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Stabilizing steep slopes with geomembranes [1]

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Abstract

The effects of five types of geomembranes, placed at the soil surface, on runoff and erosion on steep earth slopes were studied under laboratory and field conditions. In the laboratory, the soil samples were packed in boxes held at a 50% slope and subjected to three consecutive simulated rainstorms of 120 mm each. The membranes dissipated the drops' impact and reduced runoff significantly compared with the control. There was no significant difference among the membranes regarding their effect on the runoff. In the field, the membranes lined earth dikes of 33–60% slope and 12–20 m length, during 2 years. There was no runoff and erosion from the lined plots compared with 80–125 tonne ha^{-1} of erosion in the control plots. No considerable wear and tear of the membranes was observed. © 1997 Elsevier Science B.V.

1. Introduction

Denudation of slopes frequently leads to serious problems of downstream sediment — unless the slopes are stabilized to control soil erosion (Holy, 1980). Denuded slopes are often difficult to revegetate and may become unsightly. Better erosion control methods are needed for construction site slopes, so that soil movement after shaping will be minimized and subsequent reshaping will be unnecessary (Meyer et al., 1972).

A dominant factor, affecting runoff and erosion of bare soils, is seal formation on the soil surface (Duley, 1939; McIntyre, 1958; Morin and Benyamini, 1977). Agassi et al. (1981) attributed seal formation to two complementary mechanisms:

1. disintegration of soil aggregates at the soil surface by impacting drops and the compaction of the disintegrated particles into a thin and very compact sealing layer;

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2. clay dispersion and migration downward in suspension, of clay particles that clog pores beneath the surface, thus, thickening and reinforcing the seal.

The control of these processes and of the ensuing runoff and erosion, can be achieved by the following methods:

1. protection of the soil surface against impacting drops (Agassi et al., 1985);
2. reinforcement of the aggregates at the soil surface by the application of soil conditioners (Ben-Hur and Letey, 1989) and
3. introduction of electrolytes at the soil surface, to control the chemical dispersion of clay particles (Agassi et al., 1981).

Numerous studies have already proven the beneficial effect of soil surface mulching on runoff and erosion control (Meyer and Mannering, 1963; Meyer et al., 1970; Meyer et al., 1971; Meyer et al., 1972; Barnet et al., 1967; Epstein et al., 1966; Swanson et al., 1967). The common materials for mulching are plant residues, gravel, rock fragments and woodchips, used at various rates of application, but in some regions, these materials are scarce, making their use costly and impracticable.

Agassi and Ben-Hur (1992) found that the combination of soil conditioners and planting of drought-resistant plants successfully controlled erosion and runoff and stabilized steep road embankments. The soil conditioners stabilized the slope during the first rainy season after planting. During the second rainy season, the plant canopy spread to cover at least 70% of the soil surface, so that the slope became stable.

Geomembranes are used extensively by soil engineers, e.g., as an interface between compacted and uncompacted soil layers or between concrete structures and the soil, or as an envelope for underground subdrainage pipes. However, their characteristics as mulching materials, to absorb the impact of raindrops had not been studied previously. Geotextile membranes placed to cover the soil surface could absorb raindrop impacts and so control crust formation and reduce the consequent runoff and erosion.

The objectives of the present study were:

1. To study the efficiency of geomembranes in controlling runoff and erosion of steep slopes under laboratory and field conditions.
2. To study the resistance of geomembranes on the soil surface to natural wear and tear and deterioration caused by, e.g., solar radiation and wind, trampling and burrowing by animals and emergence of weeds.

Table 1
Some characteristics of the soils and the sites

Site	Soil classification	Soil texture (%)			$CaC0_3$ (%)	ESP (%)	Plot			Annual rainfall (mm)	
		sand	silt	clay			slope (%)	length (m)	aspect	1989–1990	1990–1991
Re'im	Calcic Haploxeralf	32	43	25	15.3	3–10	33	15	South	280	300
Massuot	Typic Chromoxererts	22	25	53	25.0	4–17	45–60	12	South-west	460	445
Bet Yannay	Typic Rhodoxeralf	78	12	10	0.1	1	50–60	20	West	400	490

2. Materials and methods

2.1. Laboratory experiments

The < 4 mm fractions of three Israeli soils were used in the study. The soil samples were collected from the layer 0–50 mm depth. The chemical and physical properties of

Table 2
Initial runoff rates (IRR: mm h^{-1}) and final runoff rates (FRR: mm h^{-1}) for each of the soils, geomembranes and successive simulated storms

Soil classification	ESP	Membrane type	Accumulated rainfall (mm)											
			120				240				360			
			IRR		FRR		IRR		FRR		IRR		FRR	
Typic Rhodoxeralf	1	control	0 [a]	0 [b]	45	3.2	30	2.4	46	3.1	32	2.2	46	2.9
Hamra		polyfelt 500	0	0	0	0	0	0	0	0	0	0	24	2.9
		polyfelt 600	0	0	0	0	0	0	0	0	0	0	22	0.9
		geotex. 120	0	0	0	0	0	0	0	0	0	0	20	0.7
		geopalrig	0	0	0	0	0	0	0	0	0	0	19	1.8
		spun-bonded	0	0	0	0	0	0	0	0	0	0	35	0
Calcic Haploxeralf	3	control	0	0	51	4.1	39	2.9	52	4.0	37	3.1	52	3.8
Loess		polyfelt 500	0	0	20	2.2	15	1.1	26	2.8	19	1.8	27	2.7
		polyfelt 600	0	0	16	1.1	9	0.9	22	2.4	16	1.3	25	1.8
		geotex. 120	0	0	10	0.4	6	0.3	12	1.8	6	0.5	14	1.9
		geopalrig	0	0	9	0.4	4	0.2	12	0.9	6	0.4	13	0.6
		spun-bonded	0	0	3	0.8	8	0.1	18	1.9	12	0.7	19	2.1
	10	control	0	0	53	0.8	50	0.8	53	1.1	50	1.7	53	0.9
		polyfelt 500	0	0	28	2.9	24	2.2	31	0.9	29	2.8	32	3.7
		polyfelt 600	0	0	26	1.9	22	1.9	28	3.1	24	3.0	28	3.0
		geotex. 120	0	0	20	0.8	17	0.7	30	0.9	28	4.0	32	2.7
		geopalrig	0	0	18	1.1	16	0.5	30	2.1	26	2.2	30	2.9
		spun-bonded	0	0	20	0.5	16	0.4	33	2.5	31	2.4	35	3.3
Typic Chromoxererts	4	control	0	0	52	6.0	42	3.9	52	5.0	41	3.5	52	3.3
Vertisols		polyfelt 500	0	0	22	2.0	16	1.1	26	1.9	20	1.8	26	2.1
		polyfelt 600	0	0	19	1.1	12	1.3	21	2.0	18	2.0	27	2.3
		geotex. 120	0	0	13	1.4	10	1.5	14	1.6	10	0.8	17	1.5
		geopalrig	0	0	11	0.9	6	0.8	15	1.7	8	1.0	16	1.7
		spun-bonded	0	0	14	2.0	8	1.0	19	1.5	13	1.5	20	1.5
	17	control	0	0	54	2.9	48	3.1	54	2.5	50	3.1	54	2.0
		polyfelt 500	0	0	33	4.0	30	3.0	34	3.1	32	2.8	34	2.8
		polyfelt 600	0	0	30	2.6	27	2.5	32	3.3	31	2.4	33	3.5
		geotex. 120	0	0	31	3.5	24	2.3	32	3.3	28	2.4	32	3.1
		geopalrig	0	0	28	2.4	20	1.9	29	1.7	24	2.5	29	2.5
		spun-bonded	0	0	30	3.6	21	2.1	33	2.5	26	1.7	33	4.1

[a] Average of four replicates (mm h^{-1}).

[b] CV.

these soils are presented in Table 1. The soil samples were air dried and then packed, 2.0 cm deep, over a layer of gravel in 30 × 50 cm perforated boxes. The boxes were placed in a rainfall simulator (Morin and Benyamini, 1977), mounted at a slope of 50%. The soil samples were then subjected to a simulated rainfall intensity of 42 mm h^{-1} of distilled water. Three consecutive storms, each of 120 mm, were applied. The interval between storms was 3 days, during which the soil boxes were left to dry at room temperature (25°C). Typical mechanical parameters of the applied rain were: median drop diameter, 2.3 mm; median drop velocity, 6.74 m s^{-1} and kinetic energy, 22.9 J mm^{-1} m^{-2}.

Samples of runoff and infiltrating water were collected at 5 mm steps of rainfall accumulation. Samples of runoff water were collected until the final runoff rate (FRR) was attained.

Five types of geomembrane were tested:

1. Polyfelt Ts 500, 140 g m^{-2}, 100% nonwoven polypropylene, resistant to solar radiation.
2. Polyfelt Ts 600, 200 g m^{-2}, 100% nonwoven polypropylene, resistant to solar radiation.
3. Geotextyle, 120 g m^{-2}, 100% nonwoven polyester, not resistant to solar radiation.

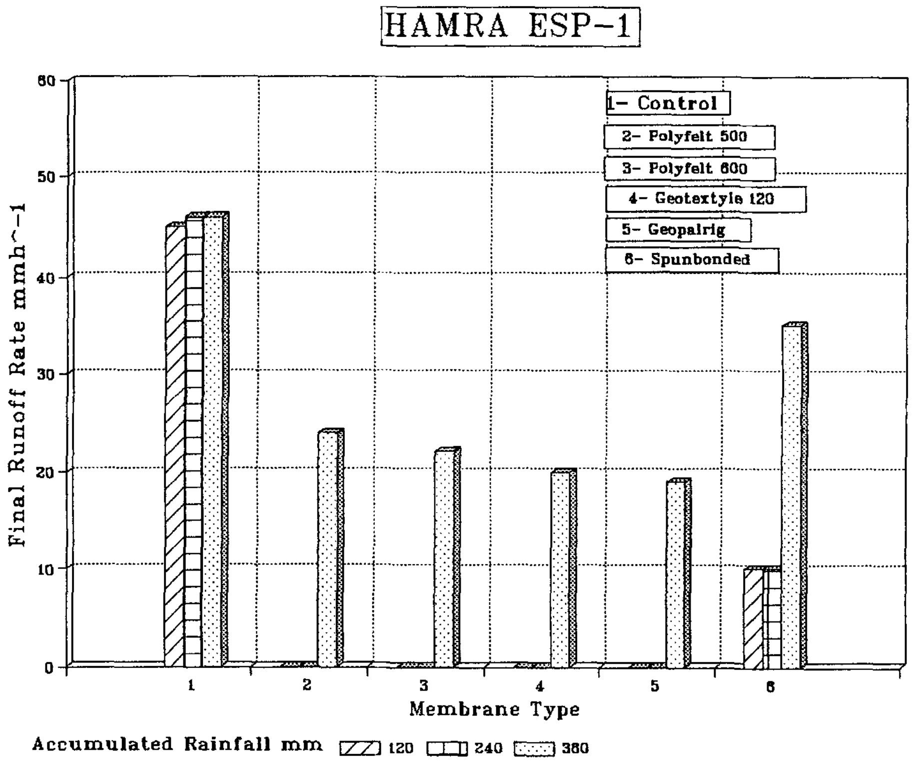

Fig. 1. Final runoff rate of hamra soil ESP 1 as a function of the membranes and accumulated rainfall.

4. Avgol-Spunbonded, 90 g m^{-2}, nonwoven polypropylene, not resistant to solar radiation.
5. Geopalrig, 120 g m^{-2}, woven polypropylene, resistant to solar radiation.

The membranes lined the soil surface. Each treatment was replicated four times. Statistical differences among treatments were tested by the *F*-test and Duncan's multiple range test.

2.2. Field experiments

Earthen dikes of water reservoirs at Re'im, Massuot and Bet Yannay, in Israel, were selected for the experiments. The soil and dike properties and rainfall amounts had fallen since the completion of the plots for each site, are presented in Table 1. The aspect of the slope selected was that facing the prevailing wind during rainfall (Agassi and Ben-Hur, 1991). The top layer (0–0.05 m) of the dikes was cultivated and raked smooth to break the old crust and then, plots, 2 m wide and of several different lengths, (Table 1) were constructed.

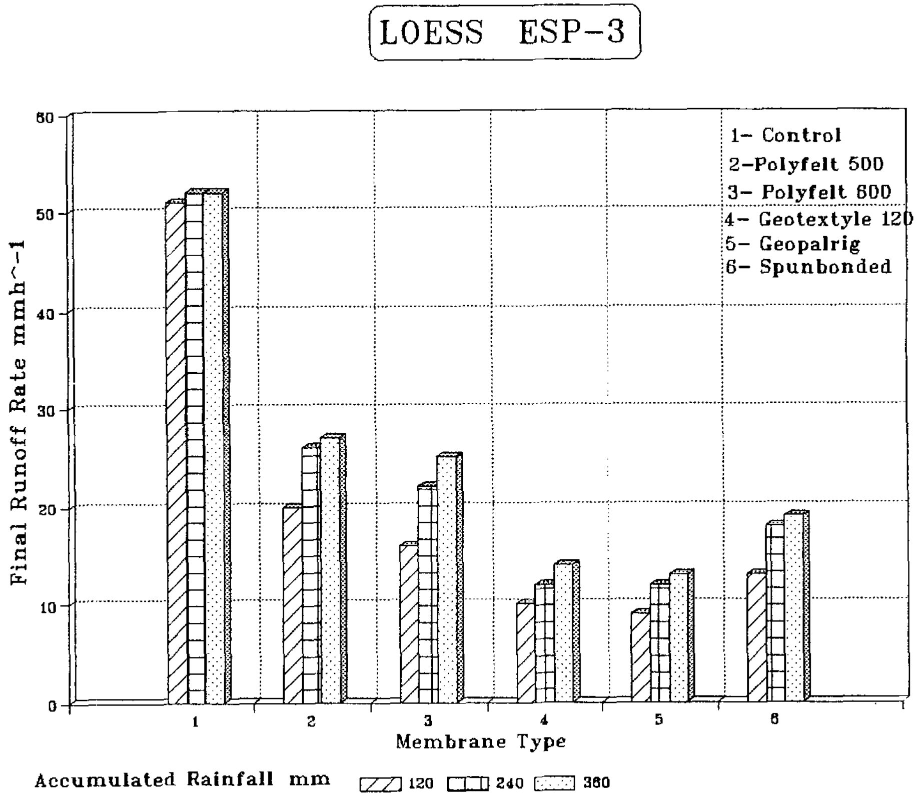

Fig. 2. Final runoff rate of loess soil ESP 3 as a function of the membranes and accumulated rainfall.

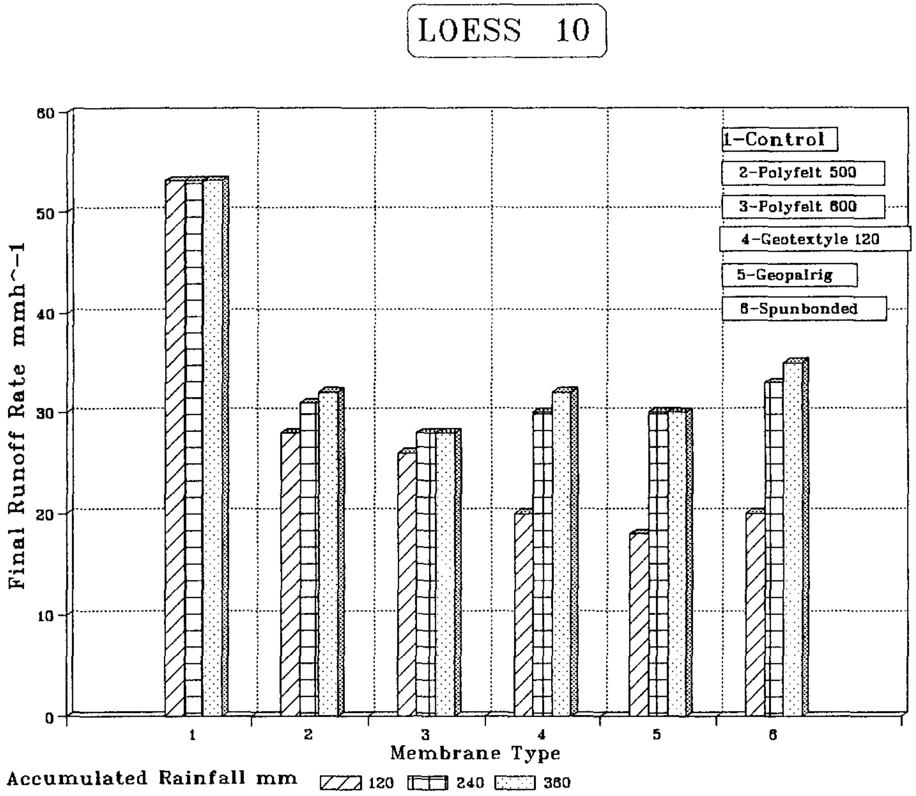

Fig. 3. Final runoff rate of loess soil ESP 10 as a function of the membranes and accumulated rainfall.

Polyfelt membranes were not used in the field experiment as we did not have any at that stage. The upper and lower parts of the membranes were buried in a trench, 10 cm deep. The Geopalrig and Geotextyle membranes were 6 m wide, while the Spunbonded was only 3 m wide. The plots were 6 m wide with three replicates for each treatment. The membranes were pegged to the ground with U-shaped iron rods, 8 mm thick and 15 cm long, at 1 m spacing. Two membranes of Spunbonded were used to cover 6 m wide plots. One membrane overlapped the other and both were pegged to the ground. At the lower part of each plot, a trough and a container were placed to collect runoff and erosion. A recording raingauge was installed at each site.

3. Results

3.1. Laboratory experiments

The results of the laboratory experiments are presented in Table 2 and Figs. 1–6. There were no significant differences in the effects of the membranes on final runoff

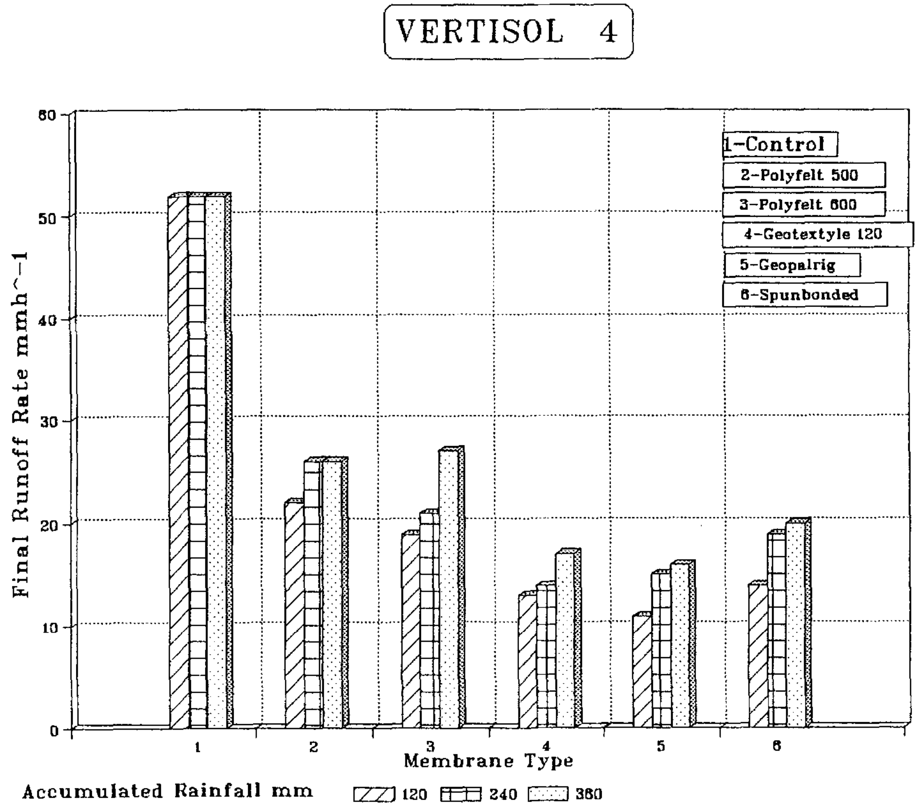

Fig. 4. Final runoff rate of vertisol soil ESP 4 as a function of the membranes and accumulated rainfall.

rate (FRR). In the Hamra soil (Fig. 1), there was no runoff at all from the Polyfelts, Geotextyle and Geopalrig membranes during the first and second storms.

In Fig. 6, the average FRR from all five membranes, for each soil, is presented. The FRR was significantly lower from the lined soil boxes than from the control. The membranes were the least efficient in runoff control with the ESP 17 vertisol. Agassi et al. (1985) had previously found that high ESP vertisols are prone to chemical dispersion when subjected to simulated rainfall of distilled water, even when the simulated rainfall was of low energy. The beneficial mulching effects of the membranes on FRR is similar to that of low energy rainfall, however, the DW was the cause of the chemical dispersion and relatively high levels of FRR in the high-ESP vertisols.

3.2. Field experiments

There were no runoff and erosion from the lined plots during the two years of experiments compared with 80–125 tonne ha^{-1} of erosion from the control plots. The Spunbonded and Geotextyle membranes disintegrated as a result of solar radiation

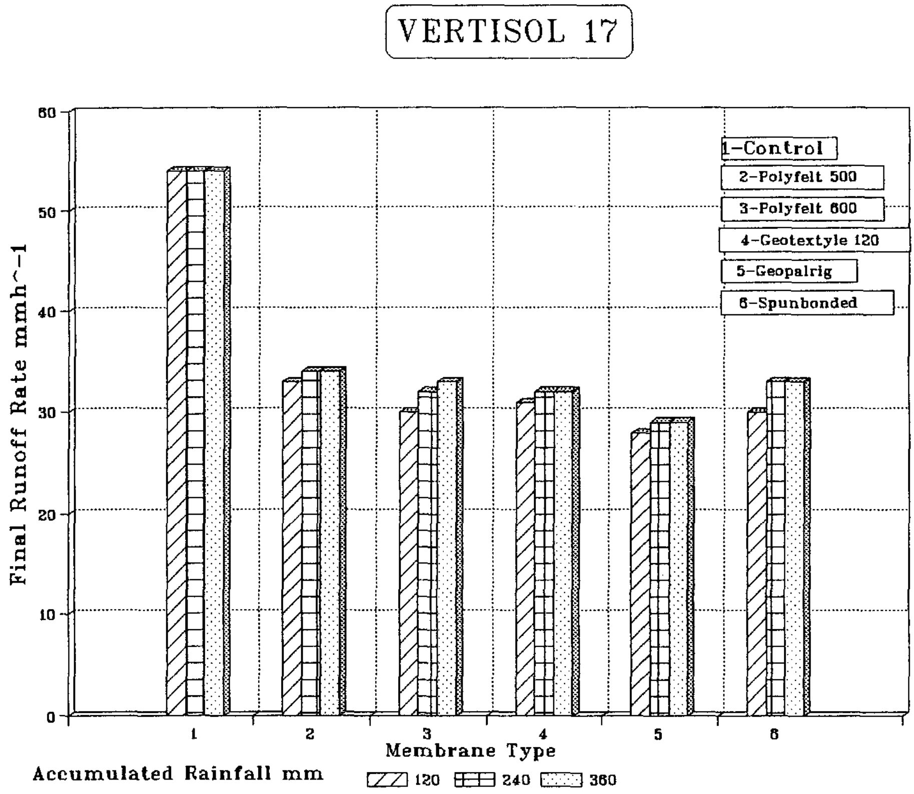

Fig. 5. Final runoff rate of vertisol soil ESP 17 as a function of the membranes and accumulated rainfall.

during the hot, dry season that followed the cold, rainy season and were replaced each year. The Geopalrig membrane has remained almost intact till today. The membranes were not disturbed by the wind nor were they damaged very much by animals or emergence of plants. In fact, plant emergence through the membranes was not observed.

4. Conclusions

In the laboratory experiments, under severe rainstorm intensity of long duration, geomembranes reduced runoff by at least 23%, compared with the control. Under field conditions, however, the membranes completely eliminated runoff and erosion. Although the Polyfelt membranes were not tested under field conditions, we believe that they would have the same performance as the other membranes. We assume that seedlings may be planted through the geomembranes covering steep slopes, so that such membranes could afford the same support to drought-resistant (and other) plants as soil

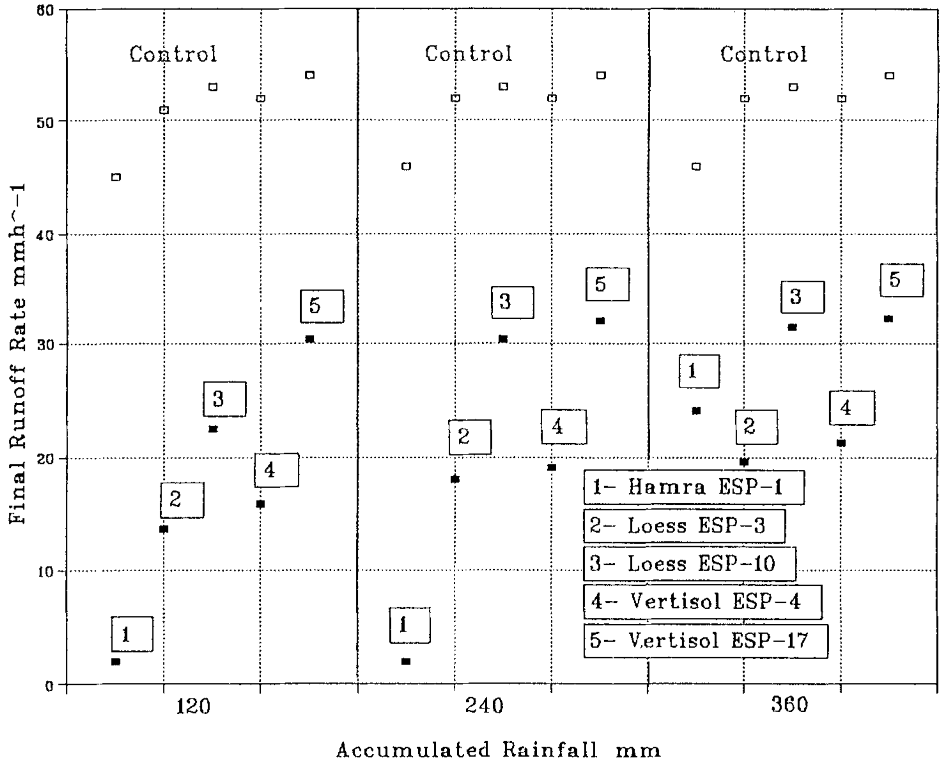

Fig. 6. Average final runoff rate, for each soil, for all the membranes and the control.

stabilizers did (Agassi and Ben-Hur, 1992). Geopalrig membranes can control runoff and erosion even in the absence of plants, for relatively long periods, if necessary.

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