Properties and performances of TENAX MULTIMAT and TENAX PROMAT

Technical Report

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1. TENAX Geomats

Geomats are synthetics products specifically engineered for erosion control and revegetation of slopes subjected to surface soil removal by rain, runoff, wind or snow.
Geomats act through two mains erosion control mechanisms:

- Confinement and surface reinforcement of the soil;
- Protection against raindrops impact.

TENAX produces two types of geomats: TENAX Multimat and TENAX Promat.
TENAX Multimat 100 (see Figure 1) is a three-dimensional product with a nominal thickness of 20 mm; it is made up of three polypropylene (PP) meshes, which have been extruded and subsequently oriented in both longitudinal and transversal directions: the process of biaxial molecular orientation allows to increase dramatically the mechanical characteristics of the basic polymer, thus obtaing very high tensile strength and very low unit weight. These characteristics allow the safe use of Tenax Multimat 100 even on very long and steep slopes.

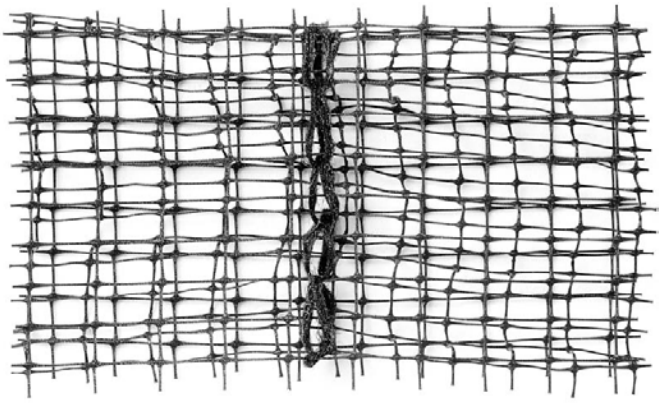


Figure 1: Geomat TENAX Multimat 100.

TENAX Multimat 030 (see Figure 2) is a three-dimensional product with a nominal thickness of 10 mm and green colour; it is made up of three polypropylene (PP) meshes, which have been extruded and subsequently oriented in both longitudinal and transversal directions: the process of biaxial molecular orientation allows to increase dramatically the mechanical characteristics of the basic polymer, thus obtaing very high tensile strength and very low unit weight. These characteristics allow the safe use of TENAX Multimat 030 even on very long and steep slopes.

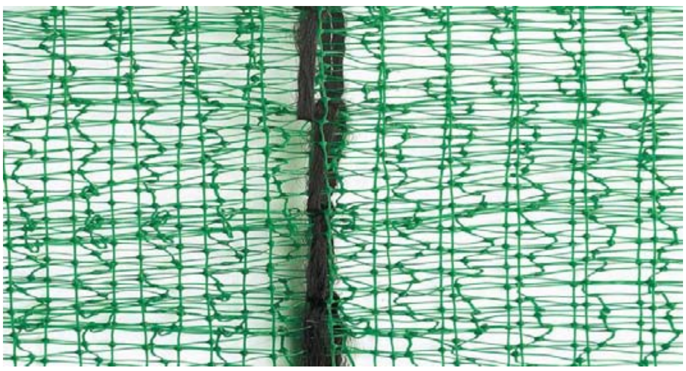


Figure 2: Geomat TENAX Multimat 030.

The three oriented meshes of TENAX Multimat are protected against UV radiation with the addition of 1% carbon black to the polymer or U.V. light stabilizer and green colour; therefore TENAX Multimat can resist sunlight, without loss of mechanical characteristics even when left exposed for long periods of time.

The structure of TENAX Multimat is obtained by stitching together the three meshes with a PP thread, protected as well against UV radiation with carbon black.
The two external meshes are plane (see Figures 1,2) and provide the high tensile strength, while the central mesh is mechanically folded in the factory, in order to provide the thickness and the compressive resistance.
The structure of TENAX Multimat allows to minimize the deformation of the geomat during filling with topsoil and to minimize the longitudinal elongation even on very long and steep slopes.
The choice of using Polypropylene find its reason in the total inertia of such polymer to atmospheric pollutants, like NO_2 and SO_2, and to its zero water absorption which prevents any possibility of hydrolysis and consequent brittleness (typical of other polymers such as Polyester and Polyamide).
TENAX Multimat can be used as a TRM (Turf Reinforcement Mat) or as an ECRM (Erosion Control Revegetation Mat), according to the terminology approved by the International Erosion Control Association (IECA).
TRM geomat has to be placed on the slope and filled with topsoil. In this way the geomats protect the surface layer of the soil, the seeds and the sprouts against the dragging action of the water, both from rain and runoff; moreover they allow the "anchorage" of the roots of growing grass and shrubs, in such a way to form with them a synergistic block, very resistant to the actions of water and gravity. Then the roots network has the possibility to grow and develop very compact and dense, thus contributing to the superficial stability of the slope.
ECRM geomat shall be placed on the slope after having prepared the topsoil and seeded it, and it shall be fixed adherent to the ground. Alternatively hydro-seeding may be used even after the installation of the geomat. Anyway, it is suggested to seed or hydroseed the soil before laying TENAX Promat 70, since these geomats have no thickness and therefore the vegetation growth is better guaranteed if started below the geomats.

Tenax Promat 70 (see Figure 3) is a bidimensional product, made up of several bi-oriented polypropylene meshes: a larger mesh grid, with high tensile strength, is coupled by stretching to finer meshes. In this way a geomat is obtained which is strong, flexible, very light, with minimum volume, able to protect the soil against the "splash" of the raindrops and to prevent soil washing by the surface runoff.
TENAX Promat 70 can be used an ECRM (Erosion Control Revegetation Mat), according to the IECA terminology.

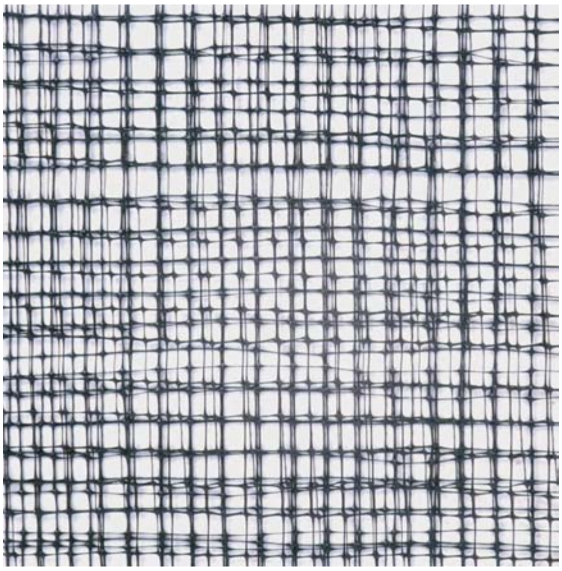


Figure 3: Geomat TENAX Promat 70.

2. Mechanism of rain erosion

When, for natural or man made causes, the vegetative cover of a slope is eliminated or is temporarily missing, the soil results at its maximum vulnerability to the erosive action of atmospheric agents, mainly of rain. In such conditions, in order to protect a slope against erosion, the target shall be the development, in the least possible time, of an ecosystem which affords the fast growth of natural vegetation, and/or which provides a proper protection against erosion.
The erosive action of the rain develops mainly through two mechanisms:

- Detachment and transport of soil particles by the impact of raindrops on the soil surface;
- Detachment and transport of soil particle by the surface runoff.

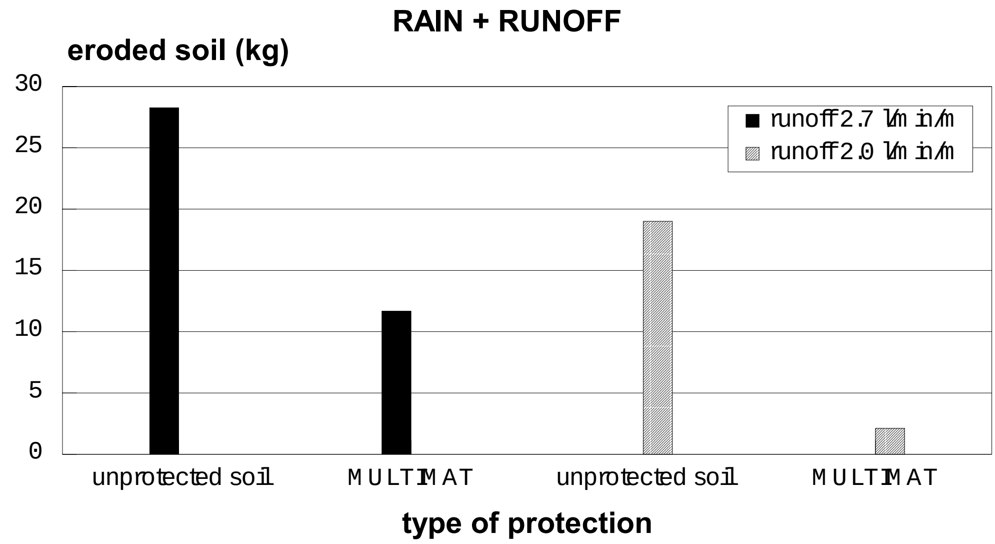
When raindrops impact the slope surface, the impacted soil particles get kinetic energy and they get displaced from their original position, in this way the geometry of the soil surface is modified, with the formation of small valleys and craters, which in turn increases the surface roughness.
The detachment due to raindrops is the most important cause of erosion before the run off starts, which causes a further detachment of soil particles and their downward transport.
The amount of erosion depends on several factors, such as rain intensity and duration, slope geometry, type of soil, slope exposition, type vegetative cover.
The role played by vegetation in protecting the soil against erosion is fundamental: vegetation particularly influences the water exchange between soil and atmosphere, the consolidation and reinforcement of the surface soil layer, and the protection of soil against raindrops impact.
Moreover vegetation reduces the volume and speed of runoff, therefore decreasing its capacity of solid transport. Hence we can say that an erosion control system reaches its maximum efficiency when the vegetation is complete and dense.

3. Performance of TENAX Geomats

At the TENAX Testing Laboratory, in Viganò Brianza (Italy) and Politecnico of Milano, a specific apparatus was developed for the evaluation of the performance of erosion control products and systems.
The choice to perform laboratory tests was due to the fact that lab testing allows a much better control of the parameters than in-situ testing.
Through a rainfall simulation, in fact, it was possible to reproduce and to measure:

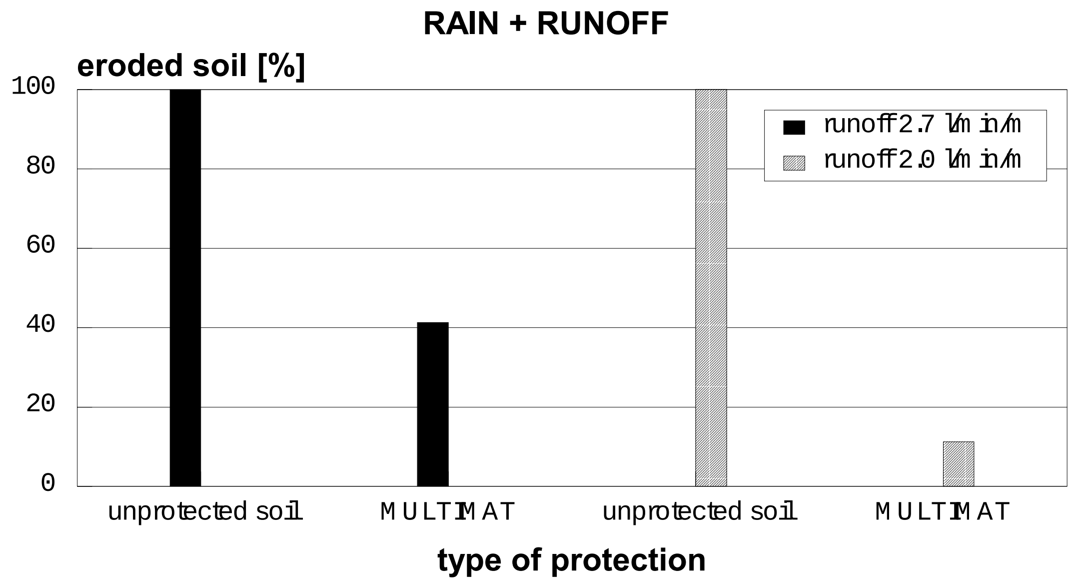
- the rain intensity and frequency;
- the raindrops diameter and the impact velocity;
- the soil characteristics (particles size, granulametric curve, clay content, bulk density , initial humidity, etc...);
- the slope length and inclination;
- the type of soil cover (bare, vegetated, lined with geosynthetics, etc...).

Among these results, the histograms in Figure 4 and by Figure 5 provide an idea of the advantages afforded by the use of TENAX Multimat: both in case of intense rainfall and of high surface runoff, TENAX Multimat is able to reduce the quantity of eroded soil to less than 40% compared to the case of unprotected soil. Even the surface runoff velocity is reduced to about the half, as shown in Figure 6.



rainfall intensity 80.7 mm/h
slope 1V:2H

Figure 4: Eroded soil (with and without TENAX Multimat).



rainfall intensity 80.7 mm/h
slope 1V:2H

Figure 5: Eroded soil percent (with and without TENAX Multimat).

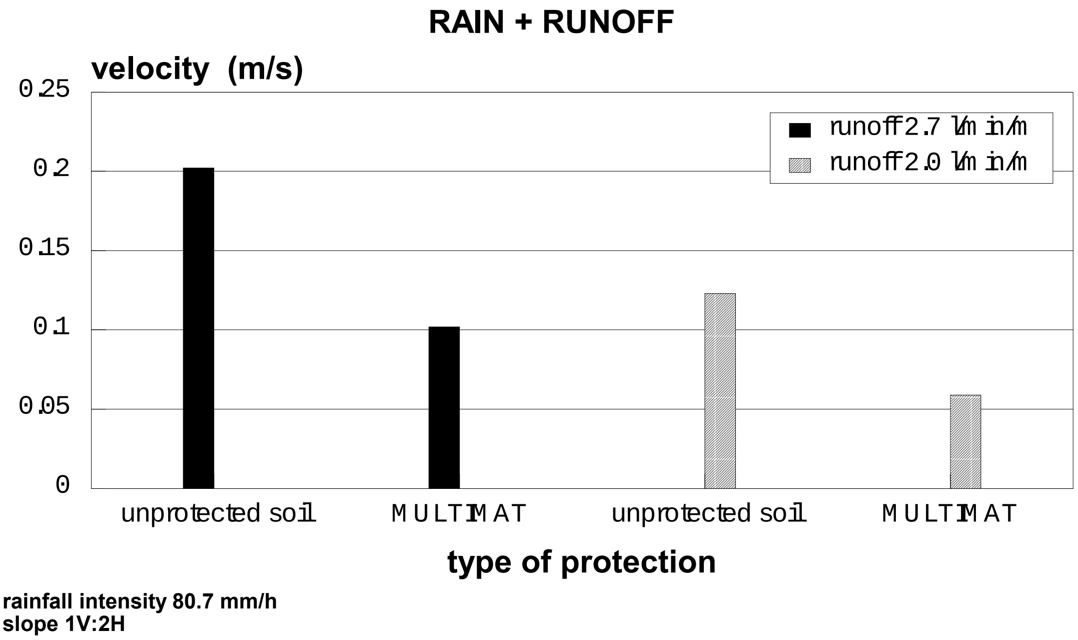


Figure 6: Surface runoff velocity (with and without TENAX Multimat).

But the best advantage of TENAX Multimat and TENAX Promat lays in the change these geomats induce in the erosion mechanism.
For a base unvegetated slope, erosion initially occurs with the water flowing in a thin laminar layer: therefore the erosion is uniform and with low intensity, since the water speed is reduce and therefore also its erosive force is reduced.
But soon the water finds preferential paths and starts to follow channelized flow in small rills, thus locally increasing its velocity. Therefore increasing its erosivity, the water excavates rills faster and faster, where the local velocity of the water further increases. Then fast channelized erosion occurs, soon degenerating when the water reaches to excavate deep rills and gullies.
At this stage the slope is no longer recoverable and the vegetation is no more able to grow. It will be necessary to re-profile the soil and to reseed for obtaining vegetation growth.
TENAX Multimat and TENAX Promat, instead, allow only limited uniform erosion, while they totally prevent the channelized erosion. In this way, at the end of rain and runoff, the seeds are still able to germinate and the slope can revegetate with a faster rate. While vegetation grows, the roots will grip themselves to the geomats, which will provide a very high tensile and shear resistance to the roots network. Then the vegetation will be able to withstand even very intense meteorological events and to stand the dragging force even of very heavy runoff.
This is a peculiar property of TENAX geomats, thanks to their high tensile strength at low elongation (Table 1).
For comparison other geomats, presenting very long tensile strength at very high elongation, absolutely cannot guarantee the same reinforcement to the roots network. Such difference is even more evident when geomats are used to protect vegetated channels.

Table 1: Comparison of TENAX geomats characteristics.

Product	Promat 70		Multimat 30		Multimat 100	
	MD	TD	MD	TD	MD	TD
Tensile Strength (kN/m)	3.5	4.0	3.8	13	10	15
Peak strain (%)	20	15	23	23	20	15

4. Flume tests on TENAX geomats

Between April and August 1997 four series of high water velocity flume tests have been performed at Utah Water Research Laboratory.
These tests were aimed to describe the behaviour of Tenax Multimat when used to protect vegetated channels.Two tests were performed with the geomat filled with topsoil but without vegetation and two tests with the geomat already vegetated.
The flume was 1.20 m deep; it was 21 m long, but it was instrumented for 16 m, since the initial 5 m have been considered as subject to approach disturbance.
The flume has been filled up with 450 mm of sandy loam (59% sand, 26% silt, 15% clay), placed in layers compacted to 90% Proctor density.
The soil has been lined with the geomat, anchored at the edges with staples. At the water inlet the geomat has also been wrapped down for limiting the underscouring which could have made the test results meaningless. Nonwoven geotextiles have been used as well to limit the boundary effects at the inlet and at the edges of the flume.
In this way, any breakage of the geomat or any soil loss was guaranteed to be due only to the erosive action of the water stream.
Water velocities and piezometric levels have been measured locally while a global Flow Probe, with the bulk flow velocity was measured with a Pivot tube.
Erosion depths were measured every 25.4 mm transversal to the flume and every 127 mm longitudinally, for the whole 16 m of the measurement past of the flume.
The testing procedure included 5 classes of flow, increasing from 0.7 m to 6.0 m/s, with duration of 30 minutes each, plus a final test at 4.60 m/s with prolonged duration.
For the unvegetated geomat during the first test it was able to withstand the whole 50 hours of flow without any failure, even if significant erosion occurred at the inlet; the second test, instead, has been stopped after 40 hours due to excessive erosion at the inlet (almost 0.5 m). In both cases, anyway deep erosion occurred only in the initial 3 m of the flume, therefore showing that it was due only to the inlet boundary conditions. Along the remaining 80% of the flume the erosion profile remained almost constant and well below (only 25 ÷30%) the maximum erosion depth.
For the case of vegetated geomat, the same deep erosion occurred in the first 3 ÷ 5 m, but the erosion was much less than for the unvegetated geomat: beyond the initial part of the flume, in fact there was non-practical soil erosion.
The short-term tests (30 minutes) didn't produce any measurable soil loss.

At the end of the tests it was possible to evaluate the applied shear stress at the soil surface, through the application of the Energy Conservation equation and of the Manning equation for non-uniform flow.

- the high tensile strength of TENAX Multimat is able to withstand the dragging force produced by a water stream flowing at 4.6 m/s;
- the "Covertop" provided by the top flat mesh of TENAX Multimat to the soil in filled which makes more difficult for the water to remove and transport the soil particles.

On the base of these testing results and of the practical experience gained in years of applications of TENAX geomats, it is possible to define the hydraulic data for water channels protected with TENAX Multimat and TENAX Promat, as reported in Table 2.

Table 2: Hydraulic data for sandy loan channels protected with TENAX geomats.

Geomats	TENAX Multimat		TENAX Promat	
	unvegetated	vegetated	unvegetated	vegetated
Maximum applied shear stress [kPa]	0.38	0.48	0.22	0.28
Roughness(Manning) [$s/m^{1/3}$]	0.036	0.038	0.036	0.038
Roughness (Strickler) [$m^{1/3}/s$]	27.8	26.3	27.8	26.3
Limit velocity [m/sec]	4.8	6.0	3.6	4.8

In year 2002, additional tests have been performed at the Politecnico di Milano University on the Tenax Multimat geomats. These tests were aimed to describe the behaviour of several Tenax geosynthetics when used to protect vegetated channels.
The flume was 0.70 m deep; it was 13 m long. The flume has been filled up with about 200 mm of sandy loam soil.
The soil has been protected with the geomat, anchored at the edges with staples. At the water inlet the geomat has also been wrapped down for limiting the underscouring which could have made the test results meaningless.
Water velocities and piezometric levels have been measured locally while a global Flow Probe, with the bulk flow velocity was measured with a Pitot tube.
The testing procedure included 3 classes of flow, increasing from 1.5 m/s to 2.5 and 4 m/s, with duration of 30 minutes each.
The short term tests (30 minutes) on the Unvegetated sections protected with TENAX Geomat did not produce any measurable soil loss as shown in table 3 to 5 and figure 7 to 10.
The vegetated geomat sections were able to withstand more than 24 hours of continuous flow without any failure and without significant erosion.

Table 3: Hydraulic data for soil channels protected with TENAX geomats.

Geomats	**Bare Soil**	**TENAX Promat 70**	**TENAX MULTIMAT 30**	**TENAX Multimat 100**
	unvegetated	unvegetated	unvegetated	unvegetated
Roughness(Manning) [$s/m^{1/3}$]	0.010	0.012	0.014	0.014
Roughness (Strickler) [$m^{1/3}/s$]	116	83	66	67
Limit velocity [m/sec]	1.5	> 2.5	> 2.5	> 4.0

Table 4: Summary table of Flume test results at the Politecnico of Milano, Italy.

Preparation		**U_1=1.5m/s**				**U_2=2.5 m/s**				
		Duration= 20 min				Duration= 30 min				
		Average erosion depth	Max erosion depth	C_v	Tot. volume erosion	Average erosion depth	Max erosion depth	C_v	Tot. volume erosion	Collapse time
		[cm]	[cm]		[m³]	[cm]	[cm]		[m³]	
Soil	SL	3.6	6.1	0.09	0.02	6.5	8.4	0.12	0.03	yes 5 min
	S	**3.83**		**0.17**		**8.74**		**0.43**		
Multimat 30	SL	1.8	2.5	0.04	0.01	2.4	3.5	0.01	0.01	no
	S	**1.7**		**0.03**		**3.6**		**0.04**		
Multimat 100	SL	3.2	4.2	0.03	0.019	5	6.3	0.04	0.011	no
	S	**2.9**		**0.03**		**4.71**		**0.04**		
Promat 70	SL	1.3	2.5	0.02	0.01	1	5.2	0.07	0.01	no
	S	**1.44**		**0.03**		**4.63**		**0.19**		

SL=Longitudinal Section; S= Total Area

Table 5: Additional test performed on TENAX Multimat 100 at 4 m/s water speed.

Preparation		U_3=4 m/s				
		Duration= 30 min				
		Average erosion depth	Max erosion depth	C_v	Tot. volume erosion	Collapse time
		[cm]	[cm]		[m³]	
Multimat 100	SL	6.8	7.7	0.03	0.0076	no
	S	**5.9**		**0.07**		

SL=Longitudinal Section;S= Total Area

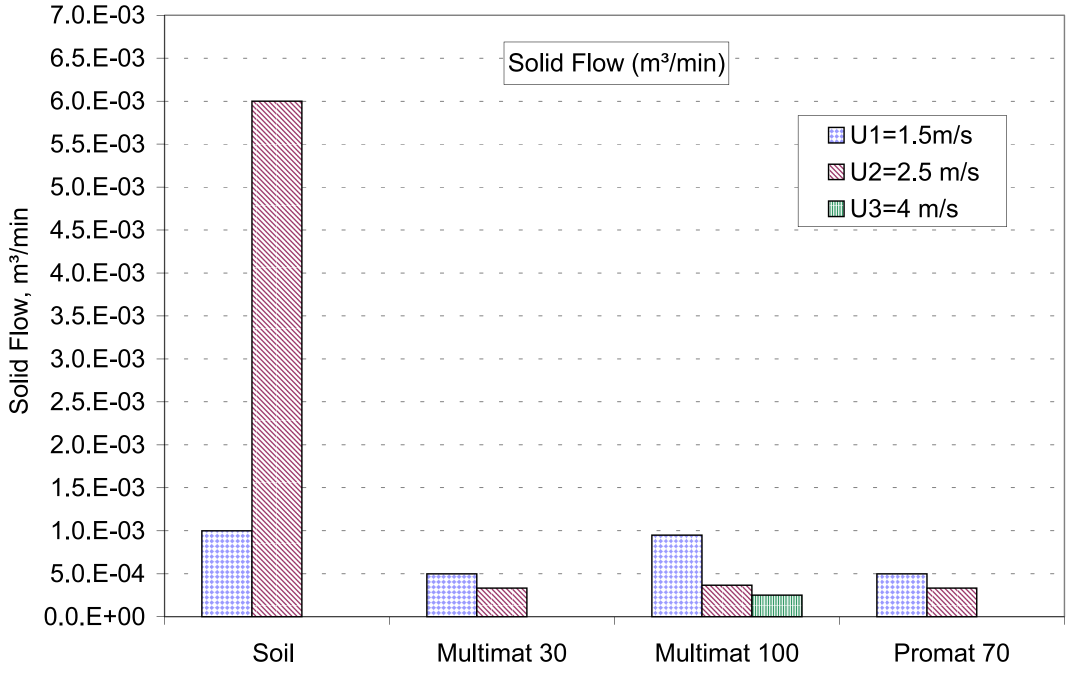


Figure 7: Solid Flow measured during the Flume Test at different flow speeds.

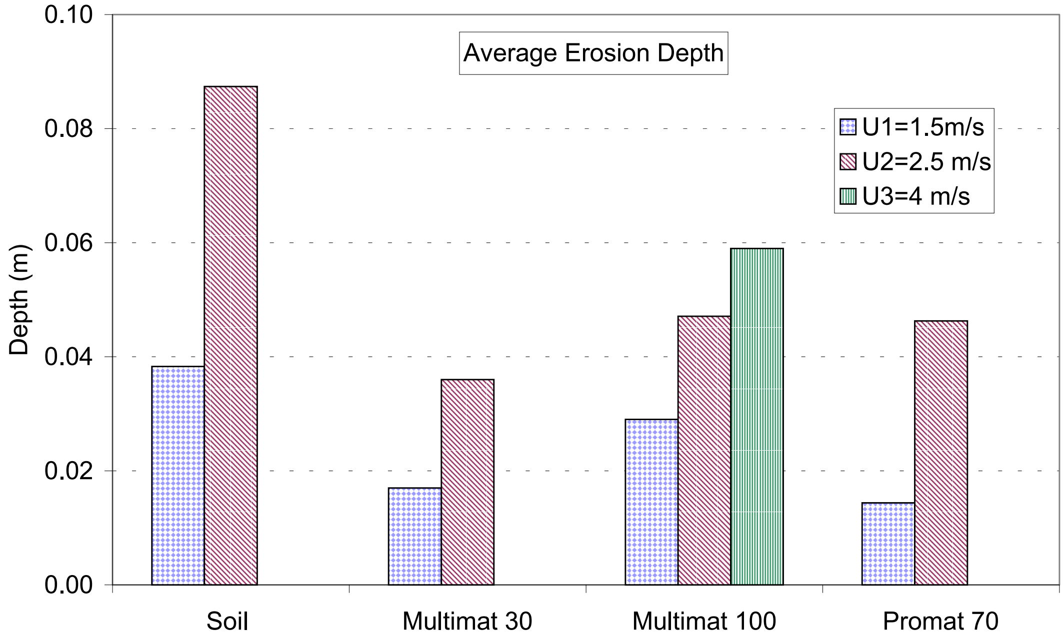


Figure 8: Average Erosion Depth measured during the Flume Test at different flow speeds.

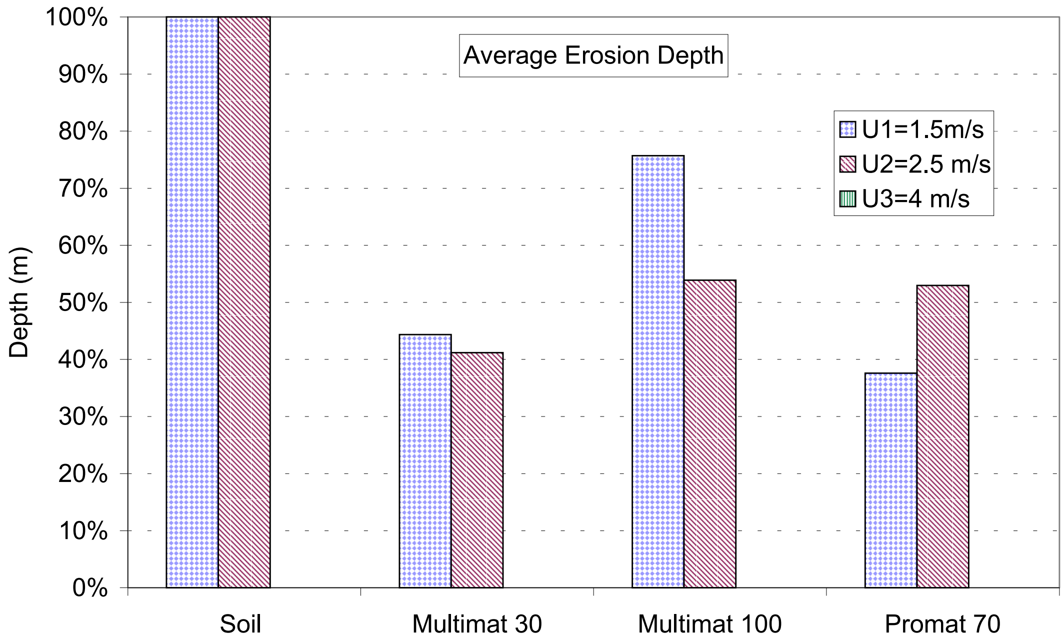


Figure 9: Average Erosion Depth expressed in percentage.

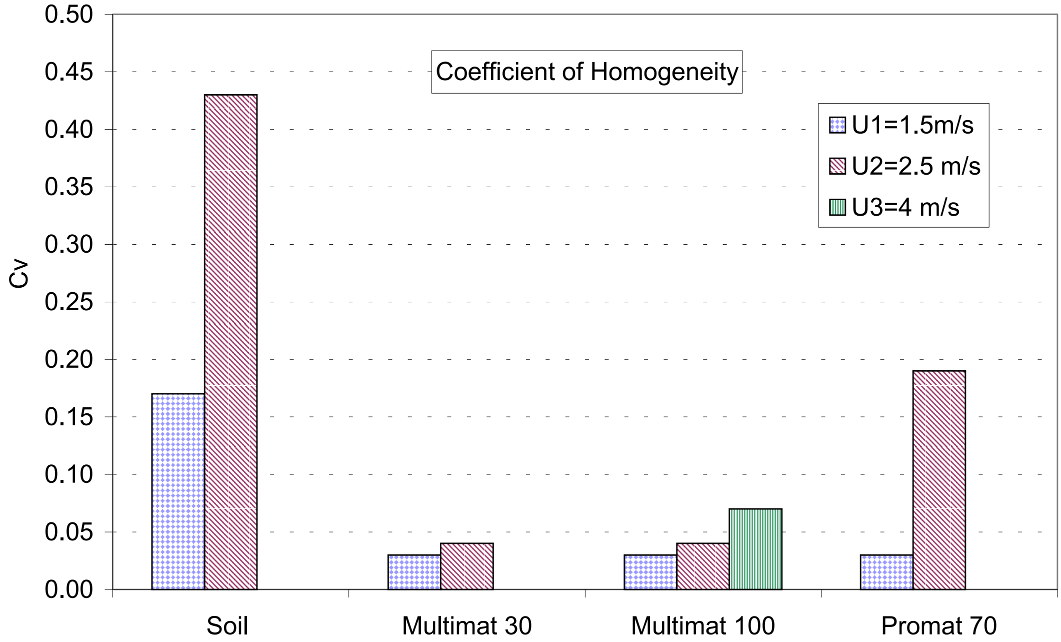


Figure 10: Coefficient of Homogeneity measured during the Flume Test at different flow speeds.

5. Other characteristics of Tenax geomats

5.1 Toxicity

TENAX Multimat and TENAX Promat are manufactured with polymers and additives listed in Enclosure 2 - Section A of the European Directive 90/128/CEE dated 23/02/90, related to plastic materials suitable for manufacturing products issued to be in contact with food.
TENAX geomats are 100% recyclable in the class “plastic material type PP”; TENAX geomats don’t prevent the recycling of other plastic products, they are not moulded and they don’t contain inks or enamels.

5.2 U.V. radiation resistance

TENAX Multimat and TENAX Promat are manufactured with Polypropylene charged with 1% Carbon Black additive or with U.V. light stabilizer and green colour.
This mixture will prevent the loss of properties of the geomats due to U.V. radiation, before the geomats being laid on the slope and filled with topsoil and/or seeded.

5.3 Attack by rodents, micro organisms and batteries

TENAX Multimat and TENAX Promat are not subject to biological aggression by microorganisms and bacteria, and they don’t constitute a nutrient for rodents.

5.4 Chemical resistance

TENAX Multimat and TENAX Promat are produced through mechanical coupling of Polypropylene extruded and biaxially oriented meshes; being Polypropylene a very highly chemically inert polymer, the geomats are considered to be resistant to the chemicals normally present in soils and even to chemicals which may be accidentally poured into the ground.

5.5 Working temperatures

TENAX Multimat and TENAX Promat can be used almost in any climate. In fact extruded Polypropylene becomes brittle at low temperatures, but being TENAX geomats produced with biaxially oriented Polypropylene meshes, the brittleness becomes irrelevant in comparison to the obtained increase in all properties.
Based on this fact, TENAX geomats are considered to have a working temperature included in the range - 20°C ÷ 100° C.
It must be noticed that if sharp sudden bending doesn’t occur, as it normally never occurs after geomats installation, TENAX geomats can be employed even at much lower temperatures than - 20°c. Installation anyway shall take place in the above mentioned temperature range.

6. Practical performances and applications

TENAX Multimat geomats have been used in many different application; among them there are; erosion protection of slopes, embankments, slope cuttings for roads and railways, vegetation of river banks, vegetated water channels, erosion protection and vegetation of landfill capping.
From the cold climates of Northern Europe and North America, to the temperate climates of Southern Europe, from the arid regions of Middle East to the tropical and equatorial climates of South East Asia, TENAX Multimat has demonstrated in practice to be an extremely effective product for the protection against rain and runoff erosion.
Thanks to its peculiar structure, which affords a very light and flexible product, yet with high tensile and compressive resistance, TENAX Multimat is ideal for optimally reinforcing the roots network of vegetation.
The superior technical characteristics and the excellent performance to price ratio make Tenax Multimat the best choice among the geomats on the market today.
TENAX Promat geomats have been recently introduced to provide customers with a very effective ECRM product. TENAX Promat has shown its performances in few months: many projects in Europe, USA, Mexico, South America, Hong Kong, Australia, South East Asia, have already experienced the effectiveness of this geomat. The extremely favourable performance to price ratio and the minimal transport cost, compared to other geomats, make Tenax Promat the ideal geomat for a vast range of projects.