TOPIC 6
SOIL CONSERVATION AND SOIL QUALITY

Effects of Palm-mat Geotextiles on the Conservation of Loamy Sand Soils in East Shropshire, UK

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Abstract

Some 30% of world arable land has become unproductive, largely due to soil erosion. Considerable efforts have been devoted to studying and controlling water erosion. However, there remains the need for efficient, environmentally-friendly and economically-viable options. An innovative approach has used geotextiles constructed from *Borassus aethiopum* (Black Rhun Palm of West Africa) leaves to decrease soil erosion. The effectiveness of employing palm-mats to reduce soil erosion have been investigated by measuring runoff, soil loss and soil splash on humid temperate soils. Twelve experimental soil plots (each measuring 1.0 x 1.0 m) were established at Hilton, east Shropshire, UK, to study the effects of geotextiles on splash erosion (six plots completely covered with Borassus mats and six non-protected bare soil plots). Soil splash was measured (10/06/02-09/02/04; total precipitation = 1038 mm) by collecting splashed particles in a centrally positioned trap in each plot. An additional field study (25/03/02-10/05/04; total precipitation = 1320 mm) of eight experimental runoff plots (10 x 1 m on a 15^{o} slope) were used at the same site, with duplicate treatments: (i) bare soil; (ii) grassed, (iii) bare soil with 1 m palm-mat buffer zones at the lower end of the plots and (iv) completely covered with palm-mats. Runoff volume and sediment yield were measured after each substantial storm. Results indicate that total splash erosion in bare plots was 34.2 g m^{-2} and mean splash height was 20.5 cm. The use of Borassus mats on bare soil significantly ($P<0.05$) reduced soil splash height by ~31% and splash erosion by ~50%. Total runoff from bare plots was 3.58 L m^{-2} and total sediment yield was 8.58 g m^{-2}. Thus, application of geotextiles as 1 m protective buffer strips on bare soil reduced runoff by ~36% and soil erosion by ~57%. Although total soil loss from the completely covered geotextile plots was ~16% less than the buffer zone plots, total runoff volume from the completely covered plots was ~94% more than the buffer zone plots. Thus, palm-mat (buffer strips) cover on vulnerable segments of the landscape is highly effective for soil and water conservation on temperate loamy sand soils.

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Introduction

Soil erosion has been defined as the process of detachment and transportation of soil material by erosive agents (Ellison, 1947). Raindrop impact has long been recognized as a major erosive agent (Ellison, 1944; Ekern, 1950). The impact of raindrops leads to the restructuring of the soil surface, for example by aggregate breakdown and crust formation (McIntyre, 1958; Moss, 1991; Le Bissonnais, 1996). The impact can also detach and transport soil fragments (Ellison, 1944; Moss and Green, 1983; Bradford and Huang, 1996). These two phenomena correspond to a splash event, that is, the simultaneous splatter of water and soil fragments following the impact of raindrops on the soil surface. The detachment and transport of soil particles ensuing from the impact of raindrops, or splash for short, is usually an important first step in the chain of processes leading to soil loss and subsequent sediment transport. Falling raindrops are able to detach much more soil than unconcentrated overland flow, after which detached particles may be entrained and transported by flowing water (Hudson, 1995). In addition, splash may result in significant net transport of sediment on sloping soils (Moeyersons and de Ploey, 1976; Wan et al., 1996).

Splash detachment rate has been related to rainfall kinetic energy, soil type, grain size (de Ploey and Savat, 1968; Sharma et al., 1991) and the thickness of the water layer at the soil surface (Moss and Green, 1983; Kinnell, 1991). Splash transport has been related to slope gradient (Savat, 1981; Planchon et al., 2000), grain size (Poesen and Savat, 1981) and raindrop characteristics (Riezebos and Epema, 1985). The kinetic energy of raindrop splash increases, resulting in increased soil detachment. Hydraulic surface flow increases with deficient vegetation cover, which also increases soil susceptibility to erosion, by reducing cohesion and shear strength (Rickson, 2001). Smith and Wischmeier (1962) pointed out that soil properties that influence soil erodibility by water may be grouped into two types: (i) those properties that affect infiltration rate and permeability, and (ii) those properties that resist the dispersion, splashing, abrasion and transporting forces of rainfall and runoff. Hence, management strategies should aim to improve soil physical and hydrological properties (Fitzgerald et al., 1998).

Considerable efforts have been devoted to studying and controlling water erosion (Lyle and Smerdon, 1965; Pimentel et al., 1987; Brooks and Brierley, 1997; Lu et al., 2001). On a near-vertical slope to provide protection at the foot of a steep shale slope, engineers used cellular confinement to promote vegetation cover and prevent erosion (Hogan and Zeinert, 1998). Vegetation growth on problematic slopes often encounters problems, such as absence of initial binding material in the soil and runoff erosion. In such conditions, geotextiles protect soil and seeds in the initial stages of vegetative growth.

Geotextiles have contributed to the erosion control industry for over 50 years (Dayte and Gore, 1994; Mitchell et al., 2003) and are mainly used in civil engineering projects, such as dam retaining walls, bases for roads and reservoir slope stabilization (Davies, 2000). They can provide instant rain splash and runoff control, creating a stable non-eroding environment (Mitchell et al., 2003). Geotextiles constructed from organic materials are highly effective in erosion control and vegetation establishment, in spite of the fact that synthetic geotextiles dominate the market (Langford and Coleman, 1996; Ogobe et al., 1998). Studies have shown that natural fibres were more effective than synthetic in controlling erosion (Sutherland and Ziegler, 1996) and were the preferred method because of their 100% biodegradability and better adherence to the soil (Langford and Coleman, 1996). Synthetic geotextiles are polymeric materials and are likely to cause soil pollution. Furthermore, their production process also cause air and water pollution. Moreover, natural fibres are less costly and easily available in many parts of the world, which make them a better choice than synthetic fibres. The ability of natural fibres to absorb water and degrade with time are the prime properties that give natural geotextiles an advantage over synthetic geotextiles for slope stability applications.

In order to reduce erosion problems in a manner compatible with the principles of sustained agriculture and at minimum cost, techniques involving the use of indigenous plant material should be effective and affordable. Geotextiles create a stable, non-eroding environment and, if constructed using indigenous materials, they could be effective, affordable and compatible with sustainable land management. Jute is fast becoming the market leader in organic geotextiles and is being promoted for its economic advantages in terms of cheaper costs and availability compared with other natural fibres, such as coir, sisal and ramie (Ranganathan, 1992). Palm-mats have the potential to conserve soil in specific targeted applications, such as gully control on urban slopes (Davies et al., 2002) and reduction in sediment yield when used as buffer strips (Davies et al., 2006). Palm-mat geotextiles provide a potential soil conservation technique for promoting sustainable agriculture and soil stabilization.

Geotextile mats constructed from the leaf of *Borassus aethiopum* (Black Rhun Palm of West Africa), were termed Borassus mats. Geotextile palm-mats can also be constructed from the leaf of *Mauritia flexuosa* (Buriti Palm of South America and termed Buriti mats). The genus *Borassus* is one of the most widely distributed of the Palmae, with a range extending from West Africa to Indonesia. They grow to 30-35 m height with ~30-40 palmate fronds. One leaf is produced each month and they naturally shed 12-14 fronds annually (Davis and Arulpragasam, 1986). If harvested correctly, the *Borassus* leaf is highly sustainable and readily available in many tropical semi-arid and sub-humid regions. They are biodegradable, providing organic matter content to stabilize soil and their permeability makes them suitable for use with cohesive soils. There is no high-energy production procedure needed in the manufacturing process (Davies et al., 2006). The mats could be constructed at an economically viable price of €0.25-0.40 per square metre, which is comparable in price to other geotextiles (Davies et al., 2006). When used in their natural environment, the mats may provide a cost-effective technique of reducing soil erosion in poorer regions of the world (Davies et al., 2006).

Available studies do not allow quantification of the effectiveness of palm-mat geotextiles in decreasing water erosion (soil splash erosion and sediment yield).

We have investigated the effectiveness of employing palm-mat geotextiles as a potential soil conservation technique.

Materials and methods

Site

Investigations were conducted at the Hilton Experimental Site, east Shropshire, U.K. (52.0°33'5.7" N, 2.0°19'18.3" W; NGR SO778952), within the southern section of the Worfe Catchment, a tributary of the mid-Severn (Fullen and Reed, 1986). The site has been used extensively for erosion studies since 1976 (Fullen, 1998). The region experiences a temperate climate with a mean annual precipitation of 620.0 mm (SD = 104.9, n = 15 years). In most of the area the Permo-Triassic sandstones are overlain by a suite of glacial and proglacial sediments (Hollis and Reed, 1981). Most soils belong to the Newport and Bridgnorth Associations, which total 2593 km^2, equivalent to 1.7% of the surveyed area of England and Wales (Soil Survey of England and Wales, 1983).

Splash erosion

The soil of the splash erosion site is loamy sand, with a typical Ap horizon texture of 79.8% sand (2000-60 µm), 14.8% silt (60-2 µm), 5.4% clay (<2 µm) and soil organic matter content of 1.9% (Fullen and Brandsma, 1995). Twelve plots were established to study the effects of Borassus mats on splash erosion. Each individual plot was 1 m^2 (1.0 x 1.0 m). Using random selection, six plots were completely covered with Borassus mats, and the other six plots were left non-protected (bare soil) with arrangements provided for splash data monitoring. The scheme of the splash experiment is presented in Figure 1. The soil was prepared by rotavating and removing grass turfs and raking the surface. All plots were maintained in a bare condition by regular 'RoundUp' ((isopropylamine salt of N-phosphonomethyl glycine) herbicide treatments. Splash height was measured (cm, with a scale). Soil splash was measured in each plot by collecting splashed particles in a centrally-positioned trap during 10/06/2002-09/02/2004. Each trap consisted of a 15.2 cm diameter circular tube inserted into the soil, containing a similar-sized funnel on top of a 1 L bottle. They were installed 1 cm above the soil surface, thus only allowing splashed soil particles to enter. Comparable splash traps have been used by Poesen and Torri (1988). The splashed particles were carefully washed off from sticky plastic pegs and plastic funnels. The collecting bottles were emptied after substantial storms and trapped fauna removed using a 2.0 mm sieve in the laboratory, then the splashed particles were dried overnight at 40°C and weighed.

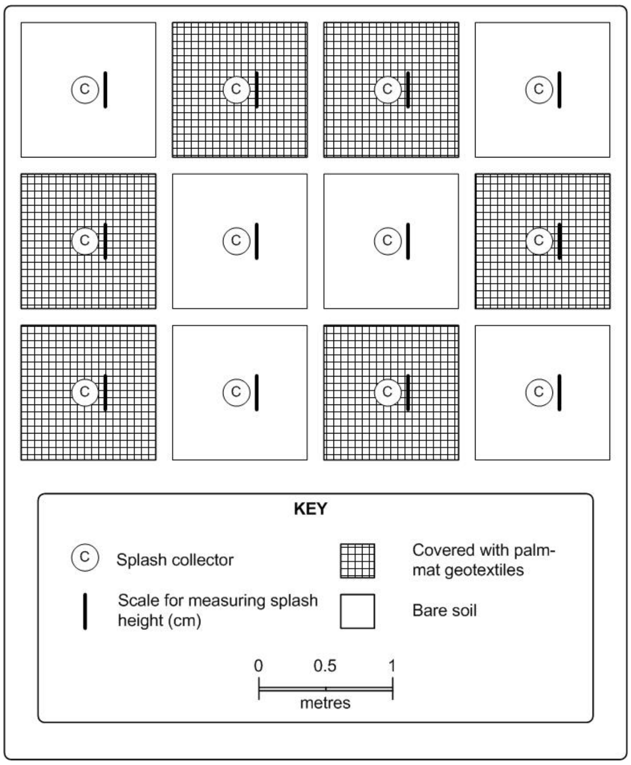

Fig. 1: Schematic plan of test plots of the splash experiment at Hilton, East Shropshire, UK.

Runoff plots

Eight runoff plots (situated on a 15° south-west facing slope, numbered D1-D8 and measuring 10 x 1 m) were established to study the effectiveness of palm-mat geotextiles on runoff volume and soil loss. The scheme of the runoff plots is presented in Figure 2. Using random selection, plots D2 and D8 were completely covered with Borassus mats, D4 and D5 had 1 m buffer zones of Borassus mats at the plot lower end, D1 and D6 were the bare soil (control) plots and D3 and D7 were grassed plots. The plots were bordered with black plastic lawn-trim, with 10 cm intruding into the soil and 10 cm protruding above the soil. Prior to observations, the bare (control) and treated plots were rotavated to ~20 cm depth and treated with 'RoundUp' herbicide to remove vegetation. Runoff volume and sediment yield were measured from 25/03/02-10/05/04. Runoff was measured to the nearest ml, while sediment yield was measured by weighing containers, oven-drying runoff overnight at 40°C, then reweighing the containers. This was performed regularly, usually every two weeks or after a substantial storm.

This work is being revalidated with another set of experiments that include: (i) another set of runoff volume, splash erosion and sediment yield data using Borassus and Buriti mats (2007-2009) and (ii) analyses of soil samples (10 per plot) to determine changes in soil physico-chemical properties and aggregate stability in response to treatments.

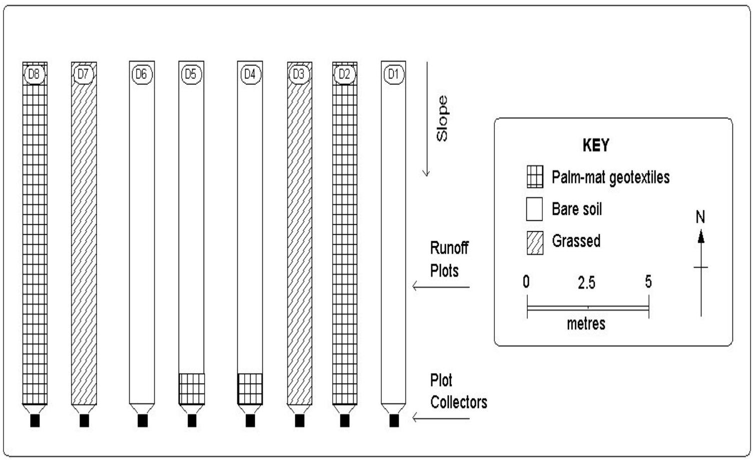

Fig. 2: Schematic plan of the runoff plots at Hilton.

Statistical analysis

Anderson-Darling's normality test was carried out to observe the normality of splash height and soil splash erosion data for both bare and covered plots. On that basis, Mann-Whitney tests were employed for splash height and splash erosion data to study differential responses to erosive processes.

Table 1: Effect of palm-mat geotextiles on soil splash erosion for the plots (area of each plot = 1 m^2) at the Hilton Experimental Site (10/06/02-09/02/04).

Parameters	Splash erosion (g m^{-2})		Splash height (cm)	
	Bare plots	Covered plots	Bare plots	Covered plots
*Total	34.2	17.1	-	-
Mean	1.90	0.95	20.5	14.1
Minimum	0.14	0.10	8.3	2.0
Maximum	9.60	4.11	37.0	33.7
Standard deviation	2.27	0.54	9.2	2.4
Standard error of mean	1.24	0.29	11.6	3.1
Number of observations	18	18	14	14
Mann-Whitney test (Bare vs. Covered)	Not significant (P = 0.062)		Significant (P<0.05)	

*Precipitation during the experiment = 1038.3 mm.

Results

Splash erosion

The initial investigation consisted of 14 observations of soil splash height and 18 observations of splash erosion weight (10/06/02-09/02/04). The results showed that covered plots had ~50% less total splash erosion than bare plots (34.2 g m^{-2}) (Table 1). Comparatively, mean splash height from geotextile-covered plots

(14.1 cm) was significantly ($P<0.05$) less than the bare plots, by ~31% (Table 1). During the first year of measurements (n = 12), mean splash erosion of the covered plots (0.95 g m^{-2}) was ~27% less than the bare plots. However, in the next year (n = 6), there was a mean decrease of ~49%. It was the same case with splash height. Splash heights were ~27 and 52% lower in the first and second year of the study, respectively, in the covered plots than the bare. Both splash height and erosion in the geotextiles-covered plots decreased at a greater extent in the second year compared with the first year. Thus, covering the bare plots with Borassus mats was very effective in reducing splash erosion, as splash height and amount of soil splashed from geotextiles-covered plots were less than those of bare plots with time.

The relationship between splash height (cm) and amount of soil splashed (g m^{-2} area) for the bare plots was significant ($R^2 = 0.76$, n = 14, P <0.001, df = 12) (Fig. 3). The soil splash erosion per unit area (here 1 m^2) increased significantly ($P<0.05$) with increasing soil splash height (cm) at a rate of ~0.13 g cm^{-1}. However, although results indicate that covering bare plots with Borassus mats was effective in reducing splash height, there was no significant relationship between splash height and splash erosion ($R^2 = 0.08$, n = 14, P = 0.33). The same relationship was also insignificant for all (bare and covered) plots ($R^2 = 0.11$, n = 28, P = 0.18).

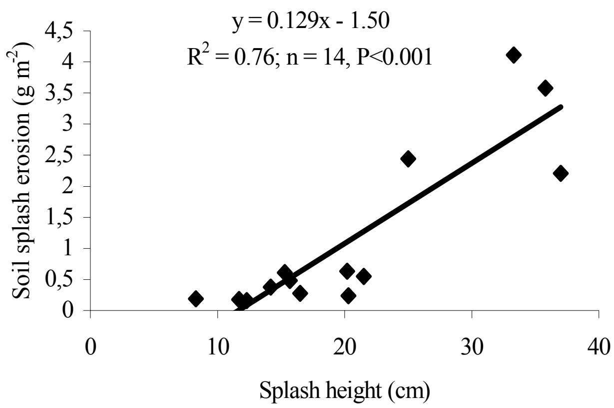

Fig. 3: Relationship between splash height and amount of soil splashed at Hilton for the bare plots.

Runoff volume and sediment yield

Results from runoff plots showed that during the experimental period total runoff from the buffer zone plots (22.92 L) was ~36 and 19% less than those of the bare plots and permanent grass plots, respectively (Table 2). Application of Borassus mats as complete cover on bare soil increased runoff by ~24% over bare soil. Total runoff as a per cent of precipitation for the bare plots was higher than both the grassed and buffer (0.17%) zone plots, but was less than the completely covered plots.

Table 2: Mean runoff and soil erosion rates for the plots at the Hilton Experimental Site (n = 30; 25/03/02-10/05/04).

	Bare (D1 + D6)	Grass (D3 + D7)	Buffer (D4 + D5)	Covered (D2 + D8)
*Total runoff (litres)	35.83	28.24	22.92	44.45
	(78)	(110)	(103)	(90)
Total runoff (mm depth)	3.58	2.82	2.29	4.45
Total runoff as a % of precipitation	0.27	0.21	0.17	0.34
Total sediment yield (g)	85.79	13.04	37.16	31.22
	(116)	(69)	(135)	(93)
Soil loss equivalent (t ha^{-1})	0.09	0.01	0.04	0.03

*Precipitation during the experiment = 1319.8 mm. Data in parentheses indicate Coefficient of Variation (%).

Total sediment yield in the buffer zone plots was ~57% less than that of bare plots (85.79 g). Mean total soil loss equates to ~0.09, 0.01, 0.04 and 0.03 t ha^{-1} from the bare plots, permanent grass plots, buffer zone (of Borassus mats) plots and completely covered (by Borassus mats) plots, respectively (Table 2). Although total soil loss from the geotextile completely covered plots was ~16% less than the buffer zone plots, runoff from the buffer zone plots was ~94% less than that of the completely covered plots. This indicates that use of 1 m buffer zones (of palm-mat geotextiles in bare plots) is very effective for soil and water conservation.

Discussion

Splash erosion

Results suggest that palm-mat geotextiles are effective in reducing splash erosion (both splash height and amount of splashed soil). The low splash height and amount of splashed soil of the covered plots reiterates the importance of retaining protective cover on sloping land, as geotextiles serve as protective barriers that dissipate the impact of raindrop kinetic energy. As geotextiles become wet they expand to the soil surface, enhancing drapability (adherence to surface microtopography) and, hence, runoff and erosion control (Sutherland and Zieger, 1996). Following intense rainfall, fine sediment was visible, trapped by the palm-mats, resulting in decreased splash erosion, as found by Mitchell et al. (2003). Geotextiles may also improve soil organic matter and, thus, improve topsoil structure and aggregate stability, thereby decreasing splash erosion.

Runoff volume and sediment yield

The low runoff and sediment yield of the grass plots confirms the importance of retaining protective vegetative cover on sloping land. This is because grass swards serve as protective barriers that dissipate raindrop kinetic energy. The swards also offer a source of organic matter to bind soil particles and the dense network of grass roots aids the retention of topsoil structure and aggregate stability and promotes infiltration (Fullen and Booth, 2006). The sward root network binds soil particles together, thereby decreasing erodibility and improving stability against slope failure. Melville and Morgan (2001) also reported that grass strips resulted in significantly ($P<0.05$) decreased runoff and soil loss on an erodible sandy loam soil in Bedfordshire, UK.

Apart from reducing the amount of splash erosion, the presence of geotextile netting on the slope controls surface erosion in several ways: (i) surface runoff is divided into a number of smaller paths, due to the numerous obstructions caused by the presence of netting, thus decreasing the overall damaging impact of flowing water. (ii) Soil and seeds are thereby preserved in place, providing increased chances of germination and vegetation growth (Pillai, 1994). Furthermore, the net of geotextiles increased infiltration with their saturation and reduced water flow by creating a network of small microdams, which further increased infiltration. Other studies conducted on runoff and erosion control support these findings. Geotextiles have proved effective in reducing soil erosion compared to bare soil surfaces (Sutherland and Ziegler, 1996; Langford and Coleman, 1996). Field experiments at Hilton, comparing the effectiveness of different treatments in controlling sediment yield, revealed jute-net had only 1.4% of the sediment yield from bare plots, while jute-mat had 1.1% (Mitchell et al., 2003). Erosion rates of ~0.1-0.5 t ha^{-1} yr^{-1} were much less than the 1-2 t ha^{-1} yr^{-1} considered tolerable on British arable soils (Morgan, 1986). The low rates even on bare plots were mainly due to low weekly rainfall amounts during the study period.

The presence of mats might have resulted in decreased time for water infiltration and, hence, there was increased runoff from completely covered plots, compared with bare and buffer-strip plots. The results also showed that buffer strips of Borassus mats significantly reduced soil loss compared with bare soil and were as effective as complete cover of the same mats. Despite physical protection and sediment entrapment, buffer zones of Borassus mats may significantly alter flow direction, thus creating several cross-drains. The rate of sediment transfer to cross-drains may be significantly reduced, due to infiltration and reduced flow speed and total flow volume. It is expected that reduced flow speeds will lead to sediment deposition within the small micro-dams. Wet networks of mats should then bind recently deposited sediment, thus effectively conserving soil on site. Vegetative buffer strips to trap sediments are an integral part of management practice in the UK. For example, in a study of vegetative buffer strips used in UK agriculture, surface runoff was reduced by a factor of six and soil loss was effectively eliminated (Jones, 1993). However, the use of non-vegetative buffer strips for effective interception of sediment has not been widely studied.

Conclusions

The results of two years of investigation indicate that the use of geotextiles constructed from palm (*Borassus aethiopum*)-leaf on bare soil significantly reduced soil splash height by ~31% and splash erosion by 50%. Results from the runoff experiment suggest that application of palm-mat geotextiles as 1 m protective buffer strips on bare soil reduced runoff by ~36% and soil erosion by ~57%. Erosion rates equated to 0.09 t ha^{-1} from bare soil, 0.01 t ha^{-1} from grassed plots and 0.04 and 0.03 t ha^{-1} from both the covered and buffer zone plots, respectively. Though total soil loss in the geotextile completely covered plots was ~16% less than the buffer zone plots, the runoff volume from the completely covered plots was ~94% more than that of the buffer zone plots. Thus, palm-mat (buffer strip) cover on vulnerable segments of the landscape (convex slopes and erodible soils) in bare plots is highly effective for soil and water conservation in these temperate loamy sand soils. Furthermore, palm-mats could become a feature of multi-faceted projects aimed at preventing further soil erosion and growing *Borassus* plants is compatible with both agroforestry and hillslope afforestation in the tropics.

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