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Evaluation of erosion control geotextiles on steep slopes. Part 2: Influence on the establishment and growth of vegetation

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ABSTRACT

Many laboratory and field studies have assessed the use of geotextiles for soil conservation, identifying the salient properties of geotextiles for an adequate slope protection. However, the influence of geotextiles on vegetation development has received less attention. In the present study, the influence of several geotextiles (a jute net, a coir blanket and a 3D polyester geogrid placed in two positions) on herbaceous vegetation cover has been evaluated during an eighteen-month field experiment on a hydroseeded experimental roadside slope with 45° and 60° slope gradients in Spain. Vegetation cover was monitored by means of a Greenness Cover Index (GCI) computed from photographs acquired weekly during the establishment phase (six weeks) and monthly for the rest of the experimental period. GCI values observed for each treatment were compared with an untreated control plot using an effectiveness indicator. The results indicate that the initial establishment was 2 to 3 weeks faster for the geogrid treatments than for the control, both on the 45° and the 60° slopes. The jute net provided contradictory results in the establishment phase for both slopes with an enhanced cover on the 45° slope but a decreased cover on the 60° slope compared with the control. The coir blanket severely deterred vegetation growth on both slopes, achieving only ~5% and ~56% GCI after the establishment phase for 60° and 45° slopes, respectively. For the rest of the experiment, geogrid treatments had no significant differences with the control on 45° slopes with mean effectiveness values of ~0%. However, biological geotextiles resulted in lower vegetation covers compared with the control with negative effectiveness values on the 45° slope of −33% and −68% for jute and coir, respectively. Reduced vegetation growth in jute and coir plots was due to runoff enhancement on such steep slopes, and in the case of the coir blanket, the reduced growth was also due to the high percentage cover of the material that blocked the contact between plants and soil. Thus, 3D polyester geogrids are recommended for a beneficial joint effect on erosion control and vegetation growth on hydroseeded steep roadside slopes with compacted soils on areas with similar climate.

1. Introduction

Civil engineering projects often result in steep slopes with disturbed, bare soils that are highly sensitive to runoff and erosion processes. Water erosion (splash, sheet and rill erosion) is the primary degradation process on such slopes, frequently leading to a partial or complete loss of the surface soil layer, which is transported downward (Cerdá, 2007). Eroded slopes have a lower fertility due to the loss of soil particles, nutrients and organic matter, affecting the soil structure, water holding capacity and porosity. Consequently, the establishment of plants and the subsequent development of a protective vegetation cover (i.e., seed production, seedling emergence and survival) are hampered (Espigares et al., 2011). Slopes are therefore exposed to further and more severe erosion processes, such as gullies or mass movements, with negative consequences for the slopes' structure (e.g., structural failure and subsidence). Moreover, off-site effects, in the form of sedimentation of eroded soil particles, cause the malfunction of gutters, road ditches and drains with severe consequences in the conservation and safety of roads and other infrastructures (Morgan, 2005).

The existence of a well-developed vegetation cover significantly reduces runoff and erosion rates on slopes (Fullen and Booth, 2006). Vegetation is highly effective for controlling soil erosion processes (Dabney a\nd Gumiere, 2013). Canopy elements protect the soil surface from the impacting raindrops, reducing their kinetic energy and soil detachment capacity (Foot and Morgan, 2005). Canopy elements also intercept rainfall, retarding the process of runoff formation. Stems reduce runoff velocity by increasing the hydraulic roughness of the slope (Weltz et al., 1992). Vegetation roots increase aggregate stability and promote infiltration, thereby reducing overland flow rates (Fullen and Booth, 2006). In addition, roots also increase soil cohesion and shear strength, thus reducing its erodibility and physically binding soil aggregates (Gyssels et al., 2005).

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Engineered slopes (both fill and cut slopes) exhibit constraints in the development of vegetation because they are specifically designed to be stable from a mechanical point of view, and not to facilitate plant colonisation and growth (Coppin and Stiles, 1995). Fill slopes are normally heavily compacted to limit water infiltration to enhance stability, whereas cut slopes expose deep soil strata (sometimes even rocky or uncohesive materials), which have experienced natural compaction. Additionally, water is very frequently excluded from those slopes by building drainage control features (e.g., gutters or benches) on their tops to reduce overland flow. Both types of engineered slopes (cut and fill) normally represent hostile conditions for vegetation growth so that human intervention is often necessary to speed up the natural process of plant colonisation.

Surface preparation techniques (i.e., soil amelioration and cultivation) can enhance seedling emergence and survival, but are often hampered by the difficult access by machinery on the steep and long slopes (Coppin and Stiles, 1995). Similarly, seeding with conventional machinery is not normally possible, and specific seeding techniques have been developed for these slopes. For herbaceous species, hydroseeding is often the most convenient option. Hydroseeding is the application (i.e., spraying) of a mixture of water, seed, fertiliser, mulch and a tackifier (an adhesive) on the slope, which offers a quick and cheap alternative, particularly for large-scale projects and steep slopes. In addition, the mulch and fertiliser provide enhanced conditions for seed germination and the tackifier binds seeds and soil particles, limiting seed washout, which could otherwise be significant during this initial phase of plant colonisation (Cerdá and Garcia-Fayos, 2002). Appropriate seed species need to be carefully selected. This is especially important in areas with periods of water scarcity (such as in locations with Mediterranean climates), where revegetation with species not adapted to the local conditions yields poor results (Bochet et al., 2010). The period before the vegetation matures and becomes fully established is crucial because of the high vulnerability of a poorly-covered slope. For these very first phases, geotextiles, or erosion control mats, are the most convenient method for offering immediate soil protection on steep slopes (Hann and Morgan, 2006).

In fact, the deployment of geotextiles (made from either synthetic or biological fibres) over an engineered slope is one of the most commonly used erosion control measures (Bhattacharyya et al., 2010). Ideally, geotextiles should have a double function for soil protection: (1) direct protection of the soil surface from the eroding action of rainsplash and runoff, and (2) promotion of vegetation establishment and growth. The effectiveness of geotextiles in reducing runoff and soil loss depends on their physical characteristics as well as on the environmental conditions of the site (e.g., soil conditions, slope gradient and length, and precipitation regime) (Bhattacharyya et al., 2010). The salient properties of a geotextile for reducing soil loss are (1) its percentage cover (i.e., proportion of ground covered by the geotextile fibres), (2) the geotextile-induced roughness, (3) its water-holding capacity, (4) its weight when wet, and (5) its ability to retain flow (Rickson, 2006). Geotextiles with high a percentage cover are most effective in reducing rainsplash erosion (Bhattacharyya et al., 2010), and materials with a greater roughness decrease overland flow velocity (Chen et al., 2011). A high moisture sorption depth enhances infiltration and promotes a tight attachment of the wet geotextile to the soil (termed drapability) (Mitchell et al., 2003). In addition, designs with transverse structures create a network of microdams that retain flow and promote sedimentation (Chen et al., 2011).

Geotextiles can be constructed of either biological or synthetic materials. Biological geotextiles (made from natural fibres, such as coir, jute, palm, etc.) are effective in erosion control (Bhattacharyya et al., 2011a) and their cost is much lower than that of synthetic products, making them particularly suitable for developing regions (Fullen et al., 2011). Synthetic geotextiles are usually made of polymers that have a higher tensile strength and last longer (≥20 years) than the biological materials (~2–5 years) (Li and Khanna, 2008). Biological geotextiles, however, are completely biodegradable and contribute organic matter to the soil (Fullen et al., 2011). The performance of a geotextile is influenced more by its physical properties (mentioned above), than by the geotextile material itself (Ziegler et al., 1997).

A large number of studies have focused on the effectiveness of geotextiles in reducing runoff and soil loss (Bhattacharyya et al. (2010) provided a review on this topic), but very few have evaluated the influence of different geotextiles on the success of plant establishment and canopy development (Bhattacharyya et al., 2012; Rickson, 2000). Rickson (2000), in a greenhouse experiment, observed that soil trays covered with geotextiles tended to increase seed germination rate and vegetation growth. However, high density blankets inhibited the vegetation emergence and provided a significantly lower final vegetation cover than all of the other experimental treatments, including the control (Rickson, 2000). Field experiments carried out in tropical regions of Asia (Bhattacharyya et al., 2012; Vishnudas et al., 2006) resulted in an increase in the biomass and yield of several crops on plots covered with biological geotextiles compared with uncovered control plots. These improvements were mainly attributed to better soil conditions (i.e., higher moisture content and lower soil temperature) in the geotextile-covered plots during critical crop growth stages, rather than better emergence or crop stand (Bhattacharyya et al., 2012). On a roadside slope in Lithuania, Bhattacharyya et al. (2012) observed that the enhancement of above-ground grass biomass with the use of biological geotextiles was greater in a dry year than in a wet year due to the soil moisture conservation effect. Nevertheless, plots covered with wheat straw mats produced very similar grass biomass amounts to those of uncovered control plots for the same roadside slope in Lithuania (Bhattacharyya et al., 2012).

In some cases, geotextiles might also have deleterious effects on vegetation growth. Depending on the local conditions, reduced evaporation rates of geotextile-covered slopes might result in poorly aerated soils, where fungal infestations and other plant health problems could be facilitated (Bhattacharyya et al., 2011a). Geotextiles with high a percentage cover, although effective for reducing erosion rates, could deter vegetation restoration because the seeds might not reach the soil due to small apparent openings (Chen et al., 2011).

In this paper, the influence of geotextiles on the establishment and growth of herbaceous vegetation was evaluated in an outdoor experimental setting in Spain. The research hypothesis was that geotextiles had an effect on vegetation growth and that this effect might be different depending on the type and characteristics of the geotextile used. Therefore, the objective of the research was to evaluate and compare the effects of different geotextiles (synthetic and biological) on vegetation establishment and growth on steep (i.e., 45° and 60°) roadside slopes.

2. Materials and methods

2.1. Experiment details

An experimental slope was built in the experiment fields of the School of Agricultural Engineering, Public University of Navarre, Pamplona, Spain. Compared to laboratory plots, outdoor settings are more convenient for medium to long-term experiments where natural precipitation and vegetation dynamics are required. The experimental setting was designed to reproduce, as closely as possible, a typical engineered slope. Therefore, earthworks, as well as geotextile installation and vegetation seeding, were performed following standard engineering practices. Full details on the experimental setting are given in Álvarez-Mozos et al. (2014).

The climate in the region can be classified as humid sub-Mediterranean, with a mean temperature of ~12 °C and total precipitation of ~800 mm. Precipitation is seasonal, with wet springs and autumns and dry summers. The soils in the area are silty-clay-loam in texture and the experimental slope was mechanically compacted (to reproduce typical earthworks) to a final bulk density of 1.57 Mg m^{-3}.