EVALUATION OF EROSION CONTROL TECHNIQUES ON FOREST ROADS

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ABSTRACT. *The cutslope and fillslope on a newly constructed forest road on the Talladega National Forest near Heflin, Alabama were treated with three erosion control techniques: wood excelsior erosion mat, native grass species, and exotic grass species. Bare soil plots were used as the experimental controls. Total sediment yield was measured during the period 21 September 1995 to 18 March 1996. A randomized complete block design was used to evaluate treatment methods on the basis of sediment yield and runoff volume. No significant difference in sediment yield was found from the fillslope among the treatments. However; on the cutslope significant differences were detected among all treatments. The erosion mat treutment was most effective in mitigating erosion losses with a 98% reduction in cutslope sediment yield and 88% reduction in fillslope sediment yield.*

Keywords. *Forest roads, Soil erosion, Conservation practices, Slopes, Economics.*

Forest lands erode at minimal levels as long as the soil surface remains undisturbed. Erosion from undisturbed forest land is less than 0.27 t/ha/year; which is less than the normal rate of geologic erosion estimated at 0.49 to 0.82 t/ha/year (Beasley, 1979: Patric, 1976; Smith and Stamey, 1965; Yoho, 1980). However. higher levels of soil erosion can occur when the forest cover and forest floor are disturbed by forest operations. Forest road construction has been cited as the dominant source of erosion in the forest of the eastern United States (Patric, 1976; Swift. 1984). Up to 90% of sediment produced from forest lands comes from roads. Sedimentation degrades the quality of forest streams and wildlife habitat (Elliot et al., 1994). Sediment from roads can clog spawning beds. shorten the life of reservoirs, and degrade drinking water. Soil erosion from forest roads requires special attention because sediment usually moves directly from road drainage structures into waterways (Elliot et al., 1994; Keid and Dunne, 1984).

Hundreds of kilometers of roads are constructed on forest land each year to access tracts for harvesting or other management operations. Sediment is produced from all components of the road surface: traveledway, fillslope, cutslope, and roadside ditch. Erosion from forest roads is a major concern due to its adverse effects on the environment caused by significant loss of soil from forest road construction if erosion control techniques are not used to reduce sediment production. Vegetative stabilization of exposed cut and fillslopes is a primary component in reducing the total sediment yield from forest roads. However, the efficacy of current stabilization practices in the southern USA is relatively unknown.

The purpose of this study was to quantify the effect of commonly used forest road sideslope erosion control techniques on sediment losses and surface runoff. The effect of utilizing species native to the southern USA in lieu of exotic vegetation to mitigate erosion losses was examined in this research. The initial costs of the erosion control techniques were also considered.

LITERATURE REVIEW

Many studies have been conducted to examine erosion and sedimentation resulting from forest management. In North Carolina. 5238 m^3 of soil loss were measured in four years from 3.7 km of road; up to 90% of the sediment following logging operations came from temporary and permanent roads (Hoover, 1952). Effective methods to control erosion from forest roads would, therefore, directly influence water quality in the forest ecosystem. Burroughs and King (1989) identified four specific road components for which erosion control methods could be employed: traveledways, fillslopes. cutslopes, and roadside ditching. Based on their research, sediment production was partitioned into 60% from fillslopes, 25% from traveledways, and 15% from cutslopes and roadside ditching.

In a study of three watersheds in Oregon, the first storm after road construction carried a peak sediment concentration of 1850 mg/L, which was 250 times the expected concentration from an undisturbed watershed. The concentration then decreased to about nine times the expected concentration nine weeks after this initial event (Fredriksen, 1965). During the first year after road construction, sediment in streams draining watershed areas was 2 to 150 times the amount produced from undisturbed watersheds.

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Establishment of plant and litter cover was found to be the most important deterrent to surface erosion (Berglund. 1976). In the mountains of western Oregon, five different seeding mixtures were used on a S-year-old 1: 1 cutslope to assess the effectiveness of grass-legume mixtures and mulch application in controlling soil erosion (Dyrness, 1975). Effective erosion control depended on fast initial vegetation growth and cover. Treatments with mulch applied at a rate of 4.5 t/ha were found to be more effective than treatments without mulch. The study showed the importance of mulching to minimize soil losses during the first few months after construction.

The effects of surface cover types. their combinations, and percent ground coverage on soil loss were studied by Benkobi et al. (1993) with a rotating boom rainfall simulator. They found that a combination of rock cover and vegetation litter may offer effective erosion control. Meyer et al. (1972) found an inverse correlation between rock cover and erosion rates. Coverage of 34 t/ha of stone showed severe rills: whereas, 303 t/ha of stone was an effective erosion control treatment.

Vegetative stabilization is a key component of many southern states' "Best Management Practices". For example. Alabatna's guidelines (Alabama Forestry Commission. 1993) note the importance of stabilizing road banks to minimize erosion. An entire section of the manual is devoted to revegetation/stabilization with detail on seeding, mulching. and fertilization.

The literature clearly indicates that careful planning and implementation of road construction can keep erosion to a minimum. However, additional information is needed to properly select appropriate vegetative controls from current alternatives. While exotic plant species may be selected for more reliable establishment and cover, native plant species may be preferred for ecological reasons. Vegetative establishment can also be enhanced by mulches or covers. Each of these choices varies in cost and erosion control efficacy.

Objectives

The objective of this study was to test the hypothesis that there are differences in the sediment yield of three commonly applied erosion control treatments and a bare soil control. Native grass vegetative mix, exotic grass vegetative mix, and exotic grass anchored with an erosion control mat were compared to a bare soil control. The treatments and control were compared during the first six months immediately following construction when the maximum sediment yields may be expected. Treatment costs were also developed to provide a comparison of cost-benefit.

Materials and Methods

Study Site

The study site was 100 m of harvest-access road in the Shoal Creek Watershed on the Talladega National Forest, near Heflin, Alabama. The soil on the test site was composed of the Tatum series, a fine loamy mixed thermic Typic Hapludult. The parent materials were slate and phyllite. The surface layer was 0.10 to 0.15 m of silt loam over a red clay loam subsoil 0.50 to 0.55 m thick. Average soil infiltration rates were estimated for bare soil control plots based on rainfall and runoff measurements from 36 data points. The cutslope and fillslope had average infiltration rates of 19.1 and 18.6 mm/h, respectively. Infiltration rates ranged frotn 5.9 to 33.3 mm/h on cutslopes and 5.1 to 32.3 mm/h on fillslopes.

The road was constructed during the summer of 1995 and completed on 9 September 1995. The road was a midslope half-bench crowned road with inside ditching constructed on hillslopes ranging from 2 to 65%. The road had a 15% grade, 2.2: 1 west-facing cutslopes, and 1.5: 1 fillslopes. The traveledway was surfaced with No. 4 aggregate (19-38 mm).

Experimental Design

A randomized complete block design was used to test the treatment effect of erosion mat, native grass and exotic grass with a bare control. Three blocks of treatments were installed on both cutslope and filislope. A total of 12 test plots were established on the cutslope. and another twelve plots were established on the fillslope of a newly constructed road. The cutslope and fillslope test areas were located parallel to each other (fig. 1).

Hand seeding (with one-year-old seed) and mulching of all treatments was accomplished on 16 September 1995. one week after the road was completed. The soil was "as-constructed" with no further scarification to apply treatments. Mulch treatments were mulched with fescue hay at a rate of 4.5 t/ha and fertilized with 13-13-13 fertilizer at a rate of 1.0 t/ha. The native grass plots were seeded with a mixture of big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), and Alamo switchgrass (*Panicum virgatum*) at a rate of 11.2 kg/ha live pure seed (LPS) each. The exotic grass plots were seeded with a mixture of Kentucky 31 fescue (*Festuca arundinacea*) at 28.1 kg/ha LPS. Pensacola bahiagrass (*Paspalum notatum*) at 22.5 kg/ha LPS, annual lespedza (*Lespedza cuneata*) at 5.6 kg/ha LPS, and white clover (*Trifolium repens*) at 11.2 kg/ha LPS. The erosion mat plots consisted of the same mulching and seeding

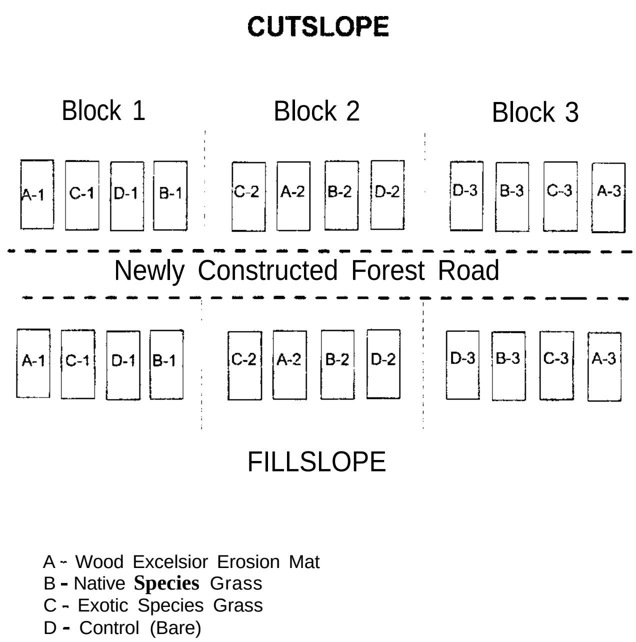

Figure I-Experimental design layout on cutslope and fillslope showing each treatment in blocks I, 2, and 3.

mixture as the exotic grass plots covered by a wood excelsior erosion mat. The erosion mat was a machine-produced mat with a photc-degradable extruded plastic net over the top side of the mat. Earth staples. 150-mm-long. anchored the erosion mat in place.

Bounded plots were used to insure that rainfall and surface runoff within each plot were isolated from the adjacent slope. Plots were 1.5 m x 3.1 m with the longer side in the direction of surface flow. Each plot was bounded by wooden boards, 200-mm high, driven approximately 30 mm into the slope surface. A 1 00-mm diameter gutter at the bottom was connected to a 130-L storage container with a 100-mm diameter PVC pipe (fig. 2).

SAMPLE ANALYSIS

Two dependent variables were examined-plot runoff volume and total sediment yield. Plot runoff volume was directly measured as the amount of water in the storage containers. Total sediment yield was determined by adding deposited and suspended sediment fractions in the containers. Suspended sediment was estimated by taking three SOO-ml. grab samples from the standing water in the container. These samples were processed for gravimetric analysis using methods defined by Greenberg et al. (1992). and the average of the three suspended sediment samples was calculated. Deposited sediment was measured by draining off the top water. rinsing the deposited sediment out of the containers. and transporting the samples to the laboratory. Settled material was air-dried to a water content of less than 1% (dry basis) and weighed. In most cases. the deposited sediment accounted for at least 97% of the total sediment yield.

Variables influencing sediment yield and runoff volume measured in this study included rainfall amount and intensity and percent vegetative cover. Monitoring of treatments began two weeks after road completion on 21 September 1995. before the first storm event had occurred. During rainfall events, rainfall amounts were recorded with a universal recording rain gauge located on site (table 1). At the time of each sample collection. the

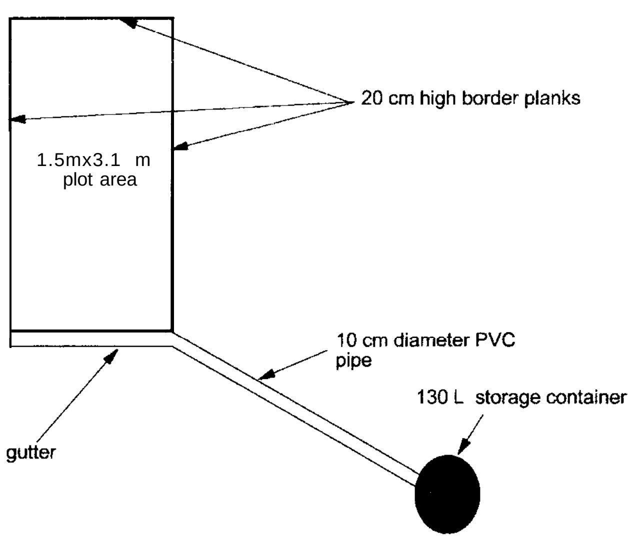

Figure 2-Individual plot design for field experiment showing specifications of the design.

Table 1. Sampling periods during the erosion study

Ohs. No.	Sampling Period (1995-1996)	Precipitation (mm)	Intensity (mm/h)
1	2 1 Sept '7 Sept	91.69	---
	27 Sept - 6 Oct*	218.95	29.46
2	6 Oct 18 Oct	13.46	9.14
3	18 Oct - 28 Oct	25.15	4.57
4	28 Oct 2 Nov	35.81	IO.92
5	2 Nov 9 Nol	9 l.69	6.86
6	'J Nov - 14 Nov	41.91	7.11
7	14 Nov 7 Dec	IX.03	3.81
X	7 Dec IL Dec	24.89	5.84
9	12 Dec 20 l Dec	69.85	10.41
10	20 Dec 12 Jan	61.98	3.05
11	12 Jan 3 1 J an	154.94	7.37
12	31 Jan 9 Feb	69.85	5 33
13	9 Feb 18 March	162.56	5.84

* Hurricane **Opal** storm event

total rainfall and average intensity for the sample period were determined by examining the gauge chart. Vegetative cover was quantified three times during the study using a visual assessment method. A rod with IO fixed observation points was placed at 10 random locations in each test plot for a total of 100 cover observations. Each observation point was classified as either covered or bare.

STATISTICAL ANALYSIS

The fillslope and cutslope data were analyzed as separate randomized complete block experiments because of the confounding of slope type with grade, permeability. and subsurface moisture. The cutslope sediment yield and runoff volume data failed to satisfy the normality assumption. The cutslope had regular heterogeneity of error which was caused by non-normality in the data. Variability within the treatments was proportional to the squares of the treatment means. which required a logarithmic transformation to equalize the variance (Steel and Torrie. 1960; Montgomery, 1991). Two statistical tests were used to analyze erosion data. correlation analysis and ANOVA. A Pearson's correlation analysis was used to test for correlations among both runoff volume and total sediment yield and rainfall amount. rainfall intensity, percent cover, and treatment age. Variables showing correlations with runoff volume and sediment yield was used as covariates in the analysis of variance. ANOVA was used to test the treatment effect for sediment yield and runoff volume. Where analysis of variance indicated significant treatment differences, Duncan's Multiple Range Test was used to compare individual means.

R ESULTS

Fourteen sampling events were monitored during the study period (table I). Some events included more than one individual storm. Immediately after initiation of the study, Hurricane Opal passed over the area, with an average rainfall intensity of 29.5 mm/h and a peak intensity of 48.3 mm/h. This single storm produced 218.9 mm of rain in a 36-h period which is equivalent to a 100-year storm for the Heflin. Alabama area. This event had such a high intensity that some seeds and mulch were washed away from the test area. Sediment yield from some treatments for this event exceeded the sum of all other periods in the

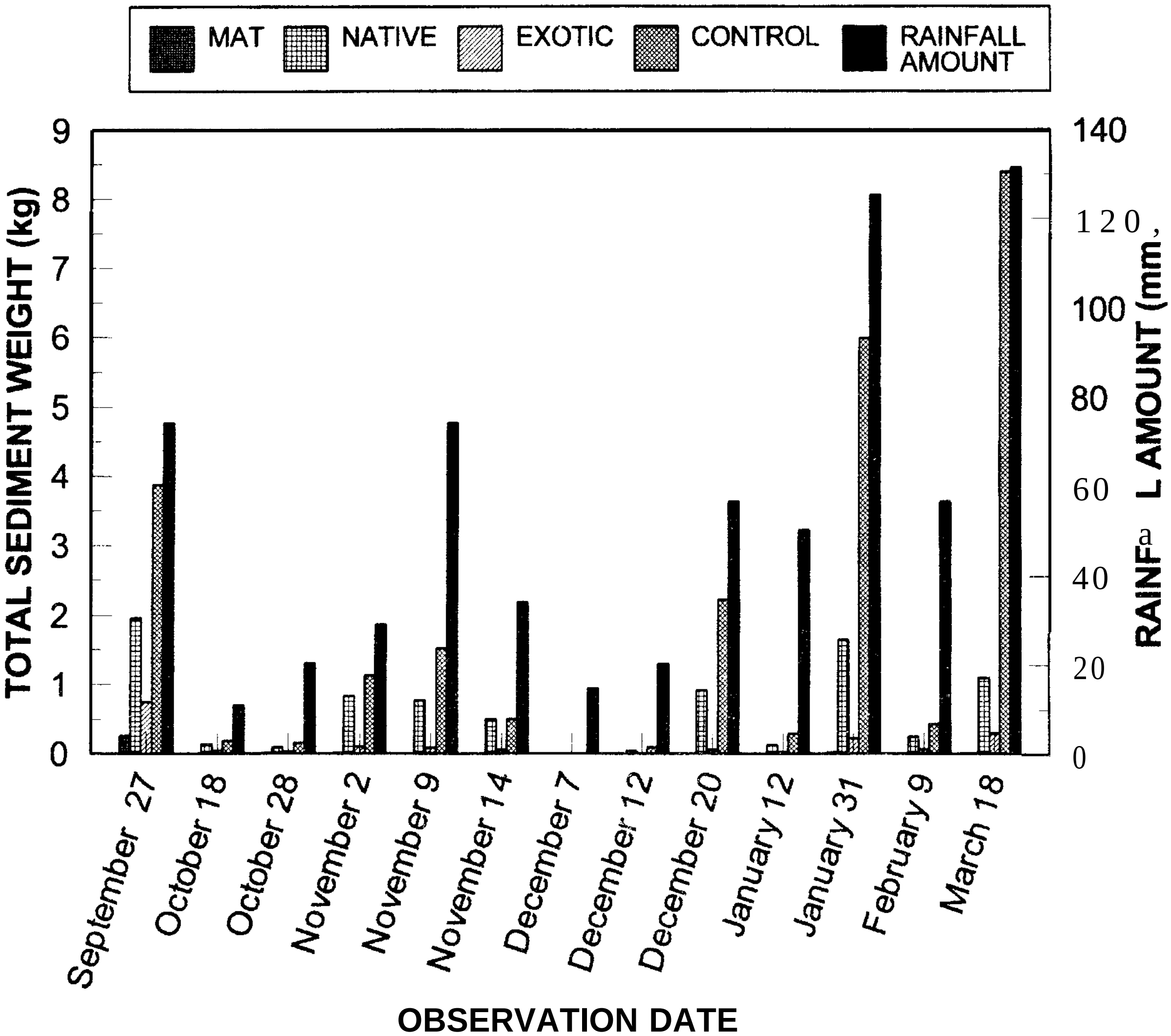

Figure 3–Observed cutslope treatment sediment yield for each sampling period during the six-month study period.

study. This unusual event. occurring immediately after the initiation of the study, was excluded from the statistical analyses for several reasons. First, the storm occurred before the vegetative cover had even germinated. Including this data would have heavily weighted the sediment production to a period when there was little difference between treatments. Second, the intensity of the rainfall was such that, even with effective erosion control treatments in place, the volume of water may have obviated any control effect. Finally. the amount of rainfall caused several containers to overflow, so valid data for sediment and runoff was unobtainable. While high intensity storms can occur on newly constructed roads, the objective of the study did not require a complete record of sediment yield to compare treatments.

Figures 3-6 show average sediment yield and runoff volume from cut and fillslopes during the 6-month study period, excluding the hurricane event. Consistent with the literature, sediment yield was highest immediately after road construction and then decreased dramatically for the erosion mat treatment and the exotic grass treatment. In the first two tnonths after construction, sediment yield from the native grass treatment and the control followed the same trend as the other plots. However. during the winter months of the study, sediment yield from the native grass plots and the control increased (Observations No. 9-13). This increase could be due to freezing and thawing action on the soil without grass cover or root systems. Native grass plots had less than 10% vegetative cover during this period of the study. Observation 9 covered a period where the first hard freeze occurred for the area with a low temperature of −10°C.

Over the entire six-month study period, the erosion mat treatment on cutslopes had 98.6% less sediment and 17.4% less runoff volume compared to the control (fig. 7). Exotic grass was the next most effective treatment on the cutslope with a 93.0% reduction in sediment, but an increase of 3.5% in runoff volume. The native grass plots were least effective on the cutslopes with a 66.3% reduction in sediment and a 10.4% increase in runoff volume.

On the fillslopes, erosion mat plots had 88.3% less sediment and 36.6% less runoff volume compared to the control (fig. 8). Native and exotic grass plots represented 80.9% and 86.8% reductions in sediment, respectively. Runoff volume was reduced in native and exotic grass plots by 25.1% and 53.8%, respectively. This effect is probably

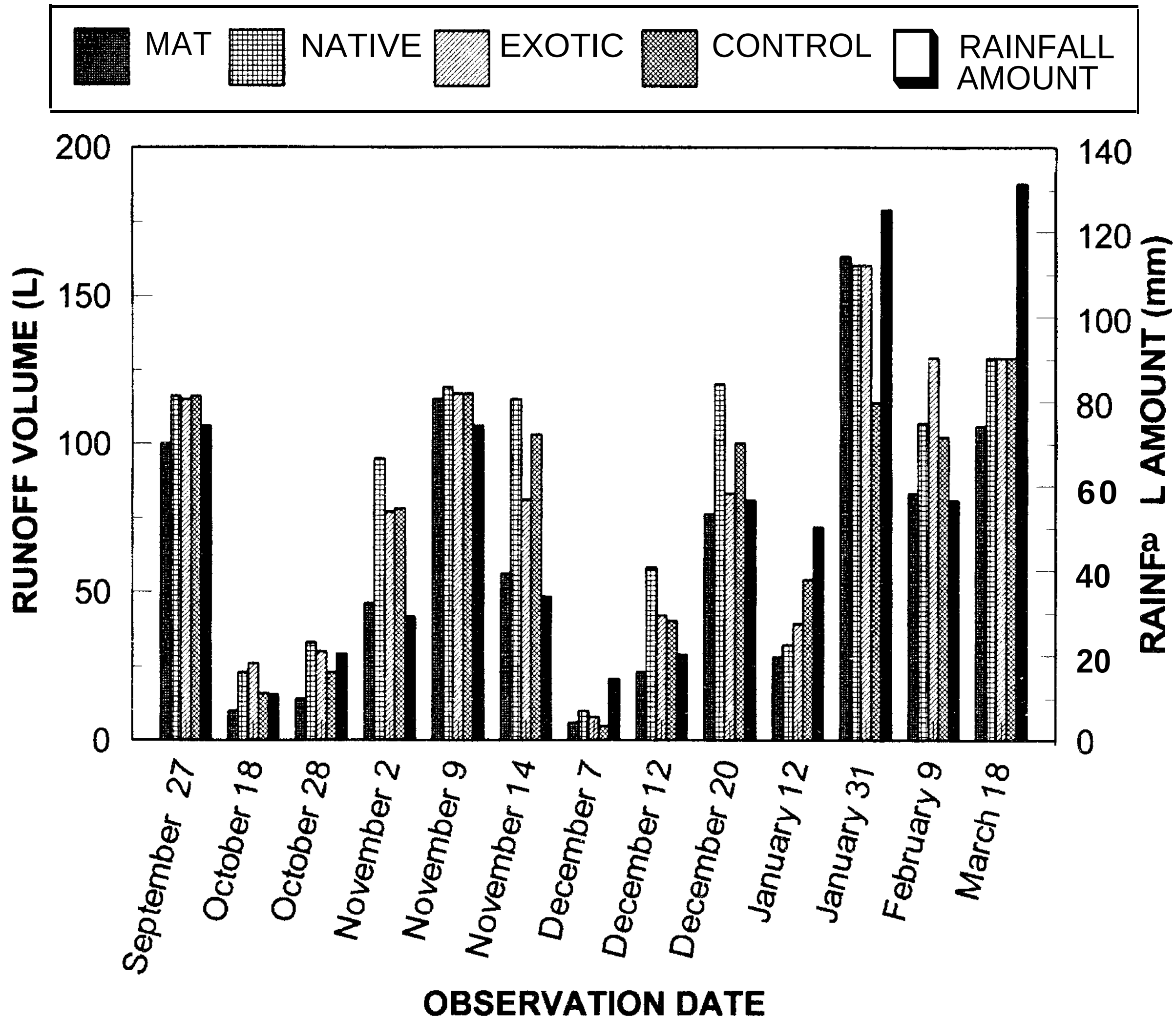

Figure 4–Observed cutslope treatment runoff volume for each sampling period during the six-month study period.

due to the differences in type of surface coverage exhibited by the erosion mat and exotic grass treatments (table 2). The erosion mat and exotic grass had a greater amount of vegetation cover as opposed to mulch cover. This would result in greater interception, decreased rain drop energy, and decreased runoff due to increased canopy in the erosion mat and exotic grass treatments.

Analysis on both slopes showed no strong correlations between rainfall intensity or percent cover, and either sediment yield or runoff volume. Runoff volume was correlated with sediment yield, rainfall amount, and treatment age. Runoff volume was used as a covariate in the sediment yield analysis of variance. The ANOVA indicated that the treatment effect was significant for both cut and fillslopes and for both runoff volume and total sediment yield. The individual treatment means were compared for significant differences using Duncan's Multiple Range Test. On the cutslopes. there were significant differences in sediment yield among treatments.

The erosion mat treatment had the lowest sediment yield, follow-ed by the exotic grass and the native grass (table 3). The cutslope control yielded more than 40 times more sediment than the erosion mat treatment. Cutslope runoff volumes showed no significant difference between the native grass and exotic grass treatments. The cutslope runoff volumes from the exotic grass treatment were not significantly different from the control. The erosion mat treatment on the cutslope had significantly less runoff than any other treatment.

Sediment yield from the fillslope followed a different trend than that from the cutslope. The fillslope erosion mat had the lowest sediment yield, followed by the native grass and exotic grass, but the differences were not statistically significant (table 4). The control treatment had significantly greater sediment yield than all of the other tillslope treatments. The control also had significantly greater runoff volume than all other fillslope treatments. Erosion mat and native grass treatments were not significantly different, while the tillslope exotic grass treatment had significantly less runoff volutne than all other tillslope treatments.

COSTS

The direct costs of installing vegetative erosion control treatments include labor and materials for fertilization, seed application. and mulching. Seed for native species is slightly more expensive than common exotic seed mixtures. Using genera1 labor estimates for seeding

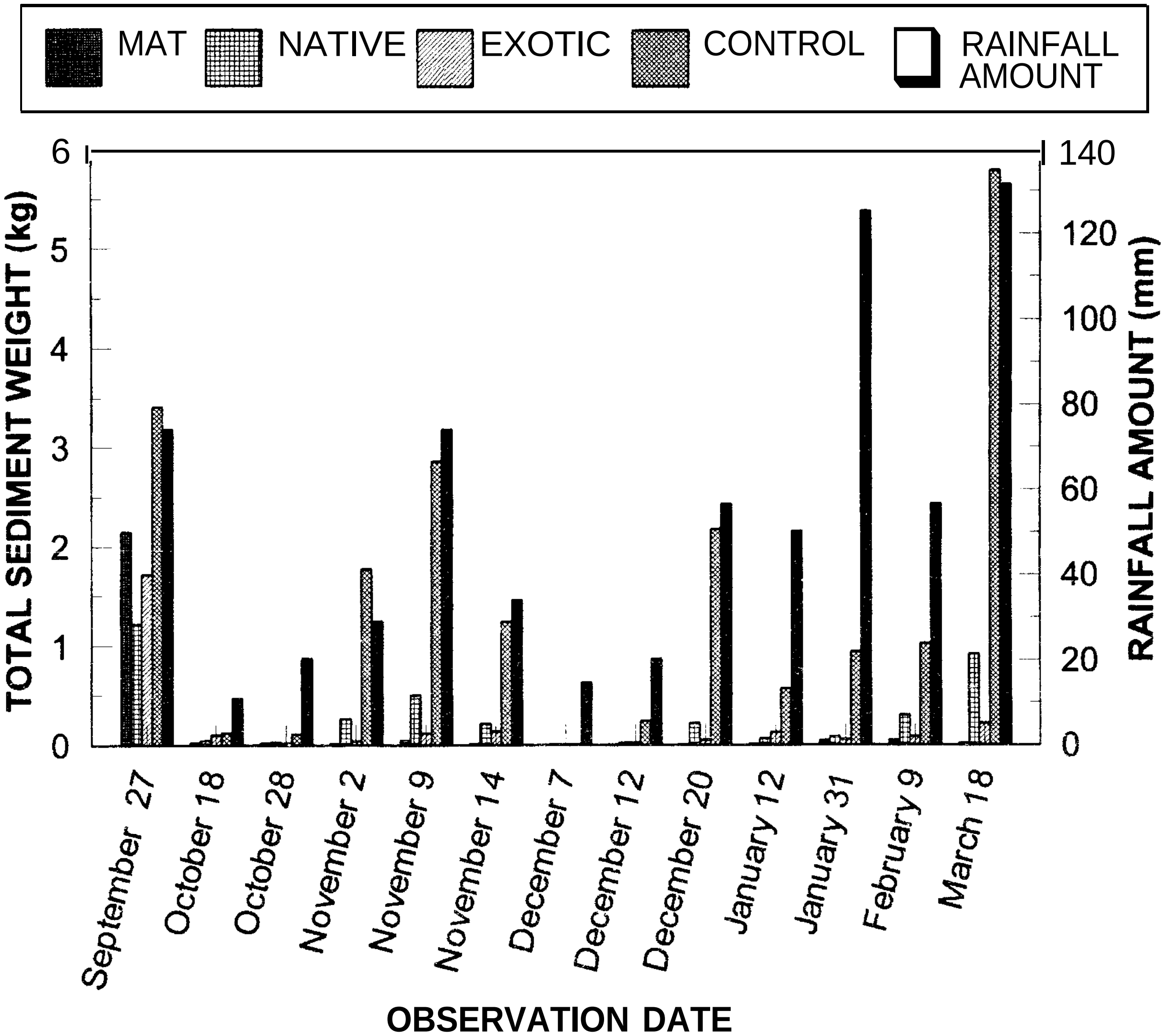

Figure 5–Observed fillslope treatment sediment yield for each sampling period during the six-month study period.

(USDA-FS 1997) and actual costs for seed, the exotic grass treatment would cost $2,470/ha while the native grass treatment would cost $2,900/ha. Erosion mat installation involves the same labor and materials as the exotic grass treatment plus the additional cost of the mat material. soil staples, and mat installation labor. Based on Forest Service labor estimates for mat installation (50% of materials). the total installed cost of the erosion mat treatment would be $12,500/ha, nearly five titnes the cost of the two basic seeding treatments.

While the installed cost of the erosion mat is high. ongoing costs should also be considered. For example. the bare soil treatment may require monitoring and maintenance to correct severe erosion which could cause gullying on the fillslope. Similarly. the basic vegetation treatments with seeding and hay mulch may require re-inspection and reseeding if bare spots occur due to surface sloughing. The erosion mat would be considered the most reliable level of erosion control since the mat provides a more secure covering to protect and enhance the development of vegetation. These ongoing costs are highly variable and difficult to estimate without long-term data.

Discussion

Erosion control can be achieved by interception of rainfall. increasing resistance to detachment, or reducing the transport capacity of the runoff. The vegetation-only treatments provide initial erosion control by rainfall interception and surface roughness of the straw mulch. As the seeds germinate. interception is increased by foliar development and detachment is reduced as the root network develops. During the period of this study, most of the plot cover in the native and exotic grass plots was due to mulch. The exotic species appeared to establish more quickly than the native species. By the middle of the study, the native species covered about 5% of the plots while the exotic grass species covered about 20%. This poor germination of seed mixtures is possibly due to either late seed application or high intensity storms, both of which are problems associated with the application of erosion control techniques during the fall.

The erosion mat treatment offered nearly 100% coverage and thus better protection from raindrop impact. However. even the erosion mat requires vegetative development to anchor the slope for longer-term erosion

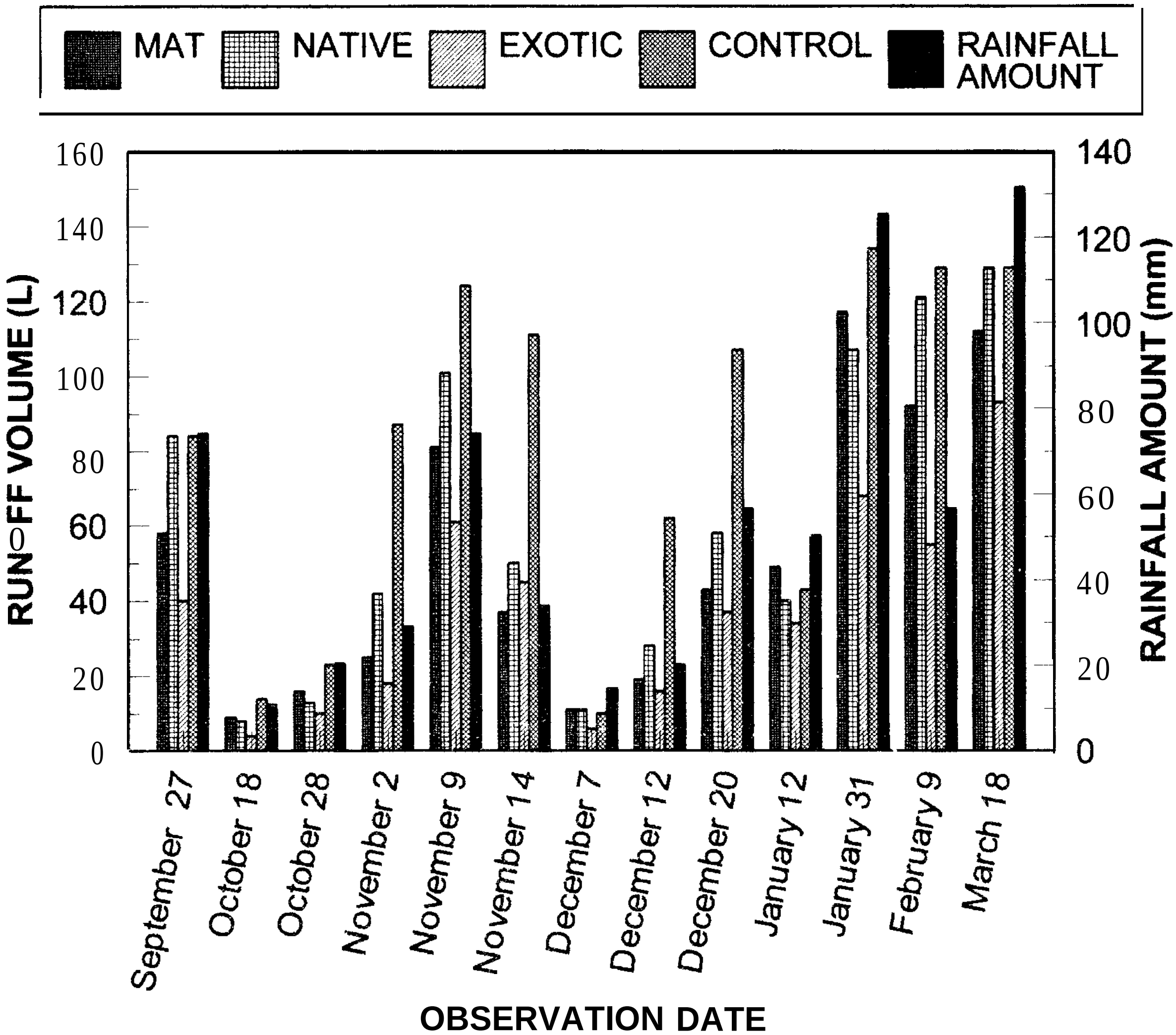

Figure 6–Observed fillslope treatment runoff volume for each sampling period during the six-month study period.

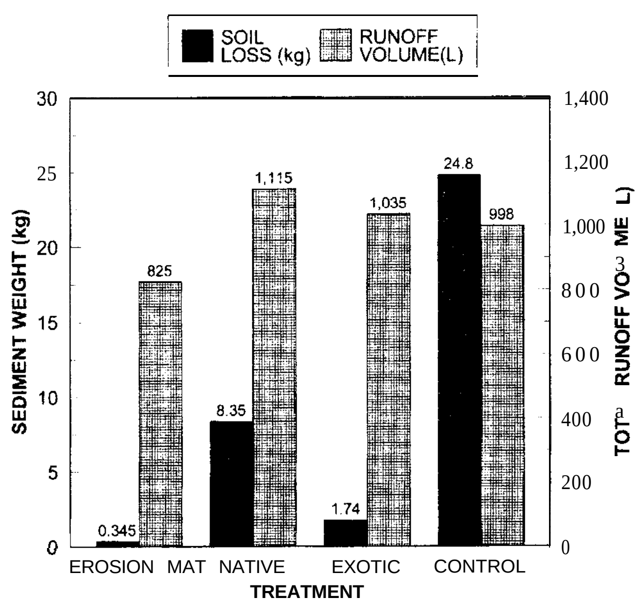

Figure 7-Average cutslope sediment yield and runoff volume for each treatment over the six-month study period.

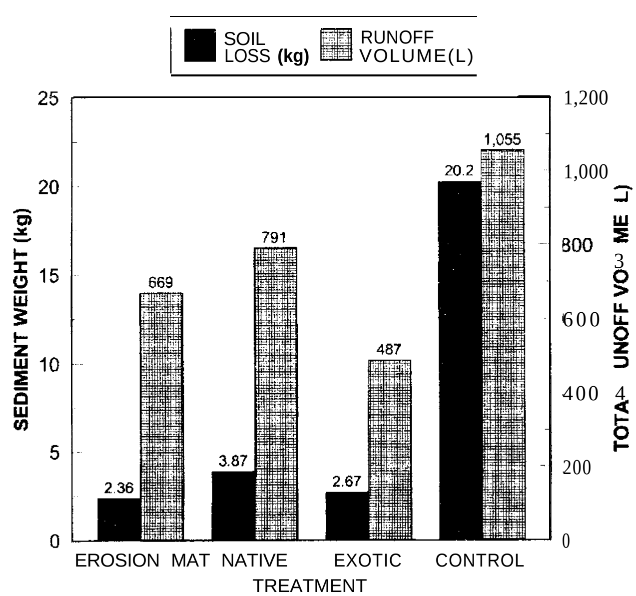

Figure R-Average fillslope sediment yield and runoff volume for each treatment over the six-month study period.

Table 2. Observed percent cover for each treatment during the study period

		Percent Cover *			
		Cutslope		Fillslope	
Date	Treatment	Vegetation	Mulch	Vegetation	Mulch
9/21/95	Erosion mat	0	100	0	100
	Native grass	0	80	0	61
	Exotic grass	0	57	0	47
	Control	0	0	0	0
11/9/95	Erosion mat	28	72	21	79
	Native grass	7	78	10	62
	Exotic grass	26	57	20	46
	Control	0	0	0	0
1/19/96	Erosion mat	29	70	17	78
	Native grass	1	68	8	60
	Exotic grass	21	55	19	43
	Control	0	0	0	0

* Total percent cover is the sum of vegetation and mulch for each treatment.

Table 3. Cutslope sediment yield and runoff volume statistics

	Sediment Yield			Runoff Volume		
Treatment	Mean* (g)	N	Std. Dev. (g)	Mean* (l)	N	Std. Dev. (l)
Erosion mat	27d	39	69	60.4c	39	48.3
Native grass	643b	39	721	83.2a	39	49.3
Exotic grass	134c	39	204	76.7ab	39	48.0
Control	1136a	39	1280	73.5b	39	49.0

* Means with same letter are not significantly different ($\alpha = 0.05$)

Table 4. Fillslope sediment yield and runoff volume statistics

	Sediment Yield			Runoff Volume		
Treatment	Mean* (g)	N	Std. Dev. (g)	Mean* (l)	N	Std. Dev. (l)
Erosion mat	181b	39	839	51.0b	38	41.7
Native grass	297b	39	396	58.9b	38	47.9
Exotic grass	205b	39	472	37.3c	37	31.7
Control	1554a	39	1747	81.0a	38	49.6

* Means with same letter are not significantly different ($\alpha = 0.05$)

control It appeared that there was little difference in establishment of the exotic grass species with or without an erosion mat cover. Thus, over titne. the erosion mat treatment should result in about the same level of erosion control as the exotic grass treatment.

The fillslope erosion mat, exotic grass. and control treatments yielded more sediment per liter of runoff than the corresponding cutslope treatments due to either greater erodability of the fillslope soil or greater detachment and transport capacity of the runoff. Fillslopes are constructed of unconsolidated material, sidecast into position during construction. The surface layer of the fillslope would thus be more erodible than the in-situ soil of a cutslope. in this study, the fillslope was also steeper than the cutslope (67% vs 45%). Greater slope increases the energy of overland flow and reduces critical shear of the surface particles. Inexplicably, the native grass treatment on the fillslope yielded less sediment per liter of runoff than the comparable cutslope treatment.

On tillslopes where the sediment yield was greater, no significant difference was found in effectiveness between the erosion control treatments. This may suggest that there is an upper limit to the control capability for vegetative stabilization treatments. At a lower sediment loading (i.e.. the cutslope) the erosion mat can control sediment movement. At a higher sediment loading. such as the fillslope with the steeper grade and more easily detached soil. the erosion mat may do little more than the vegetation-only treatments.

From a cost standpoint, no benefit was found to be derived from the more expensive installation of the erosion tnat treatment on the fillslopes. The significant difference in sediment yield among erosion control treatments was observed on the cutslopes. While the more expensive erosion mat treatment had the lowest sediment yield on the cutslopes. even the exotic grass cutslope treatment had a lower sediment yield than the erosion mat on the fillslope. Little justification was found for applying the erosion mat in the slope, climatic. and soil conditions observed in this study.

Conclusion

Erosion control treatments had a significant effect on reducing sediment yield frotn newly-constructed road sideslopes. On fillslopes. the erosion mat. exotic grass. and native grass stabilization treatments were equally effective, reducing sediment yield by about 85% compared to the bare soil control treatment. On cutslopes. the efficacy increased from native grass to exotic grass to erosion mat. In addition. the erosion mat reduced cutslope sediment production by a factor of four compared to the exotic grass treatment. On the more erodible conditions of the fillslope. the extra cost of the erosion mat treatment was not justified.

While this study only examined the first six months after construction. erosion control is an important continuing requirement. A treatment which is effective for the first month after construction may not continue to serve through the life of the road. During the course of this study. dynamic changes in erosion control occurred in the treatments. Storm events altered seed distribution, seasonal conditions varied vegetation cover, the mat materials and mulch began to degrade while vegetation development continued through the end of the initial study period. Because of the importance of the temporal dynamics of erosion control, the study plots will be maintained and monitored for longer-term comparisons.

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