Beneficial effect of palm geotextiles on inter-rill erosion in South African soils: field trials

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Geotextile mats made of woven palm leaves showed potential using a rainfall simulator for their effectiveness in reducing surface runoff and sediment load from a range of South African soils and mine tailings. This paper advances that research by using field plots to evaluate and quantify the palm mats on a larger scale. Plots at four localities (Bergville, Ladybrand, Roodeplaat and Mabula) were used. Results showed that average runoff under the palm mats decreased by between □□% and 70% at Bergville, and by between 3□% and □1% at Ladybrand, compared to bare soil. Sediment load under the mats decreased by between □□% and 7□% at Ladybrand, and by between 3□% and □9% at Roodeplaat, for three different combinations of slope, mat density and mat mesh size. At Roodeplaat, splash erosion decreased by between 62% and 6□%, while at Ladybrand and Mabula, re-vegetation increased by between 3□% and □□%. Organic carbon content and topsoil surface levels also increased under the mats. Organic, bio-degradable, easy to manufacture geotextiles, such as palm leaf mats, show much potential, especially in combining employment opportunities with enhanced environmental protection in many susceptible areas of South Africa.

Keywords: Inter-rill erodibility; runoff plots; soil and water conservation; palm leaf mats.

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Introduction

Soil erosion by water is a serious problem in many areas of South Africa and one of the methods whereby soil loss due to erosion may be tackled is by using geotextiles on the soil surface. The primary function of placing palm mats (or any similar geotextile) on a bare soil surface is to slow down the amount and flow of downslope runoff, thereby reducing the amount of sediment carried away. If the amount of runoff and sediment loss is reduced, the potential for re-vegetation of the soil surface is increased.

The *Borassus* project (funded by the European Union), which included South Africa as one of twelve participating countries, was initiated to assess the effectiveness of woven palm mats (Fullen, 2009). Such mats were first suggested following work in the Gambia (Davies, 2005), and work carried out in local communities in several countries of the *Borassus* project confirmed that the mats can easily be manufactured by local communities, at relatively low costs (Subedi *et al.*, in press).

Limited work has been done either in South Africa or elsewhere to quantify the effect of such geotextiles, so a range of experiments was carried out to attempt to obtain relevant data. A previous paper (Paterson *et al.*, 2011) dealt with a range of procedures carried out using a rainfall simulator at ARC-Institute for Soil, Climate and Water in Pretoria and showed that, for a range of South African soils (n=20), sediment load was reduced by an average of 65% when the soils were covered by woven mats made from the fronds of palm leaves.

However, the small size of the soil samples used in the rainfall simulator (contained in 350 x 500 x 200 mm boxes) meant that any small variation in the soil surface would lead to a significant variation in results, confirming similar studies carried out in Belgium (Smets *et al.*, 2007). In addition, the fact that the mats are manufactured by hand, with subsequent variation in surface properties, means that, for such a small area, the adhesion to the soil surface can vary and runoff may still occur in places, which can affect results. The next phase of the process to evaluate the palm mats therefore, involved a series of field trials in different areas of South Africa, in order to assess the performance of the mats at a larger scale under natural rainfall and other environmental conditions.

The first field trials to attempt to quantify surface run-off and associated sediment load were prompted largely by the significant soil losses caused by the "dustbowl" conditions under the drought conditions in the United States in the 1930's. The trials took place across twelve states in the mid-West corn belt from the 1930's and 1940's onwards (Wischmeier & Smith, 1965). Despite variations in results from year to year (mainly to the variation in prevailing rainfall), such plots have provided much valuable data to researchers. Most of these trials involved the study of the effectiveness of various types of mulching in croplands, and the data collected from these trials was collated and co-ordinated by the Runoff and Soil Loss Laboratory at Purdue University, Indiana (Wischmeier & Smith, 1965).

The size of run-off plots used in field experiments also varies. From the original American research, the standard size of plot used was 72.6 x 16.4 feet ($\pm$ 22 x 5 m), and the data from these plots were used to calculate the soil erodibility factor in the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965; Wischmeier, 1976). This plot size has thus become widely known as a "Wischmeier Plot". However, many different plots sizes have been used and a review paper (Smets *et al.*, 2008) reported on 41 studies, which include both field and laboratory studies. While laboratory trials (generally using a rainfall simulator) varied from 0.2 m^2 to 0.4 m^2, the field plots varied from 10 m^2 to 300 m^2 (average 52.4 m^2; n=15). The surface treatments on these plots involved a large range of mulch types, such as straw, crop residue, cut grass and woodchips (Smets *et al.*, 2008), on slopes varying from 1% to over 30% and the general finding was that the effective mulch factor (MF, the comparison between rate of soil loss between a bare slope and one covered by a mulch) increased linearly with increasing plot length.

Runoff plots have been established in many parts of the world, such as below erodible logging roads in Australian forestry sites (Croke & Nethery, 2006), in semi-arid grasslands in Mongolia (Kato *et al.*, 2009) and on earth dykes in Israel (Agassi, 1997). A study by Barthes *et al.* (2000) compared plots in three tropical countries, namely Benin (240 m^2), Cameroon (100 m^2) and Mexico (800 m^2) and found that erosion increased and aggregate stability decreased with increasingly intensive cultivation practices. In the Mediterranean area, a similar study by Gonzalez-Hidalgo *et al.* (2007) looked at plots varying from 8 m^2 to 40.3 m^2 in Spain, Italy, Morocco, France and Portugal and the relation between erosion and rainfall. They found that in some cases, up to 50% of annual erosion is caused by only three specific intense daily rainfall events. Bagarello *et al.* (2010) studied rainfall events at an experimental site in Italy where 16 plots (of six different sizes) and 40 microplots (of two different sizes) are laid out on one experimental site near Palermo. Other studies in Spain have also used runoff plots to look at erosion. Castillo *et al.* (1997) found that on a 75 m^2 plot, vegetation removal increased sediment load by 127%, while Desir and Marin (2007) used a 400 m^2 plot over 12 years to show that a rainfall intensity threshold of around 6 mm per event was significant for erosion occurrence.

In South Africa, field plots have been used since the 1940's and 1950's at both the University of Pretoria (Haylett, 1960) and at Glen (du Plessis & Mostert, 1965) to compare runoff between a range of cultivation treatments, while a similar study looked at how no-tillage practices reduced runoff by around 50% at a site in KwaZulu-Natal (Kosgei *et al.*, 2007). Stern (1990) showed for sites at Irene, Potchefstroom, Aliwal North and Piketberg how a surface cover of straw mulch reduced runoff (measured against rainfall) from over 60% for bare soil to less than 10% for mulch-covered soil. At the University of the Free State (Snyman & Opperman, 1984; Snyman & Fouche, 1991), studies into the soil erosion occurring under differing veld conditions in the Free State Province showed that surface runoff increased from 4.75% of rainfall for "good" veld to 10.21% for "poor" veld.

Material and methods

Mat manufacturing

Details of the manufacturing process of the palm leaf mats, as well as their most important properties, were reported in a previous paper (Paterson *et al.*, 2011). The finished mats were laid on the soil surface, being fixed either by sticks, rocks or by tying some of the corners together. The advantages of the palm mats include the fact that they are completely natural and therefore bio-degradable, yet relatively long-lasting and durable, despite being a basic technology. Finally, their mesh-type structure allows the emergence and growth of vegetation on the soil surface.

Research sites

Plots were located in four different provinces of South Africa, namely Potshini, near Bergville (KwaZulu-Natal), Phama, near Ladybrand (Free State), Roodeplaat (two sites with differing slope, 1.5 km apart), near Pretoria (Gauteng) and Mabula, west of Bela Bela (Limpopo). Soil topsoil textures were generally loamy sand to sandy loam, with the soils exhibiting a moderate to strong duplex character associated with susceptibility to erosion. The details of the research sites are given in Table 1.

At each site, the soil surface that was left bare could be compared with the surface covered by the palm leaf mats. At Ladybrand and Bergville, runoff was measured using a tipping bucket connected to a datalogger, while at Ladybrand and Roodeplaat, sediment load was collected in a 25 litre bucket sunk into the ground, from which representative 2 litre samples could be taken, once the runoff had been thoroughly mixed. For the 2009-10 season, at Ladybrand and at Roodeplaat (site 2) the mat density was reduced from 100% (continuous coverage) to 50% (parallel strips), to assess the effect on sediment load and runoff (see Figure 1).

Then, for the second half of the 2009-10 season at Roodeplaat 2, the mesh size of the mats (50% coverage) was cut to a larger size, so that the spaces between the strands approximately doubled (see Figure 2, with the increased mesh size on the left). This had the effect of reducing the average surface cover of each mat from approximately 40% to 30%.

In addition, at Roodeplaat (site 2, 5% slope), for the 2009-10 season, a splash erosion trial was established, using a procedure similar to that described by Bhattacharyya *et al.* (2008), who established trials in Shropshire, UK. According to them, less than 5% of particles detached from the soil surface by raindrop splash action travel more than 50 cm, so that comparatively small areas are adequate to study these effects. Thus, four adjoining areas of approximately 1.5 x 1.5 m each were laid out, of which two were covered with mats, while two were left bare. The plots were separated by a high metal frame, so that no cross-treatment deposition could occur. Cylinders were sunk into the ground, so that approximately 2 cm protruded above ground level (to ensure that no surface runoff could accumulate), and funnels were laid on top, leading to sub-surface collecting bottles inside the cylinders. Measuring bottles, painted white, with a measuring scale on the side, were sunk into the soil, so that the height of the splash erosion could be determined. Again, following every significant rainfall event (or close sequence of events), the samples of splashed water containing sediment were collected, and the height of the splashed particles was measured.

At Mabula, the experimental site was not a run-off plot as such, but mats were laid across the edge of a naturally occurring eroded area. No collections were made, but rate of revegetation was assessed and measuring posts were fixed into the soil so that the topsoil level could be monitored.

Table 1 South African research sites

Site	Co-ordinates	Elevation	AP[a]	Slope/Aspect	Plot Details	Data Recorded	Soil Form/Family[b]	Soil characteristics
Bergville	28°48'45.7"S 29°21'56.7"E	1 316 m	795 mm	5%, SW	22 x 2.5 m	Runoff	Longlands 1000	Orthic A on E on Soft Plinthic B Topsoil texture: 7% clay, 15% silt, 78% sand
Ladybrand	29°10'21.5"S 27°24'55.0"E	1 655 m	676 mm	5%, N	22 x 2.5 m	Runoff, Sediment Load, Re-vegetation	Estcourt 1200	Orthic A on E on Prismacutanic B Topsoil texture: 9% clay, 31% silt, 60% sand
Roodeplaat (Site 1)	25°36'06.1"S 28°21'50.0"E	1 130 m	641 mm	5%, N	10 x 2.5 m	Sediment Load	Sepane 1110	Orthic A on Pedocutanic B on unspecified material with wetness Topsoil texture: 22% clay, 20% silt, 58% sand
Roodeplaat (Site 2)	25°35'18.9"S 28°21'03.7"E	1 162 m	641 mm	2.5%, SW	10 x 2.5 m	Sediment Load Splash erosion	Westleigh 1000	Orthic A on Soft Plinthic B Topsoil texture: 17% clay, 22% silt, 61% sand
Mabula	24°43'03.3"S 27°53'21.1"E	1 192 m	628 mm	3%, NW	8 x 4 m	Topsoil level, Re-vegetation	Westleigh 1000	Orthic A on Soft Plinthic B Topsoil texture: 12% clay, 4% silt, 84% sand

[a] AP = Annual Precipitation
[b] Soil Classification Working Group, 1991

Table 2 Sediment load results from research sites

Site	Plot Details	Mat Coverage	Period (month/year)	Rainfall (mm)	No. of Samples	Sediment Load (Average)		Factor (Mats/Bare)
						Palm Mats	Bare Soil	
Ladybrand	22 x 2.5 m,	100%	11/2008 – 03/2009	347	8	6.28 g	25.35 g	0.247
	5% slope	50%	10/2009 – 04/2010	660	11	8.67 g	18.60 g	0.466
Roodeplaat 1	10 x 2.5 m,	100%	10/2008 – 05/2009	683	20	3.33 g	61.24 g	0.054
	5% slope	50%	09/2009 – 01/2010	454	11	2.58 g	25.29 g	0.102
Roodeplaat 2		100%	10/2008 – 05/2009	683	20	0.81 g	3.64 g	0.223
	10 x 2.5 m,	50%	09/2009 – 01/2010	454	11	1.97 g	6.15 g	0.320
	2.5% slope	25%*	01/2010 – 05/2010	330	8	3.49 g	5.62 g	0.621

* Mats remained *in situ*, mesh size increased by ±50%

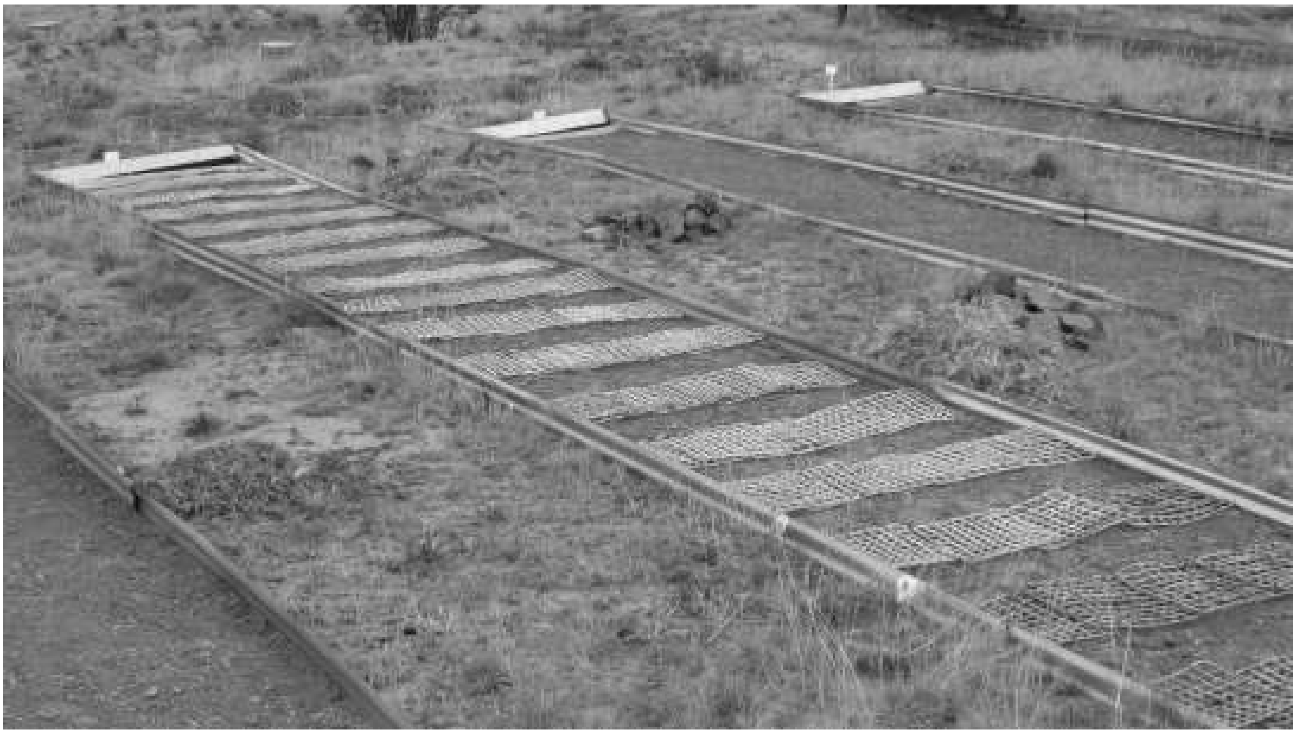

Figure 1 Plot layout showing variation in mat density

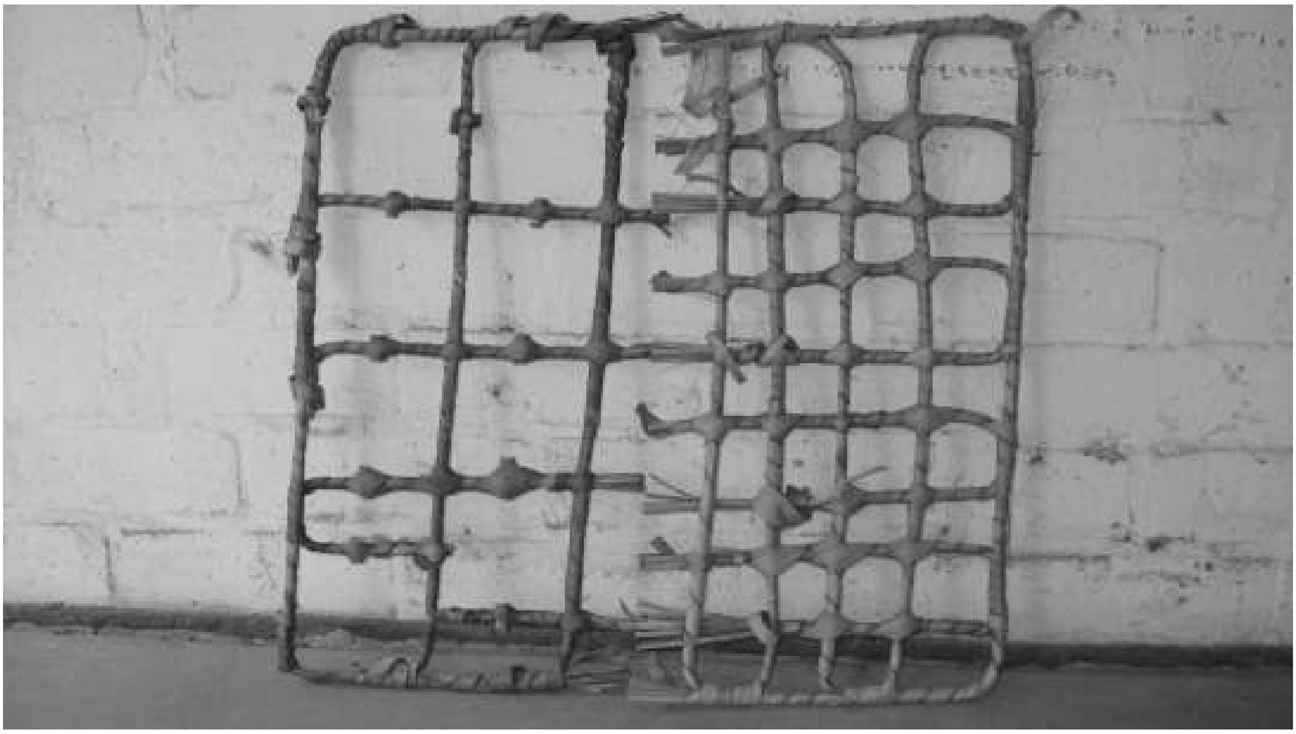

Figure 2 Palm mat showing increased mesh size on left, normal on right

Results

Runoff

Runoff data was obtained at two sites, namely Bergville and Ladybrand, comparing bare soil plots with those covered by the palm mats. At Bergville, the data covers the period September 2006 to March 2007 and January to April 2008 (some data was lost due to problems with the dataloggers). For the 2006-07 season, 361 mm of rain was recorded and the number of tips from the palm mat-covered plot was 776, compared with 1 396 tips for the bare plot, a factor of 0.465.

There was a consistent relationship between the number of tips from the "bare" and "palm" plots for each rainfall event, with an r^2 value of 0.92. For the first four months of 2008, 331 mm of rain fell, and the comparable number of tips was 894 for the bare plot, with only 266 for the palm mat-covered plot, a factor of 0.297. The relationship between the number of tips from the "bare and "palm" plots was not quite as clear as for the previous season, but still acceptable with an r^2 value of 0.77.

For the period February-April 2008, it was also possible to record the data from the third (grass-covered) plot, where 187 tips were recorded, so that the factor compared to the palm plot for the same period was 0.703, while the factor between the grass plot and the bare plot was 0.209. This confirms that palm mats made a meaningful difference in runoff control and that the difference between the grass coverage and the palm mat coverage was reasonable, with 35% more runoff recorded, as opposed to more than five times more runoff for the bare plot. If the results for both seasons are combined, 1 239 tips were recorded for the palm plot, while 3 018 tips were recorded for the bare plot, a factor of 0.411.

At Ladybrand, runoff data was obtained for both the 2008-09 and 2009-10 seasons. However, for the latter season, it was decided to reduce the mat density from 100% to 50% (a series of parallel strips, as shown in Figure 2) to see if any significant difference could be observed.

For the 2008-09 rainy season, where 347 mm precipitation was recorded, the number of tips from the palm mat-covered plot was 594, compared with 1 009 tips for the bare plot, a factor of 0.589. There was again a consistent relationship between the number of tips from the "bare" and "palm" plots per rain event, with an r^2 value of 0.869. For 2009-10 (50% mat coverage), 660 mm precipitation was recorded and the number of tips from the palm mat-covered plot was 2 778, compared with 4 446 tips for the bare plot, a factor of 0.625 (compared to 0.589 for the previous season). The relative similarity of this figure would suggest that the 50% reduction in mat coverage did not have a significant effect on the relative effectiveness of runoff control. Despite the heavier rainfall of the latter season, which led to higher levels of runoff, the relationship between the "bare" and "palm" plots remained very similar, suggesting that parallel strips of mats are almost as beneficial as full surface coverage .

Sediment load

Sediment load was measured at both Ladybrand and Roodeplaat for both the 2008-09 and 2009-10 seasons, but at both locations, the mat density was reduced from 100% to 50% for the second season. The results are shown in Table 2.

There is a consistent reduction in sediment load from the plots covered with palm mats, which ranges from a factor of 0.054 (season 1 at Roodeplaat site 1) to 0.621 (second half of season 2 at Roodeplaat site 2). At Roodeplaat, sediment load increased with slope angle of the plots, from an average of 0.81 g per 2 *l* runoff for site 2 (2.5% slope, 17% clay) to 3.33 g for site 1 (5% slope, 22% clay). Halving the mat density (from 100% to 50% surface cover) had mixed results. At Ladybrand (5% slope, 9% clay), the average amount of sediment increased by 41% while at Roodeplaat site 2 (2.5% slope) it more than doubled. At Roodeplaat site 1 (5% slope), when the mat coverage was halved the average sediment load actually decreased by 29%. This might be due to the corresponding lower rainfall (33% less), but that would not necessarily affect the average sediment load per rainfall event, as crusting and rainfall intensity could both play a role.

The enlarged mesh size at Roodeplaat site 2 had the effect of increasing average sediment load by more than 75% (1.97 g to 3.49 g per event, on average) compared to the "normal" mesh size at 50% mat density, suggesting that to increase the mesh size would have a detrimental effect on both the absolute and relative amount of sediment load. This finding is supported by additional rainfall simulator trials carried out using four other soils from Roodeplaat, where increasing the mesh size produced between 17% and 390% more sediment load (Paterson *et al.*, 2011).

Splash erosion

This was investigated at site 2 at Roodeplaat and, as expected, the presence of palm mats had a significant effect on both the amount of sediment detached (factor of 0.376) and the height to which it was splashed (factor of 0.288), compared to bare soil (Table 3). Creating larger mesh holes (as previously described) increased the average amount of sediment slightly, with the factor for average sediment load per rain event between palm mats and bare soil increasing to 0.319, while the average splash height increased significantly, from 2.5 cm to 6.8 cm.

Re-vegetation

Measurements were made at both Ladybrand and Mabula to compare the amount of vegetation recorded on the palm mat-covered plots compared to the bare plots. At Ladybrand, all the plots were cleared of vegetation at the start of each season, and the vegetation cover on the mat-covered plot at the end of the 2008-09 season was 53%, while for the bare plot it was 33%, a factor of 0.62. For the 2009-10 season (with 50% mat coverage, but significantly more rainfall), the comparable figures were 74% for the mats and 50% for the bare plot, a factor of 0.68.

At Mabula, where the bare soil area had been severely eroded, with almost total loss of topsoil, the vegetation coverage was measured in May 2009. This represented the combined 2007-08 and 2008-09 seasons, for which period the mats had lain undisturbed. Following rainfall for these two seasons of 820 mm and 660 mm respectively, the area under palm mats had more than double the vegetation cover of the bare soil, a factor of 2.35. In addition, the topsoil organic carbon level under the palm mats had increased from the original value of 0.48% (November 2006) to between 0.75% and 0.92% (May 2009), while the values in the eroded area were between 0.35% and 0.37%. This increase was accompanied by a physical gain of topsoil, measured by marker posts stuck into the ground, where the surface level of the bare soil area under the palm mats showed an increase of between 3.5 and 5.0 mm, compared to a 2.0 mm fall in the level of the bare soil area. Given the prevailing severe erosion, this ability of the mats to trap "new" topsoil and to encourage re-vegetation is especially encouraging.

Table 3 Splash erosion, Roodeplaat 2, 2009-10

Plot Details	Mesh Size	Period	Rainfall (mm)	Sediment (Average)		Factor (Mats/Bare)	Splash Height (Average)		Factor (Mats/Bare)
				Palm Mats	Bare Soil		Palm Mats	Bare Soil	
10 x 2.5 m, 2.5% slope	Normal (n=20)	09/2009 – 01/2010	454	2.54 g	6.75 g	0.376	2.50 cm	8.67 cm	0.288
	Increased (n=16)	01/2010 – 05/2010	330	2.73 g	8.55 g	0.319	6.78 cm	14.27 cm	0.475

Table 4 Runoff results from various countries in the *Borassus* project

Country		Environment	Slope (%)	Material	Reduction	Reference
RSA	Bergville	Research Plot	5	Palm Mats (SA)	45-70%	
	Ladybrand	Research Plot	5	Palm Mats (SA)	38-41%	
Lithuania		Roadside plots on dunes	35	Palm Mats (Brazil/Gambia)	95%	Jankauskas *et al.* (2008)
Hungary		Orchards and Vineyards	8	Palm Mats (Brazil/Gambia)	25%	Kertész *et al.* (2007)
UK		Research Plot	7	Palm Mats (Brazil/Gambia)	83%	Bhattacharyya *et al.* (2008)
Vietnam		Subsistence Agriculture	33-44	Maize Stem Mats	73%	Fullen (2009)
China		Research Plots	5 & 9	Rice Straw Mats	87%	Xing Xiang-xin *et al.* (In press)
Thailand		Subsistence Agriculture	30 & 100	Bamboo Mats	57%	Bhattacharyya *et al.* (2011)

Discussion

The beneficial effects of the palm mats, as shown from the various field sites in South Africa, are comparable to results of field plot tests carried out in other countries (with varying slopes and rainfall intensities) over a similar period, as part of the wider *Borassus* project (Table 4). In order to utilise locally available materials that communities had available to create their own mats, a range of naturally occurring materials was used, and each experiment showed a reduction in runoff.

Table 4 shows that all the materials (palm leaves, maize stems, rice straw or bamboo) used to make mats had beneficial effects, over a wide range of research sites. These sites included both naturally occurring areas and specially constructed plots, but the principles of geotextile mats remained virtually the same, even with the variation in material of construction and in the test site. Geotextiles, such as palm mats, have been shown to effectively reduce erosion. The advantages include: a reduction in the amount of surface runoff and consequently a reduction in the sediment load of the runoff; reduction in particles detached by raindrop splash action; increased infiltration as shown by the improved re-vegetation under the palm mats.

The reduction in mat density in the 2009-10 season from 100% to 50% at Ladybrand and Roodeplaat had an effect on the runoff and sediment load, but the reduction was less than might have been expected from the equivalent decrease in mat density. When the mesh size of the mats, which was originally approximately 5 x 5 cm, was increased to approximately 10 x 10 cm (Figure 2) at Roodeplaat (site 2), the average amount of sediment load increased by 77%. This suggests that the greater mesh size would not be effective, although the amount of sediment detached by splash erosion only increased by 26%. In addition, this was on the more gently sloping of the two plots (2.5%), so the loss of sediment would be expected to be even more severe on steeper slopes, where runoff speeds would be greater.

These mats also have several advantages over other synthetic surface coverings. They are completely biodegradable, yet relatively long-lasting (one to two rainfall seasons under South African conditions have been observed before the mats start to disintegrate completely) and generally adhere quickly to the soil surface following the first significant rainfall event. The mesh form allows plant shoots to emerge between the strands, unlike other, “sheet-like” materials, where the small mesh size means that in some cases, the vegetation pushes the textile up from the surface, thus still allowing surface runoff.

The mats are a very simple, easily manufactured product that can provide both an income and an advantage to the environment of the local community in many disadvantaged areas of South Africa. In South Africa, training carried out in KwaZulu-Natal suggested that local people, who have a tradition of weaving, could produce 1-2 m^2 of mats per day for approximately R75 (Subedi *et al.*, in press). If funding or sponsorship could be found for such a project, it could play a valuable role in poverty alleviation, while providing means for environmental protection.

Conclusion

Through this study and the previous paper (Paterson *et al.*, 2011), the efficacy of the palm mats in reducing erosion has been shown. While almost any form of plant material placed on the soil surface will have a beneficial effect on soil retention, due to the intensity of many of the rainfall events in South Africa, it is generally not feasible to use loose materials, such as branches, which are readily detached. The woven nature of the mats, with the subsequent increase in coherence, means that they can be easily fixed in place using any available means, such as sticks, stones or pegs. Their use would seem to hold great promise for soil conservation in many parts of South Africa.

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