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Reduction in interrill sediment transport by rolled erosion control systems

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Abstract

Rolled erosion control systems (RECS) reduce detachment and transport of sediment by mitigating the basic processes of run-off and erosion (e.g., splash detachment, interrill transport, run-off velocity, surface crusting). Despite the variety of products available in the market today, only limited research has been conducted on their influence on erosion subprocesses. This study addresses some of the limitations of previous research by using laboratory rainfall simulation to study rainsplash sediment redistribution, run-off, total interrill sediment transport, and aggregate size transport from an erodible Vertisol. Three 3-h rainfall simulations were conducted on a 20° slope at a rainfall intensity of ≈ 100 mm h^{-1} on (1) a bare soil control, (2) four predominately *natural* RECS, and (3) four synthetic RECS. Data indicate that all products significantly reduced run-off (enhanced infiltration), and decreased interrill sediment transport compared to the bare soil control. However, it was observed that several products (C125, Curlex I, Geojute, SC150BN, TB1000, and P300) were statistically more effective than PECMAT and TerraJute. Finally, preferential transport of selected aggregate fractions was examined. Cover percentage, three-dimensionality, and drapability were identified as favorable physical attributes for mitigating erosion processes. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Rolled erosion control systems; Interrill erosion processes; Laboratory rainfall simulation

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1. Introduction

Seeding in conjunction with the application of rolled erosion control systems (RECS) is an advantageous approach to mitigating erosion on disturbed hillslopes because RECS

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immediately provide the salient properties of vegetation that deter erosion, thereby providing seeds a greater chance to germinate (c.f., Rickson, 1995). Since introduction in the late 1950s, numerous RECS have been marketed world wide for erosion control (Ingold, 1994). Unfortunately, research on product effectiveness and performance has not kept up with application. Without a detailed scientific understanding of the influence of RECS on erosion and run-off processes no efficient means exist to improve their design, except by trial and error.

2. Objectives

Given the limitations of previous research, we conducted a detailed laboratory interrill study on a variety of commonly used RECS with the following objectives: (1) to statistically assess their effectiveness in reducing surface run-off and redistribution of sediment by the interrill processes of rainsplash and wash; (2) to characterize temporal trends in erosion-control effectiveness to identify thresholds when product performance diminishes; (3) to compare the textural properties of sediment (aggregates) transported from each RECS-covered surface to that from a bare soil control, giving special attention to the <63-μm fraction, which is critical to the transport of sediment-associated pollutants; and (4) to relate product effectiveness to physical design characteristics.

3. Background

3.1. Geomorphological benefits of (RECS)

Most RECS designed for erosion and sediment control are composed of natural (e.g., jute, coir, straw, wood) or synthetic (usually polyethylene) materials, or a combination of the two (Carroll et al., 1992; Ingold, 1994; Rickson, 1995). Application of most RECS can be integrated with reseeding, and by doing so, provides a stable, non-erodible environment in which the vegetation can establish with reduced risk of washout of seeds and seedlings or damage to new shoots (Rickson, 1995). The immediate geomorphological benefits of RECS are that they: (1) reduce the direct impact of raindrops and wind; (2) enhance water infiltration into the soil surface by reducing development of surface crusts and seals, thereby increasing soil moisture storage and decreasing run-off generation; and (3) act as surface roughness elements, thus reducing overland flow velocities and shear stress exerted on slopes. Selection of appropriate RECS depends on the specific type of erosion control desired and in situ conditions (e.g., climate, topography, soil properties). Unfortunately, there is little guidance for selection except manufacturer recommendations and little rigorous scientific evidence to support these guidelines.

3.2. Limitations of previous research

Few data are available in the scientific literature comparing RECS' effectiveness in mitigating erosion processes, rill or interrill. Those data that do exist are difficult to combine or compare. This stems from very different experimental conditions and the general lack of a rigorous statistical framework. An extensive literature review of RECS-related erosion studies has revealed the following limitations: (1) Few comparative studies have been published in peer-reviewed scientific journals; (2) Most studies conducted to date (e.g., many in IECA, 1992, 1993, 1994, 1995, 1996) are *black box* in design, with the primary focus on total output of sediment. Limited attention has been given to examining the influence of RECS on the fundamental processes of water erosion; i.e., detachment and transport by splash and wash (overland flow) are rarely separated. Additionally, there is a dearth of information on the influence of various products on the size of sediment transported; (3) Temporal variation in RECS' reduction of run-off and sediment flux have generally been ignored. Most studies were conducted for less than 1 h in duration; some were as short as 10 min; (4) Few studies in the laboratory or field have been subjected to rigorous experimental design and statistical testing.

4. Experimental set-up

Erosion control effectiveness of eight RECS was tested during 3-h laboratory rainfall simulations on 20° plots using a Hawaiian soil. Simulations for each product and a bare surface control were replicated three times in random order. Run-off and several interrill erosion indices, including sediment redistribution by rainsplash, sediment transportation by wash, total sediment output, and partitioning of sediment transport by aggregate size, were compared for each surface preparation. In addition, temporal dynamics of erosion processes were investigated in detail. Unless otherwise noted, all statistical relationships were determined using analysis of variance (ANOVA) followed by Fisher's protected least significant difference test (FPLSD).

4.1. Soil and RECS characteristics

The erodible clay Vertisol (very fine, montmorillonitic, isohyperthermic, Typic Chromustert; Dangler and El-Swaify, 1976) used in this study was collected from the 0–10 cm depth increment at a site in western Oahu. Samples were sieved through a 4-mm square-hole sieve and air-dried; gravimetric antecedent soil moisture was $10.3 \pm 1.8\%$ (± 1 standard deviation).

Four natural and four synthetic RECS were tested (Table 1). These products represent a comprehensive cross-section of products currently manufactured that are easily obtainable and widely used in the erosion control industry. Selected physical properties related to erosion control effectiveness are listed in Table 1. Light transmission values were estimated using a Sunfleck (Decagon, Pullman, WA) PAR Ceptometer and an intense light source. Light transmission (LT, %) is defined using the following equation:

$$\mathrm{LT} = \left[\frac{\mathrm{RECS\ PAR}(\mu\mathrm{mol\,m^{-2}\,s^{-1}})}{\mathrm{Source\ PAR}(\mu\mathrm{mol\,m^{-2}\,s^{-1}})} \right] \times 100 \qquad (1)$$

Table 1
Selected characteristics of eight RECS

Surface cover	Composition	Mean light transmission (%)	Mean mass/area ($g\ m^{-2}$)	Mean moisture sorbance depth (mm)
C125	Coconut	8.5 ± 2.3[a]	273 ± 46	0.84 ± 0.11
Curlex I	Aspen	38.4 ± 1.4	489 ± 74	0.94 ± 0.15
Geojute	Jute	35.2 ± 3.8	497 ± 11	3.10 ± 0.18
SC150BN	70% Straw and 30% Coconut	5.3 ± 0.8	549 ± 23	2.28 ± 0.19
P300	Polypropylene	13.2 ± 1.2	426 ± 70	0.25 ± 0.04
PECMAT	PVC	29.4 ± 1.4	1260 ± 42	0.23 ± 0.08
TB1000	Polyolefin	18.8 ± 1.4	366 ± 38	0.43 ± 0.11
TerraJute	Polypropylene	71.6 ± 0.4	88 ± 1.0	0.38 ± 0.02

[a] ± represents one standard deviation.

where PAR is photosynthetically active radiation in the 400–700 nm wave band. The potential range of values is from 0 (no light transmission) to 100% (total transmission). Reduction in light transmission is a proxy for RECS cover percentage, i.e., the lower the light transmission, the greater the surface area covered by the product.

Mean mass per area was determined from five randomly selected, 225-cm^2 square samples cut from a larger roll using a metal template (when resting upon the upper surface of a product, the template exerts a force of 14.7 N). Mean moisture sorbance depth is based on five randomly selected samples with dimensions of 15 cm × 15 cm wetted for 24 h, followed by 5-min drainage on a wire mesh. Moisture sorbance depth (MSD) was calculated from the following equation:

$$\mathrm{MSD} = \left[\frac{\text{MASS of Sorbed (kg)}}{\text{Area }(\mathrm{m}^2)}\right] \times C \qquad (2)$$

where C is a conversion factor to millimeters. Sorbance of large amounts of water by RECS influences run-off, infiltration, and evaporation. This factor is important in the early stages of a storm event prior to saturation.

4.2. Rainfall simulation apparatus

A laboratory drip-type simulator was used for this detailed interrill erosion process investigation. Raindrop fall height was 2.0 m and uniform drops with a median diameter of 3.2 mm were produced. Average rainfall intensity, controlled by an in-line pressure gauge, was 102 ± 9.0 mm h^{-1} (± 1 standard deviation) for all events. At this rainfall intensity the simulator produced an energy flux density of about 0.43 W m^{-2}, or only about 72% of natural rainfall with a mean drop diameter of 2.00 mm (Sutherland et al., 1996). Three-hour rainfall events were chosen in an attempt to exceed critical thresholds of product performance and to insure that the entire plot length contributed to run-off and sediment transport by interrill wash, but at an intensity that would not create unreasonable stress on the systems tested. To approximate a random distribution of raindrops at the soil surface, two opposing fans were used to generate turbulence.

The soil tray used in this study had dimensions of 0.30 m (W) × 0.60 m (L) × 0.10 m (D). The bottom of the tray was covered with a 3-cm layer of glass beads. A metal screen with an attached layer of cheesecloth separated the glass beads from a 7-cm layer of sieved air-dry soil. Soil was gently packed to a mean bulk density of 1.15 kg m^{-3}, similar to that found in the field. Drainage from the tray, to prevent saturation overland flow, was achieved without suction through an outlet at the base of the tray.

4.3. Data collection

Three 3-h rainfall events were simulated on all RECS and a bare control in a randomized sequence on slopes of 20°. After each event the soil was discarded to insure comparability in initial moisture content and availability of material <4 mm in diameter. The soil tray was especially fitted with two detachable lateral splash collectors 0.10 m (W) × 0.60 m (L) × 0.50 m (D), and one detachable front splash collector set 5 mm above the soil surface at the plot outlet. Further details of the experimental setup are provided in Wan et al. (1996). The soil surface was approximately 5 mm below the lip of the lateral splash collectors; thus, there was no washover into these collectors.

Surface water was conducted beneath the front splash collector into a beaker system. Therefore, sediment output from the soil tray was partitioned into that transported by rainsplash and that transported by a combination of overland-flow and rain-flow mechanisms. This latter component will be referred to as overland flow or wash in this study. Run-off, lateral side splash, front splash, and wash samples were collected at 10-min intervals throughout each run. All splash and wash samples were wet-sieved immediately after collection into three aggregate-size fractions: <63 μm (silt + clay-sized material), 63–250 μm (very fine to fine sand-sized material), and 250–4000 μm (medium sand- to granule-sized material).

4.4. Calculations

We defined two yield-type factors (c.f., Thomson and Ingold, 1988) describing reduction in sediment transport by wash (RSTW) and splash detachment (RSPD) by each product, where RSTW and RSPD are defined as follows:

$$\mathrm{RSTW} = \left[\frac{\text{Sediment Transport}_{\mathrm{RECS}}\ (\mathrm{g})}{\text{Sediment Transport}_{\mathrm{bare}}\ (\mathrm{g})} \right] \tag{3}$$

and

$$\mathrm{RSPD} = \left[\frac{\text{Splash Detachment}_{\mathrm{RECS}}\ (\mathrm{g})}{\text{Splash Detachment}_{\mathrm{bare}}\ (\mathrm{g})} \right] \tag{4}$$

We also calculated a run-off coefficient (ROC) to quantify the reduction in run-off volume by each product:

$$\mathrm{ROC} = \left[\frac{\text{Run-off Volume}_{\mathrm{surface}}\ (\mathrm{m}^3)}{\text{Rainfall Volume}\ (\mathrm{m}^3)} \right] \times 100 \tag{5}$$

5. Results and disscussion

5.1. Run-off

Mean ROCs differed significantly between the bare soil control and all the RECS (Table 2). The bare soil generated the maximum ROC (mean value of 40.9 ± 15.1%). In comparison, very low ROCs (0.4 to 3.1%) were generated by the straw/coconut SC150BN, TB1000, Geojute, Curlex I, P300 and C125 treatments. Mean ROCs for the first hour of simulation were statistically indistinguishable for all RECS. Fig. 1 shows a delay in run-off initiation for all RECS treatments until approximately 40 min, indicating that all products (1) provided initial protection against surface sealing induced by raindrop impact, thereby increasing infiltration, and/or (2) sorbed significant quantities of water. After 1 h, the protection provided by PECMAT and Terrajute diminished and run-off generation increased, approaching that of the bare control. During the second and third hours of the simulation, the ROCs for these two products were significantly higher than the other RECS products, although still significantly less than the bare surface.

Limited run-off reduction from PECMAT and TerraJute is related to minimal product thickness (<2.5 mm) and inability to sorb large quantities of water (Table 1). PECMAT had the lowest ability to sorb water owing to its impermeable PVC filaments; however, it did retain some water during laboratory testing by surface adhesion. Water was adsorbed between the polyfibers of TerraJute, but the sorbance depth was very limited because of small mass per area and significant open area. The three-dimensionality, high percentage of surface cover, tortuosity of fibers, and ability to sorb water in the early phases of the simulation by the other products delayed run-off initiation, and thus enhanced infiltration and soil-moisture storage.

Table 2
Runoff coefficients (ROC) and standard deviations for eight RECS and a bare control

Surface cover	Mean ROC event total (%)[f]	Mean ROC 0–1 h (%)[g]	Mean ROC 1–2 h (%)[g]	Mean ROC 2–3 h (%)[g]
SC150BN	$0.4\pm0.3^{a,h}$	0.1 ± 0.4^{a}	0.6 ± 0.3^{a}	0.5 ± 0.3^{a}
TB1000	0.7 ± 1.0^{a}	0.2 ± 0.3^{a}	0.4 ± 0.5^{a}	1.6 ± 1.2^{a}
Geojute	0.7 ± 2.1^{a}	0.04 ± 0.2^{a}	1.3 ± 3.6^{a}	0.8 ± 1.0^{a}
Curlex I	1.1 ± 0.8^{a}	0.8 ± 0.3^{a}	0.8 ± 0.2^{a}	1.6 ± 1.1^{a}
P300	1.4 ± 1.4^{a}	0.6 ± 0.3^{a}	0.7 ± 0.3^{a}	3.0 ± 1.7^{a}
C125	3.1 ± 3.4^{a}	0.3 ± 0.2^{a}	2.0 ± 1.9^{a}	7.1 ± 2.4^{b}
TerraJute	16.9 ± 18.7^{b}	0.0 ± 0.0^{a}	10.2 ± 8.7^{b}	40.4 ± 8.7^{c}
PECMAT	27.0 ± 20.4^{c}	2.3 ± 4.2^{a}	30.9 ± 12.7^{c}	47.7 ± 5.0^{d}
Bare	40.9 ± 15.1^{d}	24.6 ± 15.3^{b}	45.3 ± 3.4^{d}	52.7 ± 4.0^{e}

[f] $n=54$ (18 measurements per rainfall event × three replications).

[g] $n=18$ (six measurements per each hour of the rainfall event × three replications), where 0–1 h represents measurements during the first hour of the experiment.

[h] ROC values in the same column followed by the same letter are not significantly different at $\alpha=0.05$.

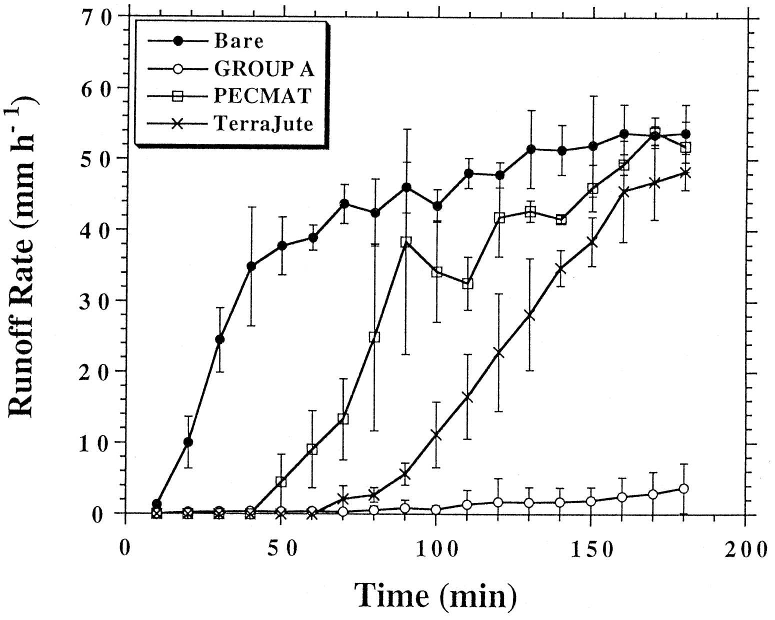


Fig. 1. Temporal variation in interrill runoff rates for the bare control, PECMAT, TerraJute and a GROUP of surface covers that were not statistically different (C125, Curlex I, Geojute, SC150BN, P300, TB1000). Average values are plotted; error bars reflect 95% confidence intervals about the mean.

5.2. Sediment redistribution by rainsplash

Sediment redistribution by rainsplash is an index for splash detachment. In this experiment splash redistribution is operationally defined as sediment trapped in lateral splash collectors and in the downslope front splash collector. All products significantly ($\alpha = 0.05$) reduced the redistribution of sediment from the plot compared to the bare soil (Table 3). While PECMAT and TerraJute (these two products will be referred to as Group B) were the least effective RECS in reducing splash redistribution, splash output from these two products was still approximately six times lower than from the bare soil

Table 3
Summary of interrill sediment transport and partitioning into splash and overland flow components

Surface cover	Mean splash output (g)	Mean wash output (g)	Total interrill output (g)
SC150BN	0.15[a,e] (95.5)[f]	0.01[a] (4.5)[f]	0.16[a]
P300	0.21[a] (63.1)	0.12[a] (36.9)	0.33[a]
C125	0.39[a] (39.6)	0.59[a] (60.4)	0.97[a]
TB1000	0.53[a] (58.5)	0.37[a] (41.5)	0.90[a]
Curlex I	0.50[a] (83.2)	0.10[a] (16.8)	0.61[a]
Geojute	15.92[a] (99.1)	0.14[a] (0.9)	16.06[a]
TerraJute	76.13[b] (71.9)	29.72[b] (28.1)	105.85[b]
PECMAT	78.23[b] (33.3)	156.60[c] (66.7)	234.81[c]
Bare	455.10[c] (47.1)	512.24[d] (53.0)	967.30[d]

[e] Values in the same column followed by the same letter are not significantly different at $\alpha = 0.05$.

[f] Values in parentheses represent the percentage contribution of each interrill subprocess to total sediment output.

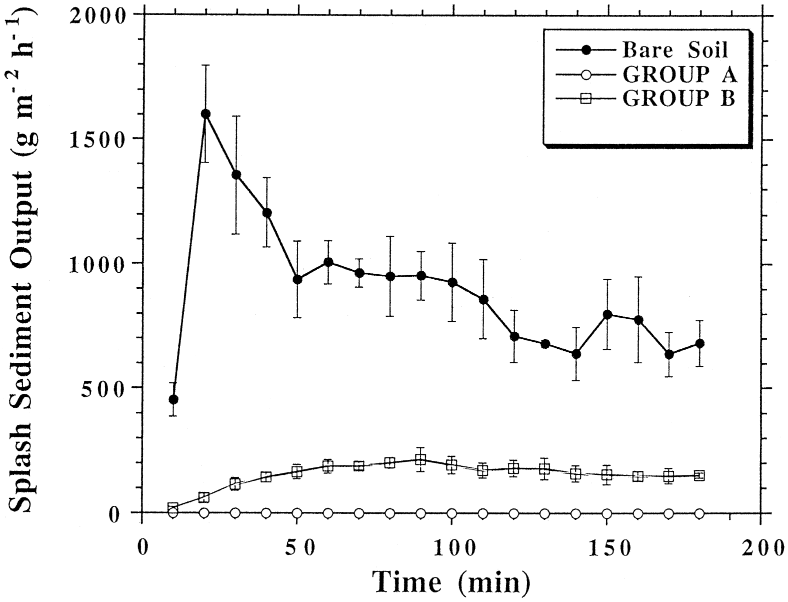


Fig. 2. Temporal variation in interrill splash redistribution for the bare control, a group of the most effective covers (GROUP A = C125, Curlex I, Geojute, SC150BN, P300, TB1000), and a group of less effective systems (GROUP B = PECMAT and TerraJute). Average values are plotted; error bars reflect 95% confidence intervals about the mean.

plot. The remaining RECS were not statistically different from each other in reducing splash redistribution.

Temporal splash response on the bare soil control was characterized by a peak output at 20 min, followed by a gradual decline to the end of the event (Fig. 2). This pattern, similar to that reported in other detailed splash studies (e.g., Farres, 1987; Ziegler and Sutherland, in press), can be described by an initial preparation period (0–20 min) when soil strength is decreased, aggregates are destroyed, and fines fill pore spaces. A thin layer of water then accumulates and sediment output peaks. This period is followed by an increase in water layer depth and a depletion of readily available sediment. In contrast, the temporal splash pattern for Group B RECS is marked by a gradual increase in sediment output up to about 90 min, followed by a minor reduction to the end of the event. Geojute, C125, TB1000, Curlex I, P300, and SC150BN form a statistically ‘similar’ group of RECS (Group A) having a temporal splash pattern indistinguishable from the zero transport line. All RECS prevented/diminished the initial preparation period (described above) by protecting the soil surface from raindrop impact energy; however, the differences in splash response suggest Group A products were somewhat more effective.

Previous studies have shown that as surface coverage increases, sediment transport by rainsplash decreases (e.g., Singer et al., 1981). Therefore, one would expect a positive correlation between reduction in LT values and reduction in splash output (i.e., products with low LT would produce low splash output). While this was true for the four products having LT values less than 20% (C125, SC150BN, P300, and TB1000; Tables 1 and 3), it was not the case for PECMAT, Geojute, and Curlex I, which have similar light transmission values (≈ 29, 35 and 38% respectively), but mean splash output values differing by more than 150 times (78.2, 15.92, and 0.50 g respectively). Variability in splash redistribution between these three products stems from not just one, but a combination of two factors, *three-dimensionality* and distribution of ‘open’ space. Splash output from Curlex I was low because it has significant thickness with very small open spaces between its thin fibers. Therefore, the kinetic energy of drop impact was primarily dissipated on the fibers rather than directly on the soil surface, thus maintaining the aggregated (unsealed) nature of the soil surface and preventing a significant reduction in infiltration associated with mechanical drop stress. If, however, raindrops reached the soil surface unimpeded, the detached particles were likely trapped within the matrix of the material. In sharp contrast, PECMAT has numerous large openings (although proportionally similar in absolute cover percentage) and minimal thickness to entrap splashed sediment. Similarly, large open spaces characterize Geojute; however, its water sorbant jute fibers expand when wetted, thus adding both to its overall coverage and thickness. This thickness (total height after wetting was about 4 mm) allowed water of significant depth to pond within open areas, reducing the direct impact of drops onto the soil surface, and cushioning the aggregates from breakdown. This is important because upon aggregate breakdown, the smaller detached particles could potentially fill the surface void space or form a low hydraulic conductivity filtration pavement at depth, which would result in decreased infiltration and thus, enhanced overland flow. Significant reductions in splash once the water layer depth equals or exceeds the median raindrop diameter have been noted in the soil erosion literature (e.g., Palmer, 1964; Moss and Green, 1983).

5.3. Total sediment transport

All RECS treatments significantly ($\alpha = 0.05$) reduced total interrill sediment transport compared to the bare control (Table 3); however, three significant effectiveness groups were observed (in order of increasing effectiveness): {PECMAT} < {TerraJute} < {C125, TB1000, Geojute, P300, Curlex I, SC150BN}. Fig. 3 illustrates the temporal differences, total interrill sediment transport, between each group and the control. Sediment transport for the six most effective RECS was negligible for the entire 3-h event. TerraJute finally differed in output from PECMAT after 70 min. The same effectiveness groups also appeared for the interrill wash data (Table 3). Fig. 4 illustrates the statistically significant regression relationship ($P < 0.05$) between the reduction in sediment transported by wash (RSTW) and that transported by splash (RSPD). The coefficient of determination is 96.2%. While sediment transport by wash was largely controlled by rainsplash detachment in this study, the wash transport data give insight to which RECS’ physical attributes are important in reducing sediment transport via hillslope overland flow.

The rigidness of PECMAT prevented this product from conforming well to the soil surface, and thus its thin, smooth surface provided minor resistance to wash transport of sediment. In contrast, TerraJute also provided limited resistance to overland flow; however, it did drape tightly over the soil surface, producing a significantly lower wash output than PECMAT. In general, the group of six most ‘effective’ RECS protected the soil surface from sealing and increased the pathway length of overland flow, resulting in

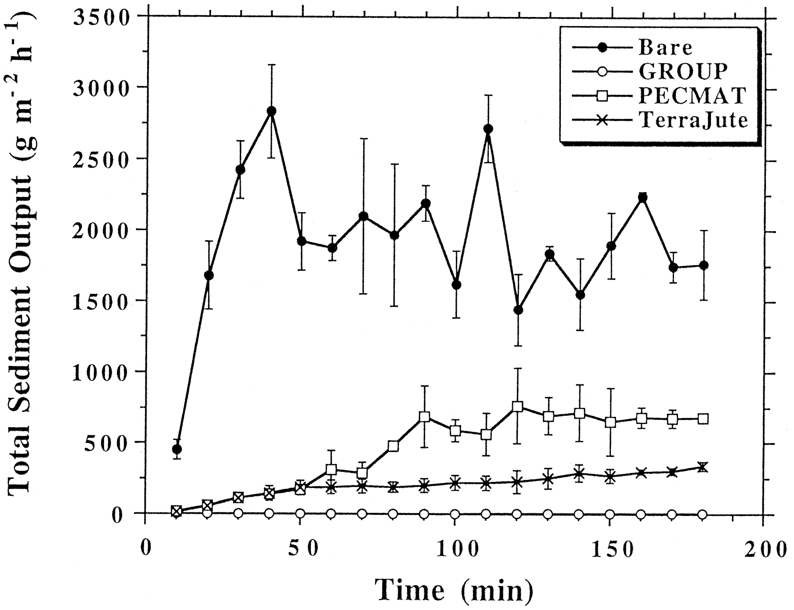


Fig. 3. Temporal variation in total sediment flux from the bare control, PECMAT, TerraJute, and a GROUP of six RECS that were not statistically different (C125, Curlex I, Geojute, SC150BN, P300, TB1000). Average values are plotted; error bars reflect 95% confidence intervals about the mean.

decreased flow velocity, decreased shear stress, and thus an overall reduction in ability to entrain sediment. In particular, Geojute gained mass by sorbing significant amounts of water, and thereby became closely integrated with the soil surface. With this enhanced

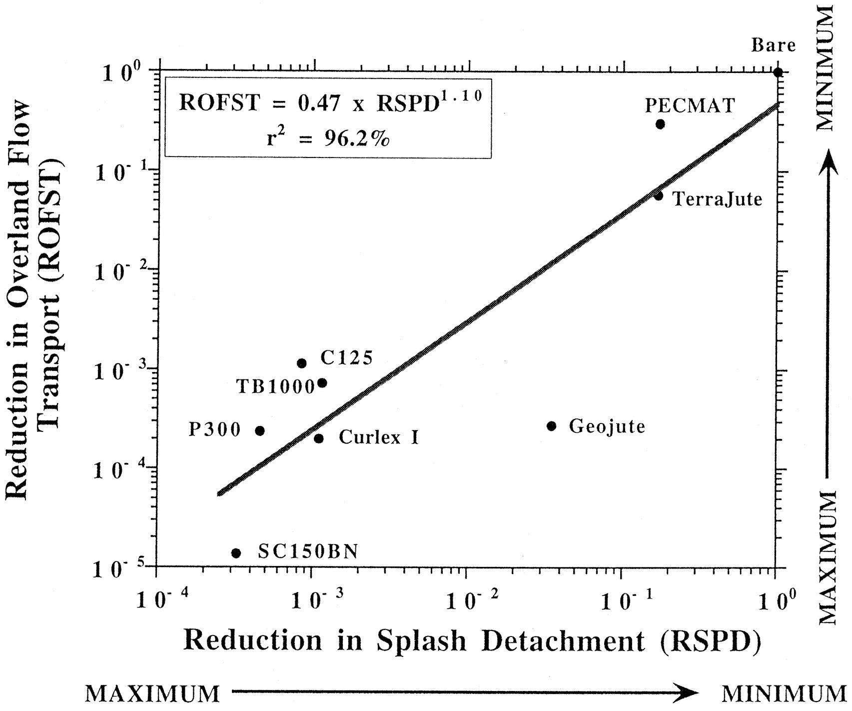


Fig. 4. Relationship between reduction in splash detachment and reduction in wash transport from interrill areas for the different surface coverings.

drapability, Geojute prevented overland flow from migrating between the soil and RECS interface, ultimately reducing sediment output despite having only moderate protection against rainsplash (i.e., Geojute is a noticeable outlier in Fig. 4). Curlex I, TB1000, and P300, have thick compositions of numerous thin (non-welded) fibers that worked their way into the pore space of the soil surface. This *three-dimensionality* provided great resistance to overland flow velocity.

5.4. Partitioning of interrill sediment transport by aggregate size

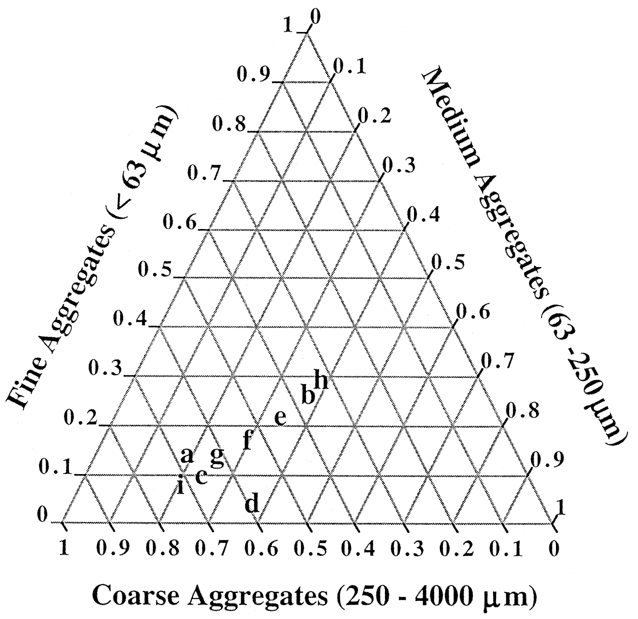
One of the most environmentally important aggregate size fractions in erosion is < 63 μm (clay and silt-sized particles) because of the ability of these particles to sorb nutrients, contaminants, and radionuclides. Additionally, these fine-grained aggregates are critical to on-site soil quality because they influence various physical and chemical characteristics. Most importantly, these soil fines are intimately linked with cation-exchange capacity and organic matter status. Thus, they indirectly influence soil resistance to entrainment and erosion, infiltration rate, and water-holding capacity. Therefore, in developing effective erosion-control products it would be beneficial to produce products that significantly reduce the transport of these fine-grained aggregates.

All RECS significantly ($\alpha = 0.05$) reduced total output of coarse- (250–4000 μm), medium- (63–250 μm), and fine- (< 63 μm) grained aggregates relative to the bare soil (Table 4), again producing the same effectiveness groups manifest in the wash and total-sediment output data. The proportion by mass of each of the three aggregate size fractions for total-sediment output are plotted on a ternary diagram (Fig. 5). In general, the sediment transported from the SC150BN ('e'), P300 ('f'), C125 ('b'), and TB1000 ('h') treatments was noticeably finer than that from the bare control ('a' in Fig. 5). The percentage contribution of material < 63 μm to total output for these four RECS (27, 35, 38, and 36% respectively) was higher than for the bare control (14%, Table 4). However, this 'preferential' transport of fines is not an environmental concern because

Table 4
Summary of means and results of multiple comparison testing for different aggregate size fractions in sediment output (splash + overland flow)

Surface cover	Coarse aggregate output 250–4000 μm (g)	Medium aggregate output 63–250 μm (g)	Fine aggregate output < 63 μm (g)
SC150BN	0.06^{ae} (40.0)[f]	0.05^{a} (33.3)	0.04^{a} (26.7)
P300	0.15^{a} (44.1)	0.07^{a} (20.6)	0.12^{a} (35.3)
C125	0.26^{a} (26.8)	0.34^{a} (35.1)	0.37^{a} (38.1)
TB1000	0.27^{a} (30.0)	0.31^{a} (34.4)	0.32^{a} (35.6)
Curlex I	0.39^{a} (65.0)	0.11^{a} (18.3)	0.10^{a} (16.7)
Geojute	9.66^{a} (60.2)	5.90^{a} (36.7)	0.50^{a} (3.1)
TerraJute	71.82^{b} (67.8)	20.69^{b} (19.5)	13.35^{b} (12.6)
PECMAT	137.11^{c} (58.4)	59.27^{c} (25.2)	38.42^{c} (16.4)
Bare	656.39^{d} (67.9)	177.50^{d} (18.4)	133.42^{d} (13.8)

[e] Values in the same column followed by the same letter are not significantly different at $\alpha = 0.05$.
[f] Values in parentheses represent the contribution of the aggregate fraction to total sediment output.



a = Bare Soil
b = C125
c = Curlex I
d = Geojute
e = SC150BN
f = P300
g = PECMAT
h = TB1000
i = TerraJute

Fig. 5. Ternary diagram showing the proportion by mass of each of three aggregate size fractions transported from the soil plots covered by eight RECS tested and the bare control.

the corresponding absolute masses were negligible (Table 4). The very small percentage contribution of fines in the Geojute data results from nearly all of the total output for this product coming from splash transport. Despite the small percentage contribution, the absolute mass was not different from those of the most effective RECS group. Nevertheless, these data suggest that RECS' minimizing entrainment of sediment by interrill wash concomitantly reduce the transport of the < 63-µm fraction.

6. Conclusions

All eight RECS tested in this laboratory rainfall simulation study significantly ($\alpha = 0.05$) reduced run-off, splash output, and sediment transport by interrill wash compared to a bare interrill soil surface. However, PECMAT and TerraJute were generally less effective than the other six RECS tested. Geojute, C125, TB1000, Curlex I, P300, and SC150BN comprise a group that significantly reduced the raindrop impact energy reaching the soil surface, and maintained an unsealed (uncompacted) surface layer thereby enhancing infiltration. Overall sediment transport for this group was low because sediment detachment was minimized, overland flow volumes were reduced, and the surface frictional resistance was increased. Individual effectiveness of these six products is practically indistinguishable under our testing environment. Preferential transport of <63-μm particles was not found to be of environmental importance for the systems tested.

Favorable RECS attributes for erosion control noted in this study include: (1) significant three-dimensionality that reduces raindrop impact, interferes with splash transport of sediment, and increases hydraulic resistance to overland flow; (2) fiber integration within the upper soil horizon, which increases shear strength of the soil thereby reducing overland flow velocities; (3) significant surface coverage with small random openings that mitigate raindrop impact and splash transport; (4) fibers with high water sorbance that reduce run-off volume; (5) fibers conforming to microtopographic variations when wet (drapability), thereby reducing overland flow between the product and the soil surface; and (6) ability to pond water to depths greater than the median raindrop diameter. A product that combines a number of these attributes will greatly reduce run-off and sediment transport under most interrill conditions.

Detailed testing of RECS under conditions that generate rill development are further required in both the laboratory and field. These process studies, in combination with investigations of biomass production and microclimate, are necessary for a complete understanding of the erosion control effectiveness of various RECS.

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