Water Quality Relative to Slope Toe Strip Type and Length

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Brent G. Hallock, Ph.D., CPSS, and CPESC, is 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 three million dollars in the past eight years.

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Michael Curto earned a MS in Biological Sciences and BS 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.

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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

Vegetation plays an important role in decreasing soil particle detachment and transport from sites following disturbance. Past rainfall simulator research (Caltrans 2004) using 2.5 m L x 0.6 m W soil test boxes with a 0.25 m sod strip (1:10 slope proportion) at the slope toe found statistically significant reduction of total sediment loss to near zero. A principle limitation of the previous in house experiment is that a 1:10 proportion of sod strip to slope length is not practical, nor equivalent with many industry specifications. Therefore, another rainfall simulator experiment was designed and conducted from October 2005 through June 2006 to compare effectiveness at reducing sediment loss of sod strips at 1:40, 1:20, and 1:10 proportions to slope length. Principal questions included 1) Does sod strip effectiveness vary directionally with sod strip length?; 2) Does sod strip effectiveness vary directionally with plant cultivar?; and 3) Are sod strips more or less effective than non-living EC blanket materials?.

A sandy clay loam subsoil was collected from a California highway construction site. Test boxes were then filled with soil to 90% compaction and positioned at a 2H:1V slope. Bare soil (control), compost, mulch, and a straw mat erosion control blankets (ECB) were each used individually as a top treatment on various boxes. Toe treatments applied at lengths of 0.2 m (8 in), 0.1 m (4 in), or 0.05 m (2 in) included bare soil, mulch, straw mat erosion control blanket, jute netting, or a sod strip of a commonly used groundcover species: *Carpobrotus edulis*, Sea Fig; *Lampranthus spectabilis*, Trailing Ice Plant; *Lantana montevidensis*, Trailing Lantana, or *Myoporum parvifolium*, 'Pink Dwarf' Myoporum. Storm water runoff was monitored for total water runoff, total sediment, sediment concentration, NTUs, pH, Electrical Conductivity (EC), nutrients, and selected metals over a series of simulated storm events.

As expected, toe treatments of mulch, ECB, jute, or vegetation performed significantly better than bare soil. The 0.2 m (8 in) sod strips (1:10 slope proportion) performed significantly better than the 0.1 m (4 in) sod strips (1:20 slope proportion), or the 0.05 m (2 in) sod strips (1:40 slope proportion). Sod strips used in conjunction with jute netting or an ECB on the slope face above provided sediment concentration reductions to less than 2 g per liter of runoff. Although vegetation reduces sediment concentration in the water drastically when compared to bare soil as a toe treatment, effectiveness varies with species owing to inherent differences in plant grow form and architecture. Herbaceous leaf succulents, such as Sea Fig or Trailing Ice Plant, grow prostrate along the soil surface forming dense, continuous mats. Prostrate shrubs, such as Trailing Lantana or Pink Dwarf Myoporum, produce arching or recumbent branches, but the soil surface may remain vulnerable to overland flow.

Key words: Stormwater, Erosion Control, Sod Strip, Vegetation

1. Introduction

Vegetation plays an important role in decreasing soil particle detachment and transport from sites following disturbance. As an alternative to many synthetic methods of soil surface protection, vegetation provides three-dimensional above-ground erosion control through leaf cover interception of precipitation and overland flow.

Past rainfall simulator research (Caltrans 2004) using 2.5 m L x 0.6 m W soil test boxes with a 0.25 m sod strip (1:10 slope proportion) at the slope toe found statistically significant reduction of total sediment loss to near zero. A principle limitation of the previous in house experiment is that a 1:10 proportion of sod strip to slope length is not practical, nor equivalent with many industry specifications. Therefore, another rainfall simulator experiment was designed and conducted from October 2005 through June 2006 to compare effectiveness at reducing sediment loss of sod strips at 1:40, 1:20, and 1:10 proportions to slope length.

As part of a cooperative effort to improve methods of establishing permanent vegetation to reduce sediment runoff and improve water quality, the California Department of Transportation (Caltrans), and the Office of Water Programs (OWP) at Sacramento State University, conducted this experiment at the Erosion Control Research Facility at California Polytechnic State University (Cal Poly), San Luis Obispo.

2. Objectives

Principal questions included the following:

1. Among toe treatments with lengths of 1:10, 1:20, or 1:40 relative to slope lengths, which provides the best "cost/benefit" compromise with regard to ***total runoff***, ***sediment***, and ***water quality***?
2. Does sod strip effectiveness vary directionally with sod strip length?
3. Does sod strip effectiveness vary directionally with plant cultivar?
4. Are sod strips more or less effective than non-living EC blanket materials?

3. Experimental Design

Treatments were applied to erosion test boxes to compare bare soil, jute netting, mulch, compost, rolled erosion control blankets, and vegetation strip applications at 0.6 m (24 in) W by lengths of 0.2 m (8 in), 0.1 m (4 in), or 0.05 m (2 in). The boxes were subjected to simulated rainfall to measure the effect of each on sediment loss and water quality.

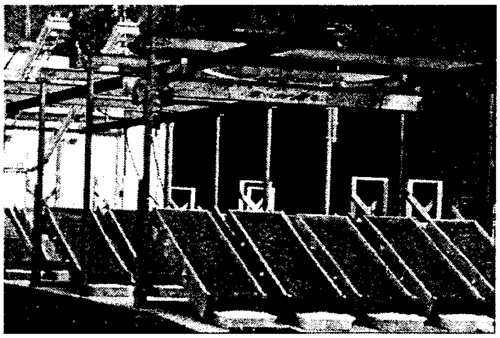

Fig. 1. Site and Test Box Setup.

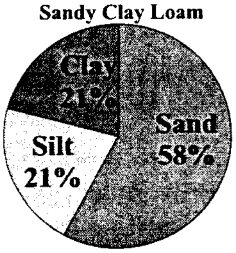

Fig. 2. Test Soil Properties

Twenty pressure-treated wood test boxes measuring 2.0 m (6.6 ft) x 0.6 m (2 ft) x 0.3 m (1 ft) which conform to field plot tests conducted by Pearce et al. (1998) were filled with Sandy Clay Loam soil (Fig. 1). The Sandy Clay Loam topsoil was collected by Department personnel from a road cut adjacent to the site of preconstruction (Fig. 2). Soil was compacted in the test boxes to at least 90% (calculated from bulk density), as typically required for construction fill (Caltrans 2002). Treatments were number 100 through 203. Bare soil, compost, mulch, and a straw mat erosion control blankets (ECB) were each used individually as a top treatment on various boxes (Tables 1 & 2). Toe treatments included bare soil, mulch, a straw mat erosion control blanket, jute netting, or vegetation, each used individually (Tables 1 & 2). Groundcover species included: *Carpobrotus edulis*, Sea Fig; *Lampranthus spectabilis*, Trailing Ice Plant; *Lantana montevidensis*, Trailing Lantana, and *Myoporum parvifolium*, 'Pink Dwarf' Myoporum (Table 3). Toe treatments were applied at lengths of 0.2 m (8 in), 0.1 m (4 in), or 0.05 m (2 in). A metal mesh grate formed the base of the boxes, and silt fabric lined the inside to minimize soil loss. Boxes were positioned at a 2H:1V slope on supports. A one-ton chain hoist was used to move boxes when necessary.

A replicate was made of each treatment and these paired boxes were rained on simultaneously to reduce between box rainfall variations. A length of vinyl gutter, PVC pipe and a 7.6 L (8 qt) plastic collection container were used to collect runoff from the base of each erosion test box. A rectangular piece of synthetic pond liner was cut and riveted to the vinyl gutter to prevent direct rainfall from entering the erosion collection system.

Table 1. Erosion Control Treatments

Code	Treatment
B	Bare soil
J	Jute netting
M	Mulch
C	Compost
ECB	EC Blanket/Single-sided woven straw mat
V	Vegetation/Sod Strip

Table 2. Experimental Design

Box	Soil	Treatment		Sod Strip Width		
		Top	Toe	0.05m (2 in)	0.1 m (4 in)	0.2m (8 in)
1	SCL	B	B			
2	SCL	J	J			
3	SCL	ECB	ECB			
4	SCL	C	M			
5	SCL	B	V - ***Ls***	X	X	X
6	SCL	J	V - ***Ls***	X	X	X
7	SCL	ECB	V - ***Ls***	X	X	X
8	SCL	C	V - ***Ls***	X	X	X
9	SCL	B	V - ***Lm***	X	X	X
10	SCL	J	V - ***Lm***	X	X	X
11	SCL	ECB	V - ***Lm***	X	X	X
12	SCL	C	V - ***Lm***	X	X	X
13	SCL	B	V - ***Mp***	X	X	X
14	SCL	J	V - ***Mp***	X	X	X
15	SCL	ECB	V - ***Mp***	X	X	X
16	SCL	C	V - ***Mp***	X	X	X
17	SCL	B	V - ***Ce***			X
18	SCL	J	V - ***Ce***			X
19	SCL	ECB	V - ***Ce***			X
20	SCL	C	V - ***Ce***			X

Table 3. Groundcover Species Used as Toe Treatments

Veg. Code	Scientific Name	Common Name	Cultivar
Ce	*Carpobrotus edulis* (L.) N.E. Br.	Sea Fig	
Ls	*Lampranthus spectabilis* (Haw.) N.E. Br.	Trailing Ice Plant	
Lm	*Lantana montevidensis* (Spreng.) Briq.	Trailing Lantana	
Mp	*Myoporum parvifolium* R.Br	Myoporum	Pink Dwarf

For simulation purposes, two Norton Ladder variable sweep rainfall simulators were used (Fig. 3). The industrial spray nozzles were pressurized to 41 kPa (6 psi), and produced drop sizes averaging a 2.25 mm (0.09 in) diameter (Fig. 3). The drop size corresponded to the average drop size of erosive storms in the Midwest region of the United States. Drop size along the Pacific coast is frequently smaller. The nozzles oscillated side-to-side by a cam driver by a small motor. The intensity of simulated rainfall was determined by the number of times the nozzles of the boom swept past the box opening. The frequency and duration of oscillations were altered during each simulation to mimic the theoretical hydrograph of a storm. The simulator dropped a total of 3.81 cm (1.5 in) of rain over 1.5 hours, equivalent to a 50-year storm. The simulators were tested before simulations and yielded 95% uniformity. The simulators returned unused rain to the water supply.

Runoff was analyzed for sediment load, pH, and salt concentration. Total solids were analyzed using a procedure that combined methods described by ASTM D3977-97 (ASTM, 2002) and EPA method 160.2 (EPA, 2001). After collection of each weighed runoff sample, samples received 10-20 ml 1M $AlCl_3$, a common water treatment flocculant. Any remaining sediment on the walls or bottom of the storage container was rinsed into an evaporating dish to be oven dried. The container with sediment was oven dried at 115 °C for 24 to 48 hours and then weighed.

The total water runoff was calculated by subtracting the sediment and container weight from the original total collection weight. The total sediment included the evaporated sediment weight. Sediment concentration (mg/L) was calculated from the total runoff and total sediment values. Salt concentration (electrical conductivity) and pH were analyzed using a pH/EC/TDS/Temperature meter built by Hanna Instruments, Inc., for each collection following simulated storm events.

Fig. 3. Rainfall simulator

Water runoff, sediment load in the runoff, and sediment concentration in the runoff were analyzed (after a normalization transformation, if needed) using analysis of variance (ANOVA), after necessary variance stabilizing transformations were applied to achieve normality for all responses except pH. Treatment effects were compared with post-hoc procedure via Bonferroni adjustment of the individual error rate (Devore 2003). Ratings of treatment performance were further compared with Main Effects Plots.

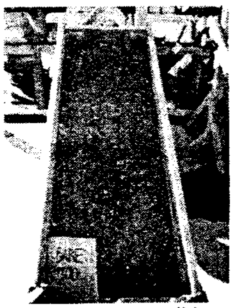

Fig. 4. Bare soil in the box with nothing

To analyze data trends, runoff and sediment yield measurements were totaled and averaged for boxes with the same vegetation width or erosion control treatment. The boxes were compared to boxes with other treatments and charts were generated to show differences. Totals were analyzed for the 50-year simulated event.

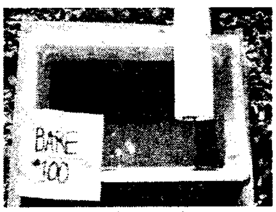

Fig. 5. Sediment in water from only bare soil being rained on

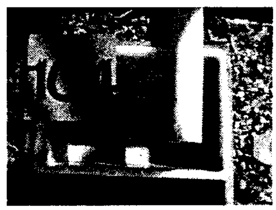

Fig. 6. Sediment remaining in water when an ECB is used at top and toe

4. Results

Erosion and sediment control treatments affected runoff pH, electrical conductivity (EC), total dissolved solids (TDS), NTU, runoff, sediment load and sediment concentration. When statistically analyzing the data, it was found the numbers were better represented using a logarithmic (log) base 10 scale. Therefore, most results are in logarithmic form.

1) pH

Toe treatments did affect on the pH (p=.891). The erosion control blanket toe treatments had a pH which was higher than average (p=.001), while the toe treatments with vegetation had a pH that was significantly lower than average (p<.001). All other toe treatments were not significantly different from the average. Moreover, the species of vegetation significantly related to pH. Sea fig (***Ce***) had a pH lower than average (p=.005), and Myoporum had a pH higher than average (p=.001). The other vegetation tested did not have pH values that differed significantly from average. It was also found that the top treatment was not appreciably related to pH.

2) Electrical Conductivity

Sea fig (***Ce***) and Trailing Lantana (***Lm***) had logs of electrical conductivity (logEC) that were lower than average. Conversely, Trailing Ice Plant (***Ls***) and Myoporum (***Mp***), both contributed to higher than average log(EC) values. Furthermore, plant species related similarly to the log of total dissolved solids (log(TDS) (p<.001).

3) NTU

The toe treatments had an effect on the log of NTU. While the bare soil contributed to significantly higher than average (p<.001) numbers, the ECB (p>.001) and vegetation (p=.001) contributed to lower than average results. The other treatments did not differ from average. The top treatments followed a similar pattern in their results. However, it was also found that the toe length is significantly related to log(NTU) (p=.024). A 5.08 cm (2 in) length had significantly higher than average log(NTU) with p=.018, and a 20.32 cm (8 in) toe length had a lower than average log(NTU) (p=.019).

4) Runoff

It was found that the bare and ECB toe treatments had higher than average runoffs, while no other treatments were significantly different from average. Plant species is also related to runoff (p<.001). ***Ce*** was much lower than average, while ***Ls*** and ***Mp*** were significantly higher than average. Moreover, the top treatment runoff results indicated that bare soil had a higher than average runoff. ECB and jute top treatments had lower than average runoffs, with compost not being significantly different from average.

5) Sediment Load

The top and toe treatments were significantly related to the log(sediment) (p<.001). Both bare soil tests had higher than average sediment loads, while ECB at the top and toe had much lower than average results. Furthermore, using jute on the toe resulted in lower than average results in sediment load. All other treatments were not significantly different from average.

6) Sediment Concentration

The top and toe treatments were important to the log of the concentration (log(conc)). Bare soil was higher than average for both top and toe, while vegetation caused significantly lower than average numbers for log(conc) when used as a toe treatment. ECB and jute resulted in lower than average log(conc) numbers, with C not being different from average. It was also found that species is significantly related to log(conc) (p=.015). ***Ce*** is higher than average (p=.005) and ***Ls*** is significantly lower than average (p=.010). The other species were not significantly different from average.

5. Discussion

According to the statistical data, the only factor that toe treatment length had a significant effect on was log(NTU). When analyzing the raw data and measuring the effect of toe length with vegetation on the average NTU, with various top treatments, it was determined that the eight-inch length performed the best (Fig. 7). The average NTU measurements were the highest in the four-inch toe lengths and the two-inch toe lengths. The eight-inch toe length with vegetation showed the lowest NTU values (Fig. 7). Furthermore, data appeared to be inconsistent between two and four inch toe lengths. This inconsistency indicates poor quality data for the two- and four-inch toe lengths probably due simply to the small size. Therefore, the rest of the figures analyze only the eight-inch toe length where applicable.

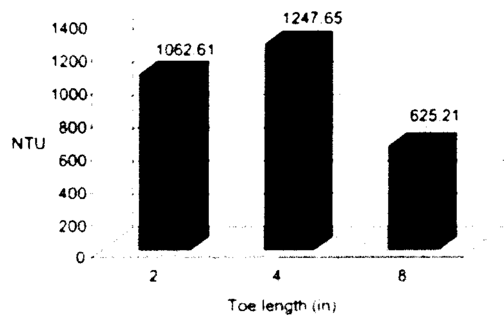

Fig. 7. The effect of vegetated toe length on average NTU with various top treatments

The top treatments consisted of bare soil (B), jute (J), compost (C), and erosion control blankets/straw mats (ECB). The average amount of runoff collected was compared between the four top treatments (Fig. 8). The bare soil had the highest amount of runoff at 44.43 liters. Using compost cut the water runoff almost in half (Fig. 8). Jute closely followed compost with 19.60 liters collected, while the erosion control blanket reduced the amount of runoff to 12.82 liters, which is a 71 % reduction in runoff when compared to bare soil. The effect of various top treatments on the average sediment concentration is also shown below (Fig. 9). The various toe treatments are not taken into account in this graph, but the effect of the top treatments can still be seen. Bare soil yielded over 33,000 mg L^{-1} of sediment concentration in the runoff water collected (Fig. 9). Compost reduced this concentration of sediment 92 %, while an ECB and/or jute reduced this loss over 98 % when compared to bare soil alone (Fig. 9). Therefore, using an erosion control treatment can be very effective in reducing the amount of concentrated sediment in runoff water.

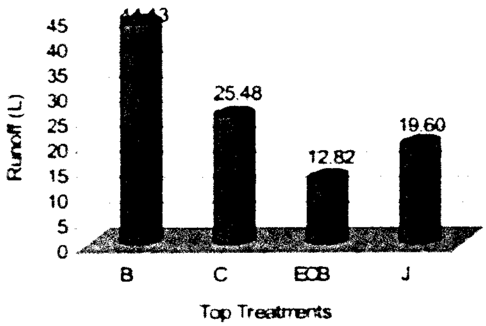

Fig. 8. The effect of the top treatment on the average amount of runoff collected

Sediment concentration was also greatly affected by the toe treatment used on each box (Fig. 10). The toe treatments used included, bare soil (B), mulch (M), an erosion control blanket/straw mat (ECB), jute (J), or vegetation (V) of four different groundcover plant species. The effect of the toe treatment on the average sediment concentration with various top treatments is shown below (Fig. 10). Bare soil at the toe yielded a sediment concentration of over 47,000 mg L^{-1}. The next toe treatment reduced the overall sediment concentration in the runoff water collected by 85 %. Although mulch, an ECB and jute all have smaller sediment losses

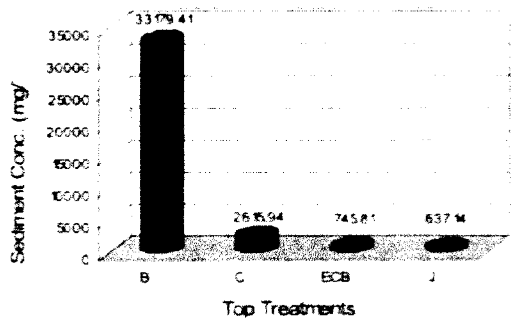

Fig. 9. The effect of top treatments on the average sediment concentration with various toe treatments

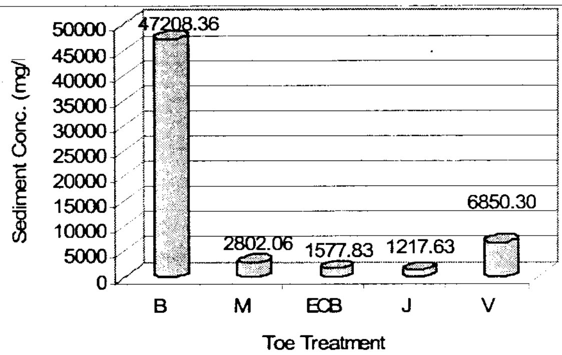

Fig. 10. The effect of the toe treatment on the average sediment concentration with various top treatments

than vegetation, vegetation is further broken down by plant species (Fig. 11). Ultimately, jute as a toe treatment had the lowest sediment concentration in the runoff water with only 1,217 mg L^{-1} (Fig. 10). Therefore, according to the raw data collected, it drastically reduces sediment concentrated in the runoff water if a toe treatment is simply applied.

Vegetation used as an eight-inch toe treatment can be further broken down to show the effect of groundcover species on the amount of sediment concentrated in runoff water (Fig. 11). Of these four species, Trailing Ice Plant (***Ls***) had the greatest impact on reducing sediment concentration in water. Trailing Ice Plant (***Ls***) allowed only 1,254 mg L^{-1} of sediment to concentrate in the water (Fig. 11). The highest sediment concentration in toe treatments with vegetation came from Trailing Lantana (***Lm***), which was 92 % greater at over 16,700 mg L^{-1} (Fig. 11). Pink Dwarf Myoporum (***Mp***) was the next highest, but still reduced sediment concentration by over 72 % compared to the Trailing Lantana (***Lm***). Thus, the eight-inch toe treatments reduced the amount of sediment allowed to concentrate in runoff water.

The different species of vegetation used as toe treatments also significantly affected the electrical conductivity (EC) and total dissolved solids (TDS) in the runoff water collected (Fig. 12 and 13). Different from sediment concentration, Trailing Ice Plant (***Ls***) had the highest EC at 668.50 µS in the water collected (Fig. 12). Trailing Lantana (***Lm***) and then Pink Dwarf Myoporum (***Mp***) followed in electrical conductivity. Sea fig (***Ce***) had the lowest

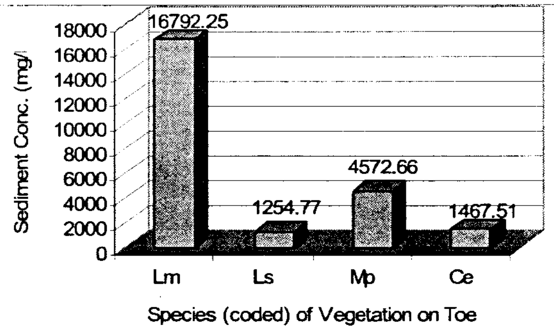

Fig. 11. The effect of different vegetation species as eight inch toe treatments on the sediment concentration

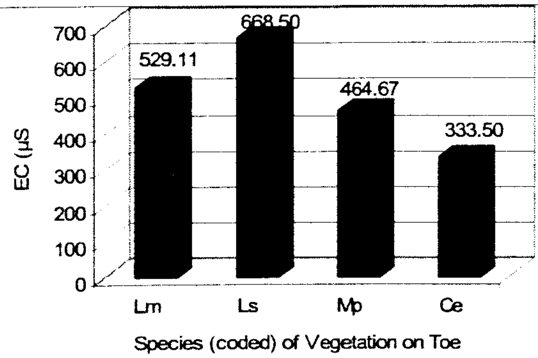

Fig. 12. The effect of different vegetation species in eight inch toe treatments on electrical conductivity

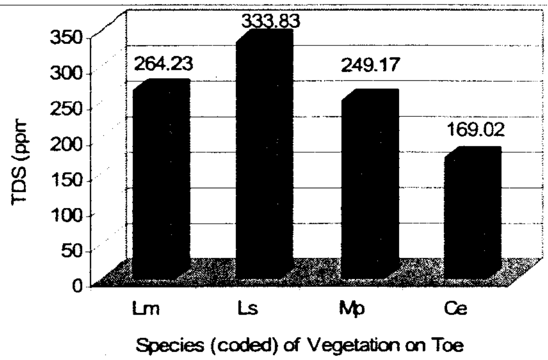

Fig. 13. The effect of different vegetation species in eight inch toe treatments on total dissolved solids

EC value at 333.50 μS (Fig. 12). The effect of these species on the total dissolved solids followed a similar pattern (Fig. 13). Trailing Ice Plant (***Ls***) was the highest at 333.83 ppm of TDS, while the Sea Fig (***Ce***) was the lowest at 169.02 ppm (Fig. 13). This shows that Sea Fig (***Ce***) cut the TDS in half when compared to the Trailing Ice Plant (***Ls***). Furthermore, Trailing Lantana (***Lm***) is slightly higher in ppm of TDS solids than Pink Dwarf Myoporum (***Mp***), but only by 15 ppm (Fig. 13). Thus, Sea Fig (***Ce***) exhibited the greatest affect on EC and TDS.

6. Conclusion

1) Toe Strip Proportion

As expected, toe treatments of mulch, ECB, jute, or vegetation performed significantly better than bare soil. The 0.2 m (8 in) sod strips (1:10 slope proportion) performed significantly better than the 0.1 m (4 in) sod strips (1:20 slope proportion), or the 0.05 m (2 in) sod strips (1:40 slope proportion). Sod strips used in conjunction with jute netting or an ECB on the slope face above provided sediment concentration reductions to less than 2 g per liter of runoff.

2) Groundcover Species

Although vegetation reduces sediment concentration in the water drastically when compared to bare soil as a toe treatment, effectiveness varies with species owing to inherent differences in plant grow form and architecture. Herbaceous leaf succulents, such as Sea Fig (***Ce***) or Trailing Ice Plant (***Ls***), grow prostrate along the soil surface forming dense, continuous mats. Prostrate shrubs, such as Trailing Lantana (***Lm***) or Pink Dwarf Myoporum (***Mp***), produce arching or recumbent branches, but the soil surface may remain vulnerable to overland flow.

Fig. 14. 167-jute with Mp; 124-ECB with Lm; 137-Bare with Ls; and 130-Compost with Lm

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