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Effectiveness of coir-based rolled erosion control systems in reducing sediment transport from hillslopes

Ross A. Sutherland*, Alan D. Ziegler

Geomorphology Laboratory, Department of Geography, University of Hawaii, 2424 Maile Way, Honolulu, HI 96822-2223, USA

Abstract

Accelerated soil erosion is ubiquitous on human-modified hillslopes. A variety of erosion control products have been developed to reduce on-site soil resource degradation, and off-site transport of sediment and sediment-associated contaminants to receiving water bodies. However, limited quantitative data are available to assess erosion reduction effectiveness, and to establish the salient properties of the erosion control products. A replicated field-based rainfall simulation study was conducted to compare the runoff and erosion effectiveness of three coir (coconut) fiber rolled erosion control systems (RECSs) with a bare (control) treatment. Detailed temporal measurements of runoff and sediment transport were made during two phases of each experiment: (1) a 110-min application of rainfall via a rainfall simulator at 35 mm h^{-1} after runoff initiation and (2) a 30-min period, at 3 times the flow rate of phase 1, applied via an overland flow generator. All coir treatments enhanced infiltration, delayed time to runoff generation, reduced intensity of rill incision, and reduced sediment output compared to bare treatments. More importantly, statistically significant differences were observed between coir RECSs of different architecture. For the two open weave coir systems tested, the most effective design had a higher mass per area, and less open space between the regularly aligned grid of fibers. The random fiber coir architecture was the most effective, having significantly lower runoff sediment concentrations, lower sediment yields, and a lower frequency of rill initiation. The differences in system architecture are examined in light of fundamental controls on runoff and erosion processes.

Keywords: Coir; Erosional effectiveness; Rill initiation; Runoff; Sediment transport; System architecture

*Corresponding author.
E-mail address: Sutherla@Hawaii.edu (R.A. Sutherland).

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Introduction

Human modification of the landscape commonly results in accelerated erosion and concomitant environmental degradation. On-site and off-site impacts associated with erosion are estimated to cost approximately $\$44 \times 10^9$ per year in USA alone (Shepley, Smith, & Jackson, 2002). Today, environmental and economic costs associated with accelerated erosion are not considered acceptable. In many developed countries, a vibrant erosion control industry (ECI) has formed to mitigate erosion on slopes modified by construction activities, road, and highway building (Sutherland, 1998b).

Erosion control specialists, construction site engineers and landscape architects have a number of ‘tools’ at their disposal to keep soil on site. These erosion and sediment control practitioners are required to identify the most appropriate and cost-effective best management practices (BMPs) for their erosion control plan. For immediate surface protection, the most commonly used non-structural BMPs on construction site slopes include straw bale barriers, silt fences, loose organic mulches, rolled erosion control systems (RECSs), hydraulically applied hydro-mulches, and dust suppressants (Raskin, DePaoli, & Singer, 2005; Sutherland, 1998b; USEPA, 1995).

Research has shown that RECSs (also known as ‘geotextiles’ in UK) are one of the most appropriate BMPs for hillslope protection (Hann & Morgan, 2006; Nelsen, 2003; Sutherland, 1998b). A wide variety of RECSs are manufactured to capitalize on a multi-million dollar market. Rolled systems can be grouped into those composed of natural fibers with life spans ranging from 0.5 to 6 years (temporary), or synthetic fibers that are considered permanent fixtures. Natural fiber RECSs include jute, coir (coconut), excelsior (wood strands), and straw. Application of RECSs usually occurs on bare slopes after broadcasting a rapidly germinating seed mixture for long-term erosion protection. Natural fiber systems are increasingly favored, as they are biodegradable, less costly to produce and to apply, environmentally friendly, equally effective in reducing erosion, and generally provide a favorable microclimate for biomass production (Sutherland, 1998b, c; Sutherland, Menard, & Perry 1998; Sutherland, Menard, Perry, & Penn, 1998). Coir, for example, has been increasingly applied to human-modified hillslopes. Several recent studies have found coir RECSs effective in reducing erosion from degraded hillslopes (Lekha, 2004), highway embankments (Benik, Wilson, Biesboer, Hansen, & Stenlund, 2003), railway embankments (Gyasi-Agyei, 2004), and from slopes similar to construction sites (Krenitsky, Carroll, Hill, & Krouse, 1998). Most published studies, however, have failed to examine the detailed temporal response of the systems under stress, and have overlooked links between system properties (e.g., fiber geometry) and basic physical erosion processes (e.g., splash, wash, and rill erosion). As Thompson (2001) states, “long-term progress in selecting erosion control measures can best be made by obtaining a better understanding of the interactions of the control measure and fundamental erosion principles”.

Land managers, department of transportation personnel, and erosion consultants are faced with a wide variety of RECSs to choose from, but little rigorous quantitative data for optimal decision making. Even for a given natural fiber there may be several design architectures, each with unique cardinal properties (i.e., physical, chemical, and hydraulic). Coir RECSs have two common architectures. The first is a randomly oriented set of loose fibers stitched with thread between two nets. This type typically has a low mass per unit area (200–300 $g\,m^{-2}$), and limited open space between fibers ($<10\%$). The second type of