Laboratory tests for evaluating the performance of geosynthetics for surface erosion control

N. Touze-Foltz
Irstea, France (nathalie.touze@irstea.fr)

H. Zanzinger
SKZ German Plastics Center, Germany (h.zanzinger@skz.de)

ABSTRACT: The objective of this paper is to describe laboratory tests that are currently under development for evaluating the properties of geosynthetics for surface erosion control. Tests that are described have been listed in prEN 00189224 produced by CEN/TC189 project group SURFACE EROSION CONTROL entitled Geosynthetics – Characteristics required for use in surface erosion control on slopes and banks. These include rain simulation.
A literature review will be presented. The effect of various parameters like rain intensity, slope of the testing device, soil used in the test will be described as far as possible based on the existing data.

Keywords: Geosynthetics, erosion control, slope

1 INTRODUCTION

Soil erosion – the loosening, detachment and transportation of soil particles from their initial position – can generally be attributed to natural processes such as rainfall, runoff, wind and landslides, as well as to man's activities which alter the natural protective cover of the ground surface (Weggel & Rustom, 1992).

Generally, natural materials such as straw, rock, brush, and soil have been used in developing the surface erosion control systems commonly employed to achieve the regulatory goals. However, the exclusive use of natural materials in surface erosion control systems has limitations regarding the quantifiable performance and specification of use in the field. The mass per square metre coverage of straw for hillside erosion control can be greatly affected by the source of the material, handling by the party tasked with installing the system, or any number of issues that may affect the uniformity and installation requirements of the associated specification. The inclusion of geosynthetics in surface erosion control systems has proven to provide significant advantages when used in place of or combined with these traditional natural materials by helping to perform unique and quantifiable functions in surface erosion control applications. For instance, dry and hydraulic mulching techniques such as straw, soil, wood, or other natural material spread over a soil surface in either dry form ineffective when exposed in substantial tensile and shear strength, which makes them ineffective when exposed to substantial storm water runoff. However, when either of these techniques is coupled with a geosynthetic net or grid that helps form a continuous, mechanically connected matrix anchored to the soil surface through pinning or stapling, a quantifiably stronger system can be created.

When these traditional materials are contained within a layer of geosynthetic net or grid, a system can be created that provides greater structural integrity and both uniform and quantifiable flow rates and storage capacity (Sprague & Sprague, 2016).

In the context of the European standardization on geosynthetics, project group "Surface Erosion Control" in CEN/TC189/WG1 is currently developing a standard related to the characteristics of geosynthetics (GSY) required for use in surface erosion control on slopes and banks (prEN 00189224). This European draft standard specifies the relevant characteristics of geosynthetics used in surface erosion control on slopes and banks and the appropriate test methods to determine these characteristics. Among the characteristics required are the results of a rain simulation and a channel simulation experiment. Laboratory experiments to evaluate erosion protection efficiency towards rain simulation are the focus of this paper. Laboratory experiments have the advantage of controlling the factors affecting erosion processes. A design storm of given intensity, duration, drop size characteristics and kinetic energy can be used over and over to test different treatments (Rickson & Vella, 1992). Furthermore the same soil can be used in all tests for the sake of comparison. Replication is thus easier. A literature review, and the work performed in CEN/TC189/WG4 emphasize the fact that parameters to take into account are the size of rain drops, the intensity and duration of rainfall event, the size of the testing apparatus, the kinetic energy of rain drops (height of fall, way to measure the speed of rain drops), the type of soil used in the experiment. Also under discussion is the output of erosion control tests.

2 BACKGROUND

2.1 *Geosynthetic functions in surface erosion control applications*

Sprague & Sprague (2016) define the following functions for GSY in surface erosion control applications:

- *Surface stabilization*
  A GSY placed on a soil surface provides stabilization when it restricts movement and prevents dispersion of surface soil particles subjected to erosion actions (rain or wind), often while allowing or promoting vegetative growth.
- *Vegetative reinforcement*
  A GSY provides vegetative reinforcement when it extends surface erosion control limits and the performance of vegetation.

The GSY is actively controlling the dislodgement of soil called surface erosion control.

2.2 *Advantages of geosynthetic-enhanced surface erosion control products*

The benefits of GSY over traditional or natural systems are described by Sprague & Sprague (2016):

- *Material quality control*: GSY undergo manufacturing quality control to minimize material variation
- *Construction quality control*: GSY can be easily and efficiently deployed.
- *Cost savings*: GSY are generally less costly to purchase, transport, and install than alternative systems.
- *Technical superiority*: GSY are engineered for optimal performance in unique applications.
- *Construction timing*: GSY can be installed quickly.
- *Material availability*: GSY are easily shipped, competitively priced, and readily available.

2.3 *Causes for surface erosion on a construction site*

Surface erosion in a construction site can be caused by:

- Raindrop impact energy causing soil or seeds to dislodge and become mobile
- Overland water flow (sheeting) causing dislodged particles to be carried downslope
- Lateral concentration of water flows (rilling) leading to gully erosion
- Wind erosion causing fine soil particles to become suspended in the air
- Wave, wake, and current erosion on the banks of streams, lakes, ponds, and other permanent water bodies

The ultimate goal of surface erosion control on most construction sites is to prevent soil and seed loss from areas of soil disturbance until the seed can germinate and establish. Thus, most surface erosion control systems are temporary in scope and are used to hold the seed and soil in place until the required coverage of vegetation is achieved. However, some surface erosion control systems are intended to be permanent. These systems remain permanently in place, reinforcing the vegetation long after establishment.

Conventional natural mulches such as loose straw, brush, soil, or compost provide only a few weeks or months of protection to the bare soil seed bed, which necessitates reapplication if arid conditions prevail during initial periods of seed germination. Thus, a diverse offering of GSY such as geoblankets (GBL) and geomats (GMA) have emerged which provide greater strength, enhanced performance, and greater longevity. These GSY-enhanced systems dependably meet two principal objectives: reducing seed and soil loss owing to erosive forces and expediting site revegetation (Sprague & Sprague, 2016).

2.4 *Geosynthetic erosion control products*

There are two categories of geosynthetic erosion control products. The first is termed temporary or degradable and the second is termed long-term or also nondegradable.

- Temporary erosion control products
  - Erosion control netting
  - Open weave geotextile (GTX)
  - Geoblanket (GBL)
- Long-term erosion control products
  - Geomat (GMA)
  - Geocell (GCE)

2.5 *Erosion control performance criteria*

An effective geosynthetic erosion control product is one which absorbs the kinetic energy of rain, slows runoff, promotes water infiltration, and provides the microclimate needed for the germination of seeds and the subsequent establishment of a self-sustaining vegetative mat to provide permanent erosion protection. It may also be proposed that when channel flow, currents, or waves predominate, the ability to provide long-term armouring is requisite (Sprague & Sprague, 2016).

To accomplish these functions, a well-designed geosynthetic requires that:

- When used on slopes, the primary consideration of GSY-systems is their ability to reduce soil loss caused by rain and immediate runoff.
- In channel lining applications, flowing water imposes shear stress on the sides and bottom of the channel. Thus, the lining must provide acceptable hydraulic shear resistance.
- When used to provide short-term mulching, along with erosion protection there is a need to nurture initial seed germination and vegetation growth.
- Additionally, to provide extended mulching in arid regions, permanent GMA, or extended armouring, it must be shown that the GSY has the appropriate functional longevity.
- As a dynamic filter, the GSY must have sufficient durability to survive installation and be selected to have compatible openings and permeability to ensure clogging resistance.

2.6 *Mechanics of surface erosion*

The susceptibility of soil to wind or rain erosion is quantified by its erodibility (Ingold & Li, 2012). For rain erosion this can be conveniently expressed in units of mass of soil loss per millimetre of rainfall. The ability of wind or rain to cause erosion is quantified by its erosivity. The most suitable expression of the erosivity of rainfall is an index based on the kinetic energy of the rain. Thus, the erosivity of rainstorm is a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops.

The mechanism of soil loss by rain erosion is a combination of soil detachment and subsequent transportation. The two prime agents in this are raindrop impacts and overland flow. On impacting with an unprotected soil surface, raindrops loosen the soil particles with the resulting splash of particle-laden water causing an incremental movement of the suspended particles downslope. If the rainfall intensity exceeds the current permeability of the bare soil then surplus water will run down the slope as overland flow transporting both soil particles detached by raindrop impact and particles loosened by the overland flow itself. The ability of overland flow to transport soil particles is approximately an order of magnitude larger than that of rainsplash (Morgan, 1986). Consequently raindrop impact may be regarded as the primary agent of detachment and overland flow as the primary agent of transport (Ingold & Li, 2012).

The magnitude of soil loss resulting from rain erosion will be a function of other variables including slope inclination and length, and of course the degree of protection of the soil.

3 TESTING OF GEOSYNTHETIC EROSION CONTROL PRODUCTS

3.1 *Index property testing*

The draft of a harmonized European Standard prEN 00189224 describes index tests for quality control and also performance tests on GSY such as rain-induced erosion simulation tests on slopes and storm water-induced erosion tests in channels. All tests are summarized in Table 1.

Table 1. Test methods to be used for GSY used in surface erosion control on slopes and banks

Characteristic	Test method
(1) Thickness at 0,2 kPa	prEN 00189224, Annex C
(2) Height	EN 1848-2
(3) Mass per unit area	EN ISO 9864
(4) Tensile strength	EN ISO 10319
(5) Elongation at maximum load	EN ISO 10319
(6) Strength of internal structural junctions of GCEs	EN ISO 13426-1
(7) Strength of internal structural junctions of GCOs	EN ISO 13426-2
(8) Short-term compressive behaviour	EN ISO 25619-2
(9) Rebound resilience	prEN 00189224, Annex D
(10) Flexibility	ASTM D7748
(11) Behaviour at low and high temperatures	prEN 00189224, Annex E
(12) Opening size	prEN 00189224, Annex F
(13) Turf-filling ratio	prEN 00189224, Annex G
(14) Light transmission	ASTM D6567
(15) Water permeability normal to the plane	EN ISO 11058
(16) Water absorption capacity (method immersion)	prEN 00189224, Annex H
(17) Resistance to weathering	EN 12224
(18) Smoulder resistance	prEN 00189224, Annex I
(19) Microbiological resistance (soil burial test)	EN 12225
(20) Root penetration	CEN/TS 14416
(21) Plant growth	ASTM D7322
(22) Environmental harmlessness	prEN 00189224, Annex J
(23) Rain simulation	prEN 00189238
(24) Channel simulation	prEN 00189239
(25) Fire resistance	EN ISO 11925-2 / EN 13501-1

3.2 *Bench-scale testing*

Small-scale tests, also called bench-scale tests, are used additionally in the USA to test the GSY – soil system under carefully controlled standard soil-hydraulic conditions that may or may not simulate field conditions. Bench-scale tests are indicators of system performance but do not take into account the effects of product installation upon performance. Therefore, the results of these tests may not indicate a GSY's actual field test performance (Sprague & Sprague, 2016).

Following are the standardized bench-scale tests methods used for GSY:

- *Slope erosion and runoff reduction*
  ASTM D7101, "Standard Index Test Method for Determination of Unvegetated Rolled Erosion Control Product Ability to Protect Soil from Rain Splash and Associated Runoff Under Bench-Scale Condition"
- *Permissible shear and channel erosion*:
  ASTM D7207, "Standard Test Method for Determination of Unvegetated Rolled Erosion

Control Product Ability to Protect Sand from Hydraulically Induced Shear Stresses Under Bench-Scale Condition”

3.3 *Field performance testing*

Field performance tests have been developed in USA to simulate expected field conditions to report performance properties of as-installed GSY. Standardized, field tests have been developed for slope and channel erosion applications. Products are installed per the product manufacturer’s published installation recommendations. The results of these tests indicate actual field performance and are acceptable for use in performance specifications and often in design calculations (Sprague & Sprague, 2016).

Following are standards commonly used in USA for full-scale evaluations of GSY:

- ASTM D6459, “Standard Test Method for Determination of Rolled Erosion Control Product Performance in Protecting Hill Slopes form Rainfall-Induced Erosion”
- ASTM D6460, “Standard Test Method for Determination of Rolled Erosion Control Product Performance in Protecting Earthen Channels from Storm Water-Induced Erosion”

The slope erosion test (ASTM D6459) is conducted on one bare soil control and three replicate GSY protected soil 1V:3H slopes. Rainfall is simulated at target intensities of 51, 102 and 152 mm/h, which are applied in sequence for 20 minutes each. Runoff form each slope is collected and soil loss is measured. From these data, the GSY protected soil loss can be compared with the soil loss of the bare soil control.

For channel erosion (ASTM D6460), the test is conducted in a rectangular flume with at least four sequential increasing flows applied for 30 minutes each (unvegetated conditions) or 60 minutes each (vegetated conditions). Unvegetated GSY protected channel testing is typically performed in a 10% slope flume. Vegetated GSY protected channel tests are typically performed in a 20% slope flume. The limiting or permissible shear stress is defined as the shear stress necessary to cause an average of 13 mm of cumulative soil loss over the entire subject test area and can be compared with the hydraulic shear stress caused by project-specific channel flows.

Data from ASTM D6459 and ASTM D6460 are used for characterizing and differentiating between various GSY and hydraulically applied erosion control product types (Sprague & Sprague, 2016).

A GSY is designed to reduce soil erosion and assist in the growth, establishment and protection of vegetation.

A hydraulically applied erosion control product is defined as a manufactured, temporary degradable, pre-packaged fibrous material that is mixed with water and hydraulically applied as slurry designed to reduce soil erosion and assist in the establishment and growth of vegetation.

3.4 *Erosion control performance testing of geosynthetics*

Performance testing of erosion control geosynthetics started in the late 1980s. Performance testing of a geosynthetic erosion control product typically refers to its ability to reduce sediment yield and/or allow vegetation establishment (Ingold & Li, 2012).

Laboratory experiments usually performed to evaluate the efficiency of erosion control can be divided into four types:

- Rainsplash tests;
- Runoff tests;
- Runoff generated from rainfall only experiments; and
- Combined rainfall and runoff tests.

Rainsplash only tests assess the ability of the GSY to control rainsplash erosion, with no runoff being generated. Soil detachment thus dominates the erosion process, as the prime agent of transport. In runoff only tests, an even flow of water can be applied just above the test bed and overland flow is simulated. In combined rainfall and runoff experiments the runoff might be generated by the simulated rainfall or generated by a flume or other apparatus (Rickson, 2000).

Only runoff generated from rainfall only tests are described in the following. Indeed, as the surface of testing plots increases, runoff is usually generated and focusing on rainsplash is from this point of view not sufficent. Small test plots make no sense if one wants to be able to incorporate the spatial variability of GSYs and get a testing device allowing incorporating a representative size of GSY.

4 RUNOFF GENERATED FROM RAINFALL ONLY EXPERIMENTS

4.1 *Review of testing devices and experimental conditions*

In rainfall experiments, rainsplash occurs but as the length of the testing cell is long enough runoff takes place as a consequence of rainfall.

The first study mentioned in the literature was presented by Cancelli et al. (1990). The experiments by Cancelli et al. (1990) were performed in a steel box placed on a bearing structure. The box is 1.5 m long and 1 m wide. It is 0.2 m deep. It is divided in two equal parts by a steel sector so that two tests can be carried out together. The box can be placed to any inclination. Measuring tanks are placed under the lower side of the box to collect and measure the runoff and infiltration water. The test includes a runoff simulator which is not the focus of this paper. Cancelli et al. (1990) also designed their experimental testing device in such a way that a rainfall simulator can also be used.

As many authors acknowledge, the rainfall simulator is the critical part of the testing device, which is leading to many discussions in CEN/TC189/WG4, in charge of preparing a standard on rain simulation erosion tests.

Indeed, the rainfall simulator has to simulate the natural rain drops distribution which ranges between 2 and 5 mm for the rain intensities used by Cancelli et al. (1990).

Subsequent testing devices were also developed on the same principle as the testing device from Cancelli et al. (1990) included the one by Böker et al. (2012) (see Figure 1). A synthesis is reported in Table 2 as regards the testing conditions in the various experiments that could be found in the scarce existing literature.

Table 2. Synthesis of testing conditions according to different authors

Authors	Cancelli et al. (1990)	Böker et al. (2012)	Midha & Suresh Kumar (2013)	Mawenu (2014)	Urroz & Israelen (1990)
Device size: length width depth	1.5 m 1 m 0.2 m	2.35 m 1.1 m 0.2 m	0.75 m 0.5 m 0.25 m	2 m 1 m 0.1 m	6 m 0.8 m approx. 0.2 m
Slope angle	26.6° (1V:2H)	33.7° (1V:1.5H)	15°, 30°, 45°	7°, 15°	up to 43°
Soil	50% of medium sand, 30% of very fine sand, 20% of silt	clay, sandy loam and loamy sand		sandy loam (75% sand, 14% silt, 11% clay)	63% sand, 24% silt, 13% clay, 1.4% organic matter
Rainfall intensity (mm/h)	75 (30 min per step)	10, 20 and 60 (420 min)	100 (3 trials of 3 min, each at 3 min intervals)	112 (15 min or 30 min)	- (40 min)
Raindrop diameter (mm)	1.5 - 2.8				
Vegetation		without, 30% and 60% coverage			

Figure 1. Testing device (SKZ, 2011)

4.2 *Rainfall simulator*

The rainfall simulator is a key aspect of the constructed devices. It will control the size and energy of the rain drops that will affect the erosion. Weggel & Rustom (1992) give an insight in the various types of rainfall simulators that can be designed and the number of different types which is larger than 100 at the time of writing of their paper. This emphasized the difficulty to choose the right type of equipment.

Rather than the question of the type of equipment, the focus could be the effect it has on the drop size, range of drop size, terminal fall velocities and intensities. This question is still one to solve. It is thus of importance to make a synthesis on the key parameters. This synthesis is presented in the following and may hopefully ease the decision in CEN/TC189 as regards the elaboration of the standard.

5 INSIGHTS IN THE RAIN FEATURES

5.1 *Rainfall intensity*

In order to produce runoff, it is important that the rainfall intensity is greater than the infiltration capacity of the soil. All other parameters are correlated with this one (Cancelli et al., 1990).

5.2 *Drop size*

While discussing the question of the drop size, various approaches were mentioned by the experts in WG4.

The first one is the one reported by Humphry et al. (2002) developed by Eigel & Moore (1983). The principle is to catch rain drops in a Petri dish containing a 2:1 ratio mixture of two different oils. 13 Petri dishes are exposed to the rainfall and the experiment is repeated twice. The oil mixture suspends the water drops in a sphere. A digital image with a scale allows quantifying the drop size and size distribution.

In the second approach flour is used as a detection material to measure the drop size. It is based on a protocol by the Erosion Control Technology Council (ECTC). Cups of flour are uncovered for a few seconds in order for the rain drops to strike the flour surface and create pellets. Cups of flour are dried during 12 hours at least at room temperature. Flour and pellets are carefully sieved through a sieve of 70 meshes/cm. Pellets which stayed in the sieve are dried during 2 hours at 43°C. Total weight (per cup) of the pellets is measured. The dry pellets represent the distribution of raindrops from the rainfall simulator.

Another possibility is to use “Water-indicator-paper” which is hold into the rain for a few seconds. Contact with water produces a deep blue colour of the indicator-paper. Drop-size distribution can then be determined easily.

5.3 *Drop velocity*

This parameter is universally recognized as the most important factor in rainfall erosion. The kinetic energy of rain drops is proportional to the mass of the drops and to the square of the impact velocity. The mass of drops is proportional to their diameter. It is proved that drop size is related to the rainfall intensity (Cancelli et al., 1990).

The final velocity v of drops is related to the drop mass, cross-sectional surface and drag coefficient according to Equation 1:

$$v = \sqrt{\frac{(2 \times m \times g)}{(c_w \times \rho_{air} \times A)}} \quad (1)$$

m = mass of drop;
g = gravity;
c_w *= drag coefficient of rain drops*[*)]*;*
[*)] *drop-shaped: 0.06; spherical: 0.4 – 0.45; concave-plate-shaped: 1.2*
ρ_{air} *= density of air;*
A = cross- sectional surface

While falling and accelerating the rain drops (especially the bigger ones) start changing their shape from spherical to finally concave plate shaped along with an increase of the drag coefficient.

Cazzuffi et al. (1991) developed a rationale to calculate the rain drop velocity, not reported here.

5.4 *Kinetic energy*

The kinetic energy is finally only a function of the drop diameter. It is therefore very important to reproduce in the laboratory the size of raindrops characteristic of a given rainfall intensity.

6 INDICATORS OF THE PERFORMANCE OF EROSION CONTROL

Thomson & Ingold (1988) defined yield factor, YF, and protection efficiency, PE. The yield factor is the ratio of the weight of soil eroded from a protected plot to the weight eroded from an unprotected plot under the same conditions.

$$YF = \frac{\text{soil loss with protection}}{\text{soil loss without protection}} \quad (2)$$

$$PE = (1 - YF) \times 100 \quad (3)$$

Similar approaches, with renaming the above two factors were used by Böker et al. (2012), Midha & Suresh Kumar (2013) and Mawenu (2014).

7 CONCLUSION

The objective of this paper was to make a brief synthesis on the existing data regarding runoff generated by rain only experiments, in the context of the development of a European standard to evaluate the performance of geosynthetic erosion control products. After the presentation of the background as regards the source of erosion, the literature on erosion control experiments was presented, for the case of runoff generated by rain. The literature is scarce but emphasizes the fact that the rain simulator is the key element of the testing device. Some insight was given in the features of the rain, and also on the parameter to define to evaluate the performance of erosion control. A single parameter, the yield factor, seems to make consensus.

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ASTM D6567. Standard Test Method for Measuring the Light Penetration of a Turf Reinforcement Mat (TRM)

ASTM D7101. Standard Index Test Method for Determination of Unvegetated Rolled Erosion Control Product Ability to Protect Soil from Rain Splash and Associated Runoff Under Bench-Scale Condition

ASTM D7207. Standard Test Method for Determination of Unvegetated Rolled Erosion Control Product Ability to Protect Sand from Hydraulically Induced Shear Stresses Under Bench-Scale Condition

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