Metallic mesh with geosynthetic retention strips for slope protection against superficial erosion

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ABSTRACT: Water erosion on inclined surfaces can cause significant damage to agricultural fields, mining areas and buildings especially when intense earthmoving and landscaping are involved such as road and rail slopes, divisions into lots and urbanization sites. In those cases the usual time delay between the intervention on the natural landscape and the effective establishment of new vegetation cover leaves the surfaces unprotected and more susceptible to the erosive process. This erosive process may cause modifications on slopes, soil flowing on plateaus and roads, blockages of tubular nets, soil deposits over channels and drainage basins and, even more, problems in foundation elements. In order to vegetate the slopes as quickly as possible there are products, constructive techniques and combinations of both that improve the germination conditions and on vegetation development. Practices such as small planting holes on the surface, biomats, HDPE geocells and hydro seeding represent some of the more common alternatives of protection. The present work describes the improvement of a widely used technological platform, galvanized wired net, with geosynthetics strips designed for soil retention. This new, improved technology has the following functionalities: protection of slopes, aesthetic appeal and respect to sustainability criteria. The design parameter and variables were investigated and tested with a prototype applied on a test site. The performance was evaluated through soil retention capacity, vegetation process and ease of handling. The prototype and its configurations proved to be well adapted for use on surfaces ramps with slopes significantly elevated, indicating that this technology is potentially suitable for vegetation of heavily skewed areas and degraded soils requiring repeated refills of enrichment items until the attainment of minimum conditions for the development of plant cover more effectively.

1. INTRODUCTION

Water erosion on sloping surfaces causes significant damages on agricultural fields, mining lands and construction sites particularly those in infrastructure involving greater earthmoving such as road embankments, rail, lots and works of urbanization. This soil movement may result in cutting slopes or embankments reducing soil fertility and physical conditions for the germination process and plant development.

Projects to prevent or control erosion involve techniques, constructive processes and use of specific products developed from parameters such as mechanical strength, performance in the erosion control, soil and vegetation interfaces, durability, ease of handling and compatibility with the landscape.

A combination of factors like low fertility and susceptibility to erosion processes due to poor soil's physical structure present in most degraded slopes indicates that it is important to provide them with protective vegetation. In this circumstance, it is appropriate to act on two fronts: improvement of fertility by the addition of substrates and protection of the topsoil. These points are the object of study in this article.

2. SCOPE OF STUDY

The soil retention capacity of the metallic mesh with geosynthetic retention strips was evaluated using five types of netting, three different degrees of ramp slope and three percentage of moisture content on the soil. Prototypes were built and applied on an experimental slope.

3. BRIEF REVIEW

3.1 *Erosion surface*

Water erosion process start with the impact of the rain drops on the ground leading to the collapse of their aggregates (splash effect), filling of the pores of the soil surface (sealing) may occur, followed by an increase on the degree of soil saturation and reduction in infiltration, resulting in puddles of water (ponds). Depending on the slope of the land, the ponds will contribute to the occurrence of runoff capable of removing, transporting and depositing sediment from land to other places along the base of the slope (Guerra, 1999; Mafra, 1999; Bandeira, 2003).

Silva (1999) cites the erosive power of rainfall, land cover, characteristics of the slopes and properties of soils (texture, bulk density, porosity, organic matter content, pH, level and stability of aggregates, including the arrangement of the constituents or soil particles and their implications with respect to the movement of water) as factors influencing the erosion processes.

Santos (2003), in the context of urban erosion, addresses the soil surface as a protecting natural seal of land surface and the saprolite soils as the most susceptible to erosion, whether they are sedimentary or crystalline in nature, which is even more critical.

Erosion processes remove fractions of this thin layer of topsoil (*epípedon*) consisting of organic matter and fine mineral fractions reducing its ability to support vegetal cover (Mafra, 1999).

3.2 *Vegetation, geosynthetics and metallic net for erosion control*

According to Styczen and Morgan (1995), the rate of water erosion on soil is limited by the availability of disaggregated particles and the material transport capacity. The same authors accentuate that the main effects of vegetation are the increase of cohesion by strengthening the soil through the roots, considering the tensile strength of the surface potential to collapse.

For Warlouzel (1999), the problem of using vegetation in erosion control is that it requires a period for development, which varies depending on the region plant species and weather incidents. Thus, during the germination and early development, additional measures for soil and seeds protection may be required, like application of mulch, emulsion projection or use of geotextiles.

In construction sites it is not uncommon a time delay between the landscape intervention and earth-moving and the effective re-establishment of plant cover leaving the soil uncovered and increasing the susceptibility to the erosive process.

The selection of materials degradable or not should be guided by the ability of vegetation to quickly establish itself on the ground and completely protect it (Ingold, 2002). In land under adverse conditions, where only the plant cover is not sufficiently able to provide the expected protection, solutions based on non-degradable materials may be applicable.

Vidal (2003) discusses the use of geosynthetics in erosion control differentiating superficial and internal modes. In the case of internal erosion, related to the flowing of particles by the effect of percolation of fluid within the soil, the author suggests preventive control measures to reduce infiltration through the surface cover and drainage as a way of prevention. This is true for early erosion processes. For more critical situations, the particles can be retained through a filter system, reducing the forces of percolation without loss to the drainage of the site. In the case of superficial erosion, the preventive actions are based on some type of surface lining, using either natural or synthetic materials to provide protection for longer time. In this regard, the geosynthetics act by reducing the impact of rain drops and runoff. The effects of geosynthetics are typically combined with the role of vegetation in question. The geosynthetics can promote the stability of the layer of vegetable soil by restraint and confinement as in the case of geocells by locking the vegetation in the case of geogrids and by adding protection as in case of direct biomats.

The metallic nets used in geotechnical applications work by improving stability against erosion thus preventing superficial landslides. The nets may have hexagonal mesh with double twist, lozenge woven or square welded mesh. The configuration of the mesh and the limit strength of yarn characteristics are interdependent. The double-twist hexagonal mesh and square welded mesh are usually made of steel wires of low carbon content, with strength in the range from 400 to 900 N/mm^2. The lozenge mesh admits the use of low or high-carbon wires, whose strength can reach values close to 1770 N/mm^2.

The mesh can be coated against corrosion. Considering the permanent contact of the material with the potentially aggressive soil and environment galvanized wire is usually chosen. This material is produced by hot dip process with heavy layers of zinc or alloy ZnAl, Zn 95% Al 5% and additions of more elements of the group of rare earth (Mischmetal), Ce (Cerium) and La (Lanthanum). The wire zinc (Zn alloy or Zn95Al5) may also receive additional plastic coating, especially PVC.

4. THE CONCEPTUAL MODEL

The concept of this new product consists on galvanized mesh that supports retention strips made with geosynthetics. The retention strips are enriched with soil substrate stored in containing cells. It is aimed at improving the capacity of the soil to support vegetation in steep slopes. The setting, steel mesh and retention strip are stapled on the surface of the slope working as a mechanical reinforcement and partially covering the surface portion of soil, making it less vulnerable to the erosive process before and after the establishment of vegetation. The added substrate can contain a mixture of fertile soil with seeds of species adapted to the region, balanced proportions of corrective fertilizers, humus, organic compounds, or specific polymers to retain moisture, creating better conditions to the germination process and plant development. The retention strips are expected to be able to retain the substrate added to the surface providing a more favorable micro-climate under strips, the availability of a fertile material and seeds to vegetate a slope or hillside.

Figure 1 illustrates the product showing the piece of hexagonal wired mesh, composed of geosynthetic slots filled with substrate. The image on the right shows the slot detail. In the back side, an opening in the geosynthetic slot allows the roots to establish in the land surface.

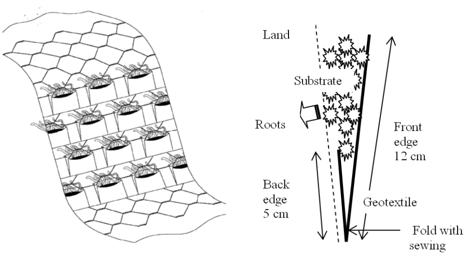

Figure 1 – Illustration of the proposed model with strips of cells filled with substrate.

The product should be installed from the crest of the slope or hillside being unrolled in bands from top to bottom. To cover the entire surface to be protected, successive woven panels of netting can be placed side by side and stitched together by tie-points using the wired staple. The loading of the retention strips with soil substrate is also done from the crest of the slope.

The retention strips can be made of geosynthetics accepting biodegradable materials or not. Its specification will depend, above all, on the purpose and conditions of the slope. It is understood that the conceptual model presented is suitable for steep slopes and embankments whose surfaces are in extremely poor conditions, with severe limitation to establishment of protective vegetation. In situations of degraded areas such as slopes of mining pits, the substrate in the retention strip may need refilling to maintain the vegetation. Thus, the design must have a minimum strength as well as a life consistent with the time for the establishment of vegetation. The prototype designed in this study appears on Figure 2 using galvanized welded mesh and a geotextile type woven. The geotextile is made of polypropylene wide-width tensile strength (NBR 12824) of 25 kN, with low to normal permeability to allow greater retention of moisture. The thinner portion of the substrate should not allow generation of hydrostatic pressure.

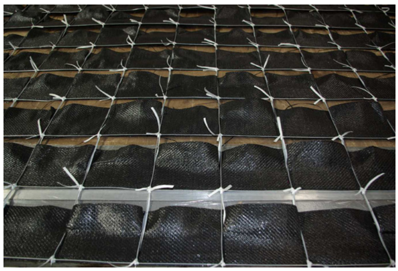

Figure 2 – Prototype of the product made with galvanized weld mesh and geotextile.

5. METHODOLOGY

5.1 *Ramp Test*

Different prototype configurations were tested to analyze the substrate retention capacity of the retention strips. There parameters varied were the geosynthetic netting type, ramp inclination and moisture content of the soil. Across the netting types were employed five product configurations as described in Table 1. A test ramp fitted with an articulated platform simulating condition ramp at three angles (40, 60 and 80°) and a mixture of soil and organic substrate managed at three levels of soil moisture (10, 18 e 21%).

The test procedure involved the positioning of the test ramp in each angle and manually dropping the soil-substrate mixture (2:1) from the top, filling first retention strip and subsequently the lower ones, as the substrate overfilled the slots and moved down ramp. Different constructive configurations, with changed slot position in the retention strips were tested in order to find the best condition for filling the cells.

As response variables it was measured the substrate mass applied at the top and drained mass at the bottom of the ramp. By subtracting the soil mass at the bottom from the amount added at the it was obtained the mass of the substrate retained in the cells of the retention strips.

Table 1 – Description of product characterized for metallic net and retention strip from geosynthetic

Code	Configuration	Cell nr.	Geotextile
T1	Retention strips in alternating lines with the total background textile and front edge (12 cm)	18	Jute
T2			Geotextile (woven of polypropylene) wide-width tensile strength of 25 kN
T3	Retention strips in alternating lines with the back edge (5 cm) and front edge (12 cm)		
T4	Retention strips in all lines, with the back edge (5 cm) and front edge (12 cm)	35	
T5	Retention strip in alternating lines with only the front edge (12 cm)	18	

Note: All models had as metallic net a square welded mesh (6x6"), produced with Bezinal wire (gauge of 2,00 mm).

Figure 3 shows the ramp during application of substrate in the configuration of netting T4 and inclination of 40°.

Figure 3 - Device used with T4 in 40°.

5.2 *Application and product handling in the slope*

In order to evaluate the handling on the field, an experimental embankment approximately 20 meters long was selected. It consists on a deep B horizon, uniform and with compact surface, not presenting problems of water percolation or any evidence of water flow or erosion due to preferential groundwater flow. It was divided into nine plots, each one with 2 meters width resting two lateral ranges as borders. Each plot received a retention system as shown in Figure 1, with variations on the position of the slots (Table 2). A "control plot" did not receive any retention system and had the plant species planted through small holes in the soil.

Partition walls using textile were built at the bottom of the embankment to analyze the soil loss individually, plot by plot (Figure 4).

Table 2 – Design of the experiment

Plot	Slope	Block	Treatment
1	43º	I	Control plot
2	43º		Retention strips in intercalated lines
3	44º		Retention strips in all lines
4	52º	II	Retention strips in intercalated lines
5	53º		Retention strips in all lines
6	54º		Control plot
7	56º	III	Retention strips in all lines
8	57º		Retention strips in intercalated lines
9	58º		Control plot

Figure 4 - Detail of the partition wall and overview of the drainage channel fitted with all divisions of parcels.

The handling of the product during its installation procedure allowed for the elaboration of a standard procedure as summarized below:

- The roll should be positioned at the top of the embankment to be unfolded as illustrated by Figure 5-A;
- The roll is then unwound. Due to its own weight the cylindrical roller rolls over the surface of the embankment until it is fully open as illustrated in Figure 5-B;
- The netting cloth must be adjusted to find the best position of coinciding with another cloth already unwound;
- Excess of netting should be cut to provide a good finish;
- Stapling: the fixation process is initiated by crimping of the wired staples over crest. Then, it is clipped at the bottom of the embankment on, the side edges, on the longitudinal axis and interior. The Figure 5-C and D show installers doing the clipping over crest and edge respectively.

The plant species were selected based on landscape, multiplication by seeds, the incorporation of Nitrogen on soil, well adaptation to slopes and indication for environmental recovery. On this basis was selected the species *Arachis pintoi*, a legume commonly known as peanut-grass.

In the control plot, seeds were placed in each hole followed by manual distribution of the substrate over them.

The retention system was filled with substrate dropped from the top, using 8-liter buckets along the crest of the embankment. Although seeds could also be included together with the substrate, they were sown manually in each cell slot.

The experiment counted on an irrigation system.

Figure 5 – Procedure to install the netting

5.3. *Initial evaluation of the vegetation process*

The process of vegetation establishment was monitored on the experimental embankment 70 days after planting. The cells and pits marked with vegetation were counted and photographed to allow visual evaluation of soil coverage.

6. RESULTS AND DISCUSSION

6.1. *Ramp test*

Table 3 presents the Descriptive Statistics regarding applied mass, retained mass and retained percentage. Figure 6 plots the interaction of the effects to retained mass per cell.

It was observed a higher retention capacity of substrate plots filled retention strips in all lines.

These results coupled with field observations indicate that the retention capacity of this product is directly proportional to the number of strips and the uniformity of the opening of their containing cells type.

Table 3 – Descriptive Statistic.

Variables		Applied Mass			Retained Mass			% Retained		
		Mean (Kg)	St Dev (Kg)	Coef Var (%)	Mean (Kg)	St Dev (Kg)	Coef Var (%)	Mean (%)	St Dev (%)	Coef Var (%)
Netting	T1	31,6	6,3	20	17,3	7,5	43	55,0	17,5	32
	T2	28,0	6,9	25	18,1	7,0	39	64,4	14,1	22
	T3	27,0	4,8	18	15,4	5,5	35	57,2	16,8	29
	T4	53,5	6,3	12	33,1	12,5	38	61,8	20,6	33
	T5	35,1	6,6	19	17,8	7,8	44	51,9	21,0	41
Slope	40º	39,0	10,6	27	28,0	12,7	45	70,2	17,8	25
	60º	30,0	11,1	37	19,2	6,7	35	64,7	7,1	11
	80º	36,1	11,4	32	13,9	4,5	32	39,3	8,0	20
Soil moisture	10%	36,7	12,2	33	17,1	6,2	36	48,1	12,6	26
	18%	33,1	10,4	32	20,6	10,3	50	61,4	16,8	27
	21%	35,3	12,1	34	23,4	12,9	55	64,7	20,1	31

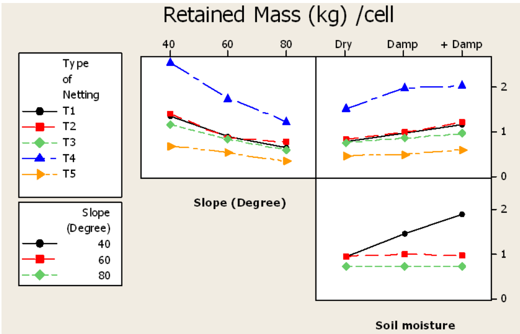

Figure 6 – Interaction plot for retained mass per cell in Kg

6.2 *Application and product handling in the slope*

The stapling operation of the netting over the embankment surface is a key operation for the proper functionality of the product. The experiment generated a density of approximately 5 staples per square meter.

For purposes of measuring the operating cost the execution times were recorded and the productivities presented in Table 4.

Table 4 – Productivity of operation

Task description	Time (hours)	Area (m^2)	Productivity (m^2/hr.man)
Opening of pits	12	21	1,75
Positioning, adjustment, clipping and opening of closed cells	12,75	42	3,29

The geotextile type adopted was well adapted to handling and very resistant to the soil loading, indicating that there is opportunity to use one lighter, with a lower strength and produced with a woven of pores opener.

Another critical factor is the alternation of container cells with flat cells. This alternation is decisive for the perfect flow of substrate and the loading of cells by successive derivation. The poor uniformity of opening the cells of retention at the expense of smooth cells causes inefficiency retention substrate and increase in volume not retained at the bottom of the embankment. This event features a loss of substrate.

6.3. *Initial evaluation of the process of vegetation*

From 40 days after planting lateral branches were observed in the plans that showed more vigorous growth.

It was observed at 70 days after planting, a greater vegetative vigor of plants belonging to blocks I and II.

The Kruskal-Wallis Test was applied on a number of holes or cells with plants past 70 days after planting. The median and the p values are described in the Table 5.

Table 5 – Number of holes or cells with plants (70 days)

Treatment	Median	P value
Control plot	84	0,066
Retention strips in intercalated lines	86	
Retention strips in all lines	115	

7. CONCLUSION

The conceptual model presented is derived from the combination of the well known technology platforms, wired mesh and geosynthetics constituting an additional alternative technique for slopes and embankments protection against erosion surface with an innovative character.

The prototype and its configurations proved to be well adapted for use on surfaces ramps with slopes significantly elevated.

The main constructive aspects observed that determine quality in the installation and performance in using the product can be summarized in the following points: choice of netting with retention strips in all lines of the square grid; retention strip with alternating containing cells and cells type planned; implementing a good clipping to eliminate gaps between the netting and the slope surface; uniform opening of cells containing type and flatness of the smooth cells; access to the crest of the slope to release the substrate; verification of substrate moisture for better substrate dispersion; selection of plant species that do not require maintenance; deployment of the substrate to small volumes and irrigation system if the planting has been performed in months too dry.

This solution model is potentially suitable for vegetation of heavily damaged areas and degraded soils with limited capacity to support vegetation. The latter may require repeated refills of substrate until the attainment of minimum conditions for plant development are attained.

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