of gold mine tailings dams. p. 35-39. Proc. Int. Conf. “Problems of anthropogenic soil formation”. Moscow, 16-21 June 1997. Russian Academy of Agricultural Sciences, VV Dokuchaev Soil Institute, Moscow.

VAN RENSBURG, L.D., MABOETA, M.S. & MORGENTHAL, T.L., 2004. Rehabilitation of co-disposed diamond tailings: growth medium rectification procedures and indigenous grass establishment. *Water, Air, Soil Pollution* 154, 101-113.