Overland Flow and Rainfall Simulation Studies on Ornamental Vegetation, Compost, and Jute Netting

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Biographical Sketches

Brent G. Hallock

Brent G. Hallock, Ph.D., CPSS, and CPESC, has been a professor at California Polytechnic State University (Cal Poly), San Luis Obispo, since 1979. He teaches an undergraduate course in Soil Erosion and Water Conservation, an upper division course in Rangeland Resources, and a graduate course in Environmental Assessment for Erosion Control. Brent earned Cal Poly's highest award of Distinguished Teacher in 2000. He has taught over 35 seminars and short courses in site analysis, erosion control, and selection of management measures. Dr. Hallock's research grants with Caltrans, RWQCB, and EPA on the use of vegetation in erosion control and water quality total over four million dollars in the past eight years.

Candace Kimmelshue

Candace Kimmelshue is a research associate for the Roadside Erosion Control Management Studies within the Earth & Soil Sciences Department at California Polytechnic State University, San Luis Obispo. She received her BS degree from Cal Poly in Animal Science and is currently completing her MS degree in Agriculture, with a concentration in Soil Science.

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Steven Rein, Ph.D. is an associate professor in the Statistics Department at California Polytechnic State University, San Luis Obispo. Between receiving his Ph.D. in 1993 from U.C. Berkeley and coming to Cal Poly in 1998, he was an assistant professor at Virginia Commonwealth University in Richmond, Virginia where he held appointments in both the Mathematical Sciences Department and at the Center for Environmental Studies. His primary area of research interest is in the application of statistical methodology to problems in ecology and biological sciences. Past work includes an analysis of the relationship between environmental factors and California's Chinook salmon population and contributing to the development of Virginia's Environmental Quality Index (VEQI).

Michael Curto

Michael Curto earned a MS degree in Biological Sciences and BS degree in Ecology & Systematic Biology from California Polytechnic State University, San Luis Obispo. His interests and experience center on plant biogeography, ecology, and systematics, especially of Western North American grasses. Michael is presently designing and constructing *transPLANT*, a Caltrans database and highway planting specification tool.

Misty Scharff

Misty Scharff has been involved with Sacramento State University, performing research in erosion and sediment control for the California Department of Transportation since 2000. She received her MS and BS degrees in Soil Science from the California Polytechnic State University, San Luis Obispo, were she assisted in numerous erosion control research studies. She has been a member of IECA since 1996.

Abstract

The literature is replete with studies quantifying erosion control effectiveness from raindrop impact on various vegetation types and erosion control products. However, there is little published overland flow research documenting the effectiveness of ornamental vegetation and erosion control products in filtering sediment and nutrients from stormwater runoff. The California Department of Transportation and the Office of Water Programs, California State University, Sacramento, has conducted two studies at the Erosion Control Research Facility at Cal Poly State University, San Luis Obispo addressing the use of ornamental vegetation as an erosion control treatment. The first study addressed how well ornamental vegetation, jute netting, and a combination of jute netting and vegetation decreased soil erosion and runoff during rainfall simulation. The second study compared the performance of ornamental vegetation, 0.5 inches of compost, and jute netting treatments in decreasing sheet erosion due to overland flow. Both studies used sandy loam soil in test boxes set at a southwest aspect with 2:1 and 3:1 slopes, respectively. Treatments were evaluated by measuring the runoff quantity, sediment load, sediment concentration, pH, total dissolved solids (TDS), electrical conductivity (EC) and turbidity of the runoff. Ornamental plant species included *Lonicera japonica*, *Lantana montevidenses*, *Carpobrotus edulis*, *Hedera helix L.*, *Myoporum parvifolium*, *Rosmarinus officinalis L.* and *Vinca major*. Rainfall simulation trials yielded significant reductions in total runoff and sediment by any treatment compared to bare soil, with 100 % vegetative cover yielding 98.6 % and 99 % reductions, respectively. Turbidity was significantly reduced by all treatments, while TDS and EC were not significantly different among trials. Average pH values for bare soil were significantly higher than those of jute netting and/or vegetation. In overland flow experiments, compost reduced runoff, sediment, and turbidity by greater than 96 % and increased EC by 430 % when compared to bare soil. Jute netting reduced runoff, sediment, turbidity, and EC by 43 %, 99 %, 97%, and 65 %, respectively, when compared to bare soil. Higher pH and salt concentrations were detected in runoff from boxes treated with compost; however, levels were not substantial enough (1673.9 μS) to be harmful to plants. Since no runoff was produced in overland flow trials, ornamental vegetation treatments were 100 % effective in controlling overland flow under test conditions. Differences among the plant species will be elucidated with future research involving steeper slopes and increased flow rates.

Key words: Erosion, overland flow, ornamental vegetation, water quality.

1. Introduction

In primarily urban settings, the California Department of Transportation (Caltrans) has landscaped significant roadside areas with ground cover and low growing vegetation. The most notably used vegetation is *Carpobrotus edulis*, Sea Fig, but Caltrans has also utilized plant species including, but not limited to: *Acacia, Baccharis, Hedera. Lampranthus, Lantana, Myoporum,* and *Rosmarinus*. Rainfall simulation (RS) and overland flow (OF) studies have been conducted to address the usage of these ornamental plants as erosion control and stormwater treatments. The RS study replicated rainfall on slopes and explored whether ornamental vegetation and/or other erosion control materials guarded against raindrop erosion. OF experiments used erosions control materials and ornamentals as well to investigate if those treatments would prevent sheet erosion from runoff.

Soils adjacent to roadways often contain higher than normal quantities of heavy metals and other pollutants. Vehicles deposit small amounts of heavy metals, oils, and other pollutants onto the roads, and stormwater translocates these pollutants to nearby soils and water bodies. Vegetation strips remove pollutants such as sediments and heavy metals, acting as a filter by dissipating the velocity of flowing water, allowing sediment to settle out.

Heavy metals have a high affinity for soil particles and organic matter, causing heavy metal pollutants in the soil to be strongly associated with the solid soil phase. Hence, effective erosion control is successful in reducing toxic heavy metal transport. Vegetation filter strips can provide inexpensive and effective erosion control and stormwater treatment if vegetation cover is greater than 65 percent (Scharff, 2005; Caltrans, 2003).

2. Rainfall Simulation Experimental Design

A total of twenty test boxes were used in this study. The boxes were positioned at a 2H:1V slope and filled with sandy clay loam soil consisting of 58 % sand, 21 % silt, and 21 % clay. Four different ornamental vegetation species were used concurrently with erosion control materials, while bare soil served as a control. The plant types used were Sea Fig (*Carpobrotus edulis*), English Ivy (*Hedera helix*), Rosemary (*Rosmarinus officinalis*), and Creeping Myoporum (*Myoporum parvifolium*). Erosion control materials included jute netting, erosion control blankets, and compost. Runoff was collected and analyzed for volume, sediment load, and other characteristics. No natural rainfall contributed to the results of this study; boxes were covered during natural rain events.

Table 1. Top and toe treatment combinations.

Toe (lower 20 %)	Top (upper 80 %)	100% Vegetation
Bare Soil	Bare Soil	
Jute Netting	Jute Netting	
Sea Fig	Jute Netting	
Sea Fig	Sea Fig	X
English Ivy	Jute Netting	
English Ivy	English Ivy	X
Creeping Myoporum	Jute Netting	
Creeping Myoporum	Creeping Myoporum	X
Rosemary	Jute Netting	
Rosemary	Rosemary	X

3. Overland Flow Experimental Design

Previous research determined vegetation filter strips reduce erosion and associated toxic metal translocation; however, no research has quantified the effect of different species of vegetation on water quality. Additionally, there is no lab data quantifying overland flow erosion by itself. The overland flow studies aimed to address these issues. There were three overland flow studies total, each varying slightly in experimental setup.

The California Department of Transportation requested this research as a pilot *ex situ* study to determine the effects of different vegetation types and erosion control products on water quality under simulated overland flow erosion. The results of this study will be used to determine the best analysis method for an *in situ* study, and eventually for developing new Best Management Practices.

Each of the three overland flow studies had two boxes assigned to each respective treatment. The number of non-vegetated treatments varied among the different overland flow studies. Treatments applied in the overland flow experiments are shown in Table 2. Figure 1 shows the setup of a vegetation treatment with rosemary (*Rosmarinus officinalis* L.).

Table 2. Overland flow experiment applied treatments.

OF Experiment	**Vegetation treatments†**	**Non-vegetation treatments**
OF 1	All	Bare , Jute, Compost and Erosion Control Blanket (straw mat)
OF 2	All	Bare
OF 3	All	None

†: See Table 4 for vegetation treatments

Figure 1. Experimental setup using *Rosmarinus officinalis* L.

1) Test Boxes

Test boxes had identical construction and dimensions as those used in previous rainfall simulations (Figure 1). Test boxes were constructed of pressure-treated lumber, and box dimensions were 200 cm (79 in.) L x 61 cm (24 in.) W x 20 cm (8 in.) D, conforming to field plot tests conducted by Pearce et al. (1998). Perforated steel sheets were placed in the bottom of test boxes to allow for percolation of soil water, simulating soil depth. Landscape fabric was placed along the bottom and sides of the boxes to prevent soil loss. Test boxes were positioned in rows on a concrete slab 70 ft long by 35 ft wide, and oriented such that soil surfaces faced approximately 165˚ south for adequate sun exposure. Slopes were obtained by changing the height at which the top of the test boxes rested.

2) Test Soils

Soil used in all overland flow simulations was collected by District 5 personnel from a road cut adjacent to California SR 46, east of Paso Robles in San Luis Obispo County (Table 2). Soil was compacted in the test boxes to at least 90 % (calculated from bulk density).

Table 3. Soil Physiochemical Properties.

Collection Site	USDA Type	%Sand	%Silt	%Clay	Small Gravels	Lime Nodules	pH
SR 46 East, PM 37.9	Sandy Clay Loam	58	21	21	< 2 % < 1.27 cm	1-2 mm	8.1

3) Installation of Vegetation Treatments

Vegetated boxes contained sandy clay loam soil below flats of vegetation (16 in. x16 in.). Soil was applied to a depth of 0.5 inches over the vegetative groundcover in order to have soil, rather than organic material from the flats, at the surface. Vegetated boxes were allowed to grow to 70 % cover before simulations commenced. Vegetation was watered using non-deionized water.

4) Installation of Jute and Compost Treatments

In compost treatments, 0.5 in. of Hydro-Post™ compost was applied to compacted bare soil. Jute netting was applied to bare soil by tucking it into the toe of the box and stapling the netting to the soil surface as needed in order to ensure soil contact.

5) Vegetation

Seven species of ground covers commonly found on Caltrans highway planting projects were studied (Table 4). Vegetation was supplied in 16 x 16 inch flats purchased from wholesale growers.

Table 4. Ground cover species used.

Scientific Name	Common Name: English	Cultivar	Biostrips	Bioswales
Carpobrotus edulis (L.) N.E. Br.	Sea Fig		Y	Y
Hedera helix L.	English Ivy		Y	Y
Vinca major	Periwinkle		Y	Y
Lantana montevidensis (Spreng.) Briq.	Trailing Lantana		Y	
Lonicera japonica Thunb. Var. *repens* (Sieb.) Rehd.	Japanese Honeysuckle	'Halliana'	Y	
Myoporum parvifolium R. Br.	Myoporum	'Prostratum'	Y	Y
Rosmarinus officinalis L.	Rosemary	"Prostratus'	Y	

6) Methods for Overland Flow-1 (OF-1) Simulations

OF-1 simulations were performed on a 3H:1V slope using deionized water applied at a rate of 15 gallons per hour for a total of 1 hour. Boxes were allowed to dry for 3 days prior to running simulations.

7) Methods for Overland Flow-2 (OF-2) Simulations

OF-2 simulations were conducted on a 3H:1V slope using deionized water at a rate of 15 gallons per hour for a total of 1 hour. Boxes were allowed to reach field capacity prior to simulation initiation. Soil moisture samples were obtained immediately before and after simulations.

8) Methods for Overland Flow-3 (OF-3) Simulations

Overland flow simulations in OF-3 were run on a 2H:1V slope using deionized water at a rate of 15 gallons per hour for a total of 2 hours. Boxes were allowed to reach field capacity prior to simulation initiation. Soil moisture samples were obtained immediately before and after simulations.

9) Runoff Collection and Analysis

Runoff from the test boxes was collected from the toe of the boxes using 28-gallon polyethylene receiving containers. Test boxes were covered during any natural storm events to prevent rainwater from entering into the boxes. The runoff pH, electrical conductivity (EC) and total dissolved solids (TDS) were analyzed using a handheld PASCO Explorer GLX multi-meter. pH was determined using a double junction glass electrode. Turbidity was determined in nephelometric turbidity units (NTUs) using a HACH 2100P optical turbidity meter. TDS was analyzed using a procedure that combined methods described by ASTM D3977-97 (ASTM, 2002) and EPA method 160.2 (USEPA, 2001).

After collecting and weighing each runoff sample, 10-20 ml 0.41M $CaCl_2$, a common water treatment flocculent, was added to each sample. Flocculated sediments were oven dried at 105 °C for 24 to 48 hours and weighed. Total sediment mass was calculated by subtracting the mass of the oven dry soil from the total water plus sediment mass.

Soil water content for OF-2 and OF-3 simulations was determined by obtaining soil moisture samples from test boxes immediately before and after simulations. Percent soil water content was calculated by the following equation.

$$\textbf{Soil water content} = \frac{\textbf{Moist soil mass – Oven dry soil mass}}{\textbf{Oven dry soil mass}} \times 100\ \%$$

(Hillel, 1998)

10) Vegetation Data Collection and Analyses

Percent canopy, litter, and rock soil surface cover were estimated using a point cover, or point intercept, method. This process involved using a rod to project a point from above down to the soil surface. Any contact with vegetation surfaces, individual plant structures, soil surface litter, rock, or bare soil is recorded to determine percent cover.

4. Key Results

1) Rainfall Simulation

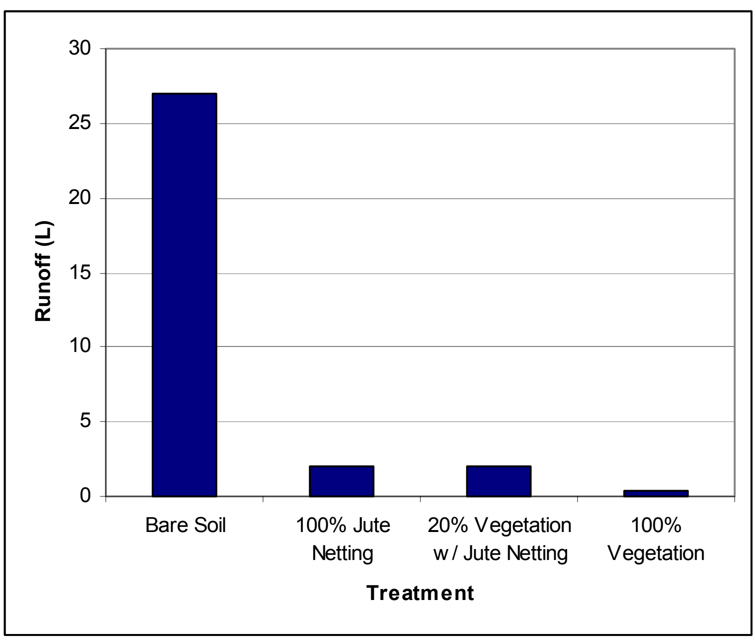

Figure 2. Effect of different treatments on total runoff.

i. Total Runoff

Total runoff for bare soil was significantly different than that of all other treatments. There was not a significant difference between the 20 % toe and 100 % vegetation treatments, or among ground cover vegetation type.

Runoff varied among the bare soil boxes and those with erosion control treatments (jute netting, 20 % toe vegetation, and 100 % vegetation). Bare soil yielded the greatest quantity of runoff at nearly 28.62 quarts. Jute netting and 20 % toe vegetation exhibited nearly identical reductions in runoff (92 %) to about 2.23 quarts. 100 % vegetation strips yielded only 0.403 quarts of runoff, which was a 98.6 % reduction compared to bare soil.

ii. Total Sediment

Total sediment was significantly greater in bare soil, compared to all other treatments. There was not a significant difference between the 16-inch or 80-inch vegetation treatments, or among vegetation types.

Total Sediment followed the same trend exhibited by runoff. Bare soil yielded the greatest quantity of sediment at nearly 1,873.93 lbs. Jute netting, 20 % toe vegetation, and 100 % vegetation exhibited nearly identical 99 % or greater reductions in sediment with 8.93 lbs for jute netting, 13.77 lbs for 20 % toe vegetation, and 5.23 lbs for 100 % vegetation.

iii. Sediment Concentration

There was a significant difference in the sediment concentrations between bare soil and all other treatments. No significant difference was found between the 20 % toe and 100 % vegetation treatments, or among ground cover vegetation species.

iv. Turbidity

Turbidity was significantly greater in bare soil, compared to all other treatments. No significant difference was found between the 20 % toe and 100 % vegetation treatments. However, turbidity values among ground cover vegetation types were significantly different.

v. Total Dissolved Solids and Electrical Conductivity

TDS and EC values were not significantly different among all treatments.

vi. pH

Mean pH levels were significantly different between bare soil and all other treatments. Within the vegetation treatments, there were pH differences among ground cover vegetation species, and the pH effect of ground cover vegetation depended on toe strip length. Bare soil had the most alkaline average pH at 8.3; whereas jute netting alone had the most acidic pH, averaging 6.2. Ground cover vegetation plus jute netting or vegetation alone had neutral average pH values (7.0).

2) Overland Flow

i. Runoff and Sediment

All treatments significantly reduced erosion compared to bare soil. However, overland flow simulations were not large enough to produce any runoff in vegetation treatments. Therefore, vegetated treatments could not be compared to other treatments. The pH, EC, turbidity, runoff, sediment load and sediment concentration for bare soil, jute netting and 0.5 inches of compost is shown below (Table 4).

Table 5. Means ± standard errors for all non-vegetated treatment results.

Treatment	pH	EC	Turbidity (NTU)	Runoff (L)	Sediment (g)	Sediment Concentration (g^{L-1})
Bare Soil	7.07 ± 0.18	610 ± 55	1958 ± 2265	33.7 ± 5.7	725.32 ± 687.01	20090 ± 16988
Jute Netting	6.89 ± 0.18	214 ± 323	113 ± 84	19.1 ± 1.8	2.95 ± 2.03	149 ± 97
Compost (0.5 in.)	6.44 ± 0.06	2616 ± 1703	50 ± 23	1.3 ± 1.3	0.85 ± 0.11	1256 ± 1188

Compared to bare soil, compost reduced runoff by 96 %, reduced sediment load by greater than 99 %, reduced turbidity by 97 %, and increased EC by 430 %. Jute netting reduced runoff by 43 %, reduced sediment load by greater than 99 %, reduced turbidity by 97 % and reduced EC by 65 % when compared to bare soil (Figure 3).

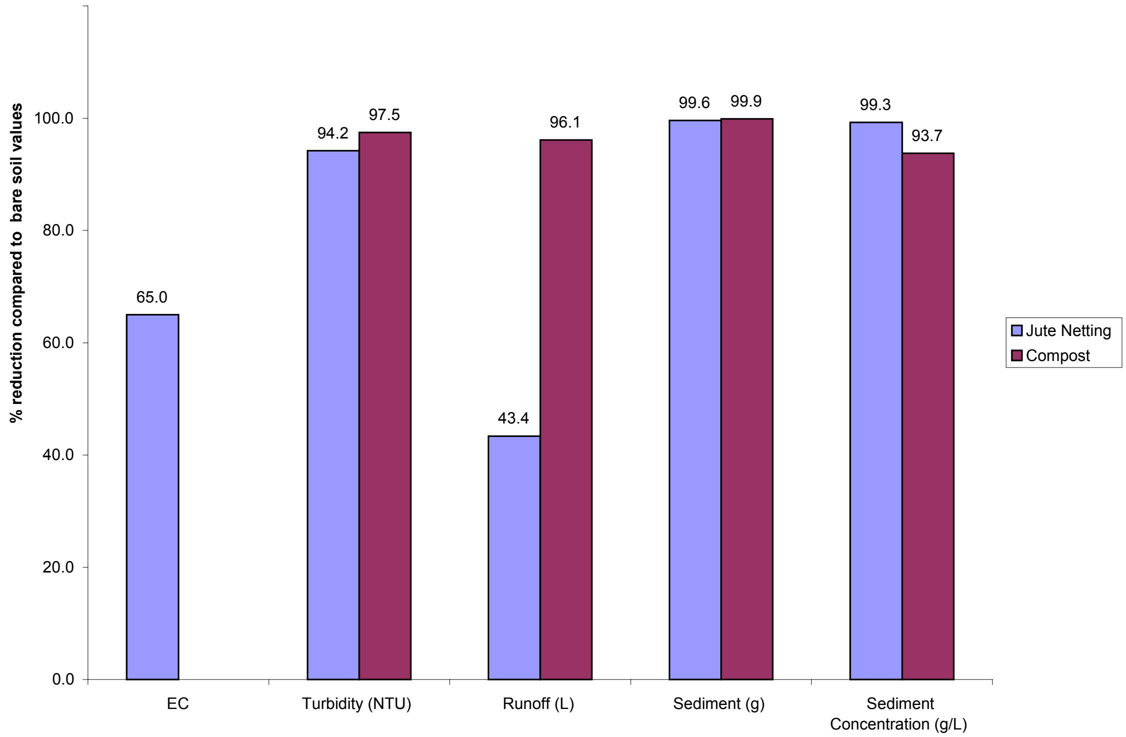

Figure 3. Effects of jute netting and compost on water quality and quantity in OF study.

Figure 4. Runoff on bare soil after 12 minutes.

ii. Total Runoff

Bare soil had significantly higher runoff than jute netting and compost treatments. Jute netting slowed water and trapped sediment, yielding a moderate quantity of runoff. The jute netting trapped soil but did not induce infiltration to the same degree as compost. Compost treatments absorbed a large quantity of water and transmitted it into the soil.

iii. Total Sediment

Bare soil had significantly more sediment than both jute netting and compost. Bare soil had over 200 times more sediment than jute netting, and over 700 times as much sediment as compost. When water was slowed by erosion control treatments, it lacked the energy to scour and transport sediment. There was large variation in sediment load among bare soil boxes, but the differences between the bare soil and the jute netting and compost treatments were nonetheless large enough to be significant. The jute netting had significantly more (over 3 times as much) sediment than the compost. Total sediment of jute netting and compost treatments were significantly different from each other, but were quite similar when compared to bare soil.

iv. Sediment Concentration

Bare soil yielded a significantly higher sediment concentration than jute netting and compost. The sediment concentration from the compost treatment was significantly higher than from the jute netting treatment. This was due in part to the large difference in runoff between the jute netting and compost trials. Compost forced the water to infiltrate, decreasing runoff; and since sediment concentration equals the sediment load divided by the runoff, constant sediment with decreased runoff caused sediment concentration to increase.

v. pH

The runoff pH for the bare soil and jute netting were near neutral and not significantly different. Compost had significantly lower runoff pH than jute netting and bare soil due to leaching of organic acids from the compost layer.

vi. Total Dissolved Solids and Electrical Conductivity

Total dissolved solids and EC for bare soil and jute netting were not significantly different from each other. The compost had a significantly higher EC and TDS than both bare soil and jute netting since water moving through the compost extracted soluble salts.

vii. Turbidity

No significant differences in turbidity were found among the treatments. Bare soil had higher turbidity than the other treatments, but large between-box variation in the bare boxes obfuscates these data through very large standard errors.

5. Conclusions

1) Rainfall Simulation

i. Ground cover vegetation strip length

Length of ground cover strip alone, whether 10 %, 20 %, or 100 % of total box length, was not significant due to the relatively short two-meter slope run available in the soil test boxes. All ground cover strips performed significantly better compared to bare soil.

ii. Ground cover vegetation toe strip with jute netting upslope

Boxes with 20 % vegetative cover on toe slopes and 80% jute netting upslope averaged a 92 % reduction in total runoff compared to bare soil. Average total runoff from all 100 % vegetation boxes exhibited a 98.6 % reduction in runoff versus bare soil.

iii. Ground cover vegetation compared to jute netting

Jute netting provides nearly the same soil surface protection as ground cover vegetation over a short slope run. Boxes with 100% jute netting over bare soil were equivalent in effectiveness of erosion prevention to boxes with 20% or 100% ground cover vegetation.

iv. Comparison among common cultivars used by Caltrans

All of the ground cover cultivars tested at either 20 % vegetative toe coverage with 80 % jute netting coverage upslope, or 100 % ground cover vegetation significantly reduced total runoff and total sediment (by more than 90 %) compared to bare soil. No significant differences were observed among cultivars tested.

2) Overland Flow

Erosion occurs on many roadsides, potentially transporting toxic heavy metals and other contaminants. In general, heavy metals have a high affinity for soil particles. When soil erodes, these metals are transported to other locations. Accordingly, the best strategy for preventing this transport of heavy metals is erosion prevention and control.

Established vegetation provides the best erosion control from overland flow, but only when vegetation cover is greater than 70 %. In this study, the overland flow simulation was not large enough to generate runoff in vegetated treatments due to root channels which allowed water to infiltrate more quickly than it was added to the box.

Jute netting and 0.5 inches of compost reduced sediment by over 99 % compared to bare soil. Jute netting holds the soil in place and allows water to flow without scouring soil. Compost has a very high water holding capacity and absorbs water, subsequently releasing it slowly into the soil. Jute netting yields more runoff than compost, but similar sediment loads.

6. Discussion

Both rainfall simulation and overland flow studies indicated that ornamental vegetation is an effective means of erosion prevention and control. Any vegetation strip length performed significantly better than bare soil with regard to runoff volume and quality. Overall, 100 % vegetative cover controlled runoff volume and quality of runoff most effectively. Therefore, ornamental vegetation is an effective Best Management Practice for stormwater treatment.

No comparisons among vegetation species were possible in overland flow studies since runoff was not generated during the simulations. However, observations indicate plant architecture may determine the effectiveness of vegetation in filtering runoff and sediment. Future research should increase the slope and/or flow rate until the differences between species is elucidated.

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