Erosion Control Techniques on Forest Road Cutslopes and Fillslopes in North Alabama

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Road cutslopes and fillslopes account for approximately 50 percent of the total road disturbance area on steep terrain and contribute as much as 60 percent of sediment from forest roads. The significance of erosion control techniques on these vulnerable components of the road prism has become evident in recent years. A study to gain a better understanding of erosion control techniques on road cutslopes and fillslopes is detailed. Sediment and runoff yield from three erosion control treatments and a control were investigated on west-facing 2: 1 and 1.5 : 1 cutslopes and fillslopes, respectively, on a newly constructed road during a 30-month study. The treatments evaluated were a wood excelsior erosion mat, native species grass, and exotic species grass. Factors detected to significantly affect sediment yield from road sideslopes were treatment, time, and treatment-time interaction based on analysis of variance. Significant reductions in sediment yield and runoff were found on all treatments on both the cutslope and fillslope. The erosion mat most effectively controlled erosion losses on both slopes for all study periods.

Soil erosion and water quality have become major concerns in land management in the United States. Special attention has been given to nonpoint source pollution, including soil erosion, on the nation's forested lands. Accelerated erosion can result from forest management activities such as harvesting, site preparation, and road construction. Forest roads present the greatest potential for detrimental impacts, accounting for as much as 90 percent of all sediment produced from forested lands. The U.S. Department of Agriculture (USDA) Forest Service alone reports more than 600 000 km (400,000 mi) of roads that traverse national forests. The forest road system, consisting of federal, state, industry, and private road systems, is much more extensive than the Interstate highway system, presenting a serious national erosion problem.

Obvious impacts of forest toad erosion are the effects on the roadbed. Erosion can make passage on damaged roads for management activities extremely difficult. In extreme situations, erosion can render the road impassable, which may require expensive remediation measures. Other issues, such as environmental and social impacts, are sometimes hidden, but can result in costs that are difficult to estimate or measure. Eroded sediment from forest road systems causes negative environmental impacts on the nation's waterways, drainage systems, reservoirs, and aquatic life.

Forest roads have increased potential for accelerated erosion losses because of several factors:

- Elimination of surface cover by construction process,
- Concentrated flow caused by interception of natural drainage patterns,
- Destruction of natural soil structure,
- Increased slopes created from construction of road sideslopes,
- Compacted roadbed, which reduces infiltration rates, and
- Changes in subsurface hydrology.

This combination of factors for accelerated erosion potential is unique to the road prism, consisting of the roadbed, cutslope, fillslope, and roadside ditches.

The forest road prism has been identified as the major contributor to total soil erosion and sedimentation resulting from forest management activities (*1–4*). The two most susceptible road prism components, the cutslope and fillslope, constitute nearly 50 percent of the road prism area in sloping terrain. Previous work has shown that as much as 90 percent of total sediment loss from the road prism is contributed by the road sideslopes (5). Considering the accelerated erosion potential forest road sideslopes present in the forest ecosystem, quantifying and mitigating erosion and sedimentation is essential in designing environmentally sensitive forest systems. The objective of this work was to test the hypothesis that there is difference in the sediment yield, ground cover, and runoff production from three commonly applied erosion control treatments: native species grass, exotic species grass, and exotic species grass anchored with an erosion mat.

PREVIOUS WORK

Erosion from undisturbed forest lands is typically less than the normal geologic erosion rate, with less than 0.30 t/ha (0.13 ton/acre) per year (*2,6–8*). High levels of soil erosion have been reported after road construction, which disturbs the forest cover and forest floor. In a study conducted in southeast Oklahoma by Vowell (*9*), annual sediment yields ranged from 18 to 173 t/ha (8 to 77 ton/acre), with an average of 92 t/ha (41 ton/acre). Megahan and Kidd (10) reported sediment yield increases of 770 times that of undisturbed sediment yields during a 6-year study period. Road segments in the Alum Creek Watershed in Arkansas yielded erosion rates of 34 t/km (60 ton/ml) per year, and basinwide road erosion averaged 41 t/km (72 ton/mi) per year (I I). In North Carolina, 5200 m^3 (6,800 yd^3) of soil loss was measured in 4 years from 3.7 km (2.3 mi) of road, and up to 90 percent of sediment after logging operations came from roads (12).

Erosion losses from forest roads require special attention because sediment from roads can be carried directly to waterways through ditches and crossings. One major concern in managing the forest ecosystem is the sediment load from forest roads into waterways (13). The erosion loss from roads can be related to the sediment load introduced into streams. Fredriksen (*14*) found that sediment loads increased in streams draining watershed areas from 2 to 150 times the amount produced from undisturbed watersheds during the first year. King and Gonsior (1) reported sediment loadings caused by the movement of newly exposed cutslopes, ditches, and roadbeds in the order of 100 to 10,000 times the normal sediment fluxes from watersheds

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in north central Idaho. Investigators concluded that effective methods to control erosion resulting from forest roads would directly influence the quality of waler in the forest ecosystem.

The first year after forest road construction in the Zena Creek study area in Idaho. sediment yields averaged 38 t/d/km? (109 tons/d/mi²) of road, which is 1,560 times greater than undisturbed sediment production rates. Sediment yield during this first year was 84 percent of total sediment yield during a 6-year study. Sediment yield had decreased nearly SO times that of the first year by the end of the study. The research results suggest guidelines to effectively control surface erosion and sediment export downslope in the Idaho Batholith: (a) apply erosion control techniques immediately after road construction, (b) protect the surface until vegetation is established, and (c) reduce sediment export downslope by using debris barriers (IO).

Swift (*15*) investigated soil loss from roadbeds and sideslopes in the southern Appalachian Mountains. The roadbed accounted for 54 percent of the roadway area with cutslopes and fillslopes accounting for the other 46 percent of the road construction disturbed area. Road sideslopes and ditches accounted for as much as 90 percent of total sediment yield during a 23-month study period. During the first 4 months after construction, the cutslope and fillslope yielded 52 and 82 percent, respectively, of their total sediment yield during the study period. The investigator found that from two study sites the total roadway yielded 72.0 and 88.0 t/ha (32. I and 39.2 ton/acre) per year.

In early road sideslope work by Hursh (*16-19*), the effect of surface cover was investigated and minimum recommendations were suggested. Surface cover as mulch was reported as a minimum to reduce sediment yield from road sideslopes. Two methods of mulch application were outlined: staked weed mulches and staked brush and litter mulch. The use of mulch was successful in assisting the establishment of natural vegetation on road sideslopes.

Expanding on the previous work, Berglund (20) reported that the establishment of plant and litter cover is the most important deterrent to surface erosion. In western Oregon, five different seeding mixtures were used on a 5-year-old 1 : 1 cutslope to assess the effectiveness of grass-legume mixtures in controlling soil erosion (21). The study emphasized the importance of mulch in minimizing soil losses during the first few months following construction. The treatments that did not use mulch were the least effective during the first year.

The effects of surface cover types, their combinations, and the ground coverage on soil loss have been investigated using a rotating boom rainfall simulator (*22*). Surface coverage of 100 percent litter and rock was the best protection from erosion losses. Meyer et al. (23) found an inverse correlation between rock cover and erosion rate. Coverage of 34 t/ha (15 ton/acre) of stone showed severe rills, whereas 300 t/ha (134 ton/acre) of stone was an effective erosion control treatment.

Burroughs and King (24) studied mitigation of erosion from specific components of the roadway, including traveled ways, fillslopes, cutslopes, and roadside ditches. They concluded that the effectiveness of erosion control techniques was directly related to the timing of application, type of treatment, rate of application for mulch treatments, erodibility of the soil, gradient, and road design. The investigators looked at six different erosion control treatments on fillslopes:

- Straw with asphalt tack,
- Straw with a net or mat,
- Straw alone,
- Erosion control mats,
- Wood chips or rock, and
- Hydromulch.

They found that the greater the ground cover. the more effective the erosion control treatment. The most effective treatment with respect to ground coverage was straw with asphalt tack.

Ohlander (25) reported large reductions in sediment production after application of erosion control techniques in the Zena Creek study area in the ldaho Batholith. Straw mulch. jute netting, and asphalt-straw had reductions from untreated areas in sediment yield of 72.93, and 97 percent, respectively. In a similar study. seed. fertilizer, mulching, and netting effectively controlled erosion to 610 ± 370 kg/ha (540 ± 330 lb/acre) per year (26). Erosion losses were significantly reduced by seed, fertilizer, mulching. and netting compared with seeding and fertilizing, which yielded losses of 120 000 ± 8900 kg/ha (107,000 ± 7,900 lb/acre) per year on a fillslope with an average slope of 80 percent (26).

The past 60 years of research have identified forest road sideslope erosion and sedimentation resulting from sediment export as a major issue in forest management. Since the initial investigations in the 1930s, studies have been conducted to quantify soil losses, define treatment objectives, mitigate sediment yield, and control sediment transport to waterways. This work has begun to build an extensive database on forest road sideslope erosion. However, the impact of sideslopes on erosion and sedimentation continues to be a major concern in forest management. Erosion control alternatives that consider economic. environmental. and social issues require further investigations to design environmentally sensitive forest road systems.

METHODS

The study site is located in the Shoal Creek District of the Talladega National Forest in Cleburne County near Heflin. Alabama. Soils are Tatum series, a fine-loamy mixed-thermic Typic Hapludult. The soil profile in its undisturbed state consists of a silt loam surface layer of 0.10 to 0.15 m (4 to 6 in.) that overlays a red clay loam subsoil 0.50 to 0.55 m (20 to 22 in.) deep. Because of the road construction process, the 2.2: 1 cutslopes were primarily the exposed subsoil, whereas the 1.5 : 1 fillslopes were composed of a mixture of surface and subsoil. Infiltration rates are estimated for the cutslope and fillslope at 19. 1 and 18.6 mm/h (0.75 and 0.73 in./h), respectively, on the basis of rainfall and runoff measurements from bare soil. The area receives on average 1400 mm (54 in.) of annual precipitation: long-term averages show that approximately 70 percent of this precipitation occurs from September to March.

The mid-slope half-bench crowned road with inside ditching was constructed during summer 1995. The study began immediately after construction and was monitored for 30 months.

Experiment Design

The experimental design was a randomized complete block on both the cutslope and fillslope with three blocks of three erosion control treatments and a bare soil control. Twelve test plots were located on west-facing cutslopes and fillslopes (Figure 1). Plot dimensions are 1.5 x 3.1 m (5 x 10 ft), with a total area of 4.65 m² (50 ft²). The plots are oriented with the 3. l-m (10-ft) length along the slope length. Plots were bound on all sides withboards 20 cm (8 in.) high driven approximately 5 cm (2 in.) into the slope surface. A gutter, located at the plot bottom, channels plot runoff into a 130-L (34-gal) storage container.

Erosion control treatments were seeded and mulched by hand September 16, 1995, 1 week after road completion. A Fescue hay

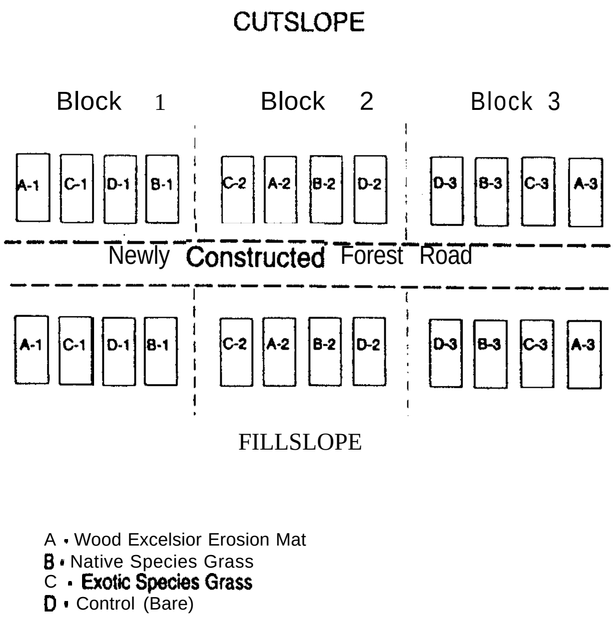

FIGURE 1 Experimental layout of erosion control plots.

mulch was applied at a rate of 4.5 t/ha (2 tons/acre). Fertilizer and lime were applied at the rate of 1.0 t/ha (0.45 tons/acre) of 13-13-13 fertilizer and 4.5 t/ha (2 tons/acre) of agricultural limestone. Treatments investigated and compared with a bare control in the experiment were native species grass, exotic species grass, and erosion mat. Native species grass treatments were seeded with a mixture of big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), and Alamo switch grass (*Panicum virgarum*), each at a rate of 11 kg/ha (10 lb/acre). Exotic species grass treatments were seeded with Kentucky 31 tall fescue (*Festuca arundinecea*) at 28 kg/ha (25 lb/acre), Pensacola bahiagrass (*Paspalum notatum*) at 23 kg/ha (20 lb/acre), annual lespedeza (*Lespedeza cuneata*) at 6 kg/ha (5 lb/acre), and white clover (*Trifolium repens*) at 11 kg/ha (10 lb/acre). Erosion mat treatments were seeded with the exotic species grass mixture and covered with a wood excelsior erosion mat anchored in place with staples 15 cm (6 in.) long. The control had no mulch or seeding applications.

Data Collection

Monitoring of treatments began 2 weeks after road completion. Precipitation amounts and duration were recorded with a universal recording rain gauge located on site during four 6-month study periods (Table 1). Frequency of study measurements varied from 1 to 8 weeks depending on the time required for treatment runoff to fill any of the calibrated storage containers. Frequency of measurements decreased as treatments aged because of greater infiltration and decreased runoff from the slopes. Runoff from each associated treatment was measured directly as height of water in storage containers. Sediment yield measurements involved measuring suspended and deposited sediment in storage containers. Suspended sediment was determined by taking 500-ml (0.5-qt) samples from stored runoff and processing samples for gravimetric analysis using methods defined by Greenberg et al. (27). Deposited sediment was collected by draining off standing water in storage containers, collecting remaining sediment, and transporting it to the laboratory. Deposited sediment was then dried to a moisture content of less than 1 percent (dry basis) at 105°C. Total sediment yield was determined as a combination of both suspended and deposited fractions in the containers. Ground cover, the sum of mulch cover and vegetation cover, was quantified 12 times (3 times per study period) during the study by classifying 100 random points within each plot as either mulch covered, vegetation covered, or bare. The total of covered points was taken as percent ground cover.

Thirty-one observations of precipitation amount and intensity, runoff, suspended sediment, deposited sediment, and treatment age were collected during the 30-month study. Variables considered in this experiment as independent variables were precipitation amounts, precipitation intensity, and treatment age. Dependent variable measurements of sediment yield per unit depth, runoff, and ground cover were repeated over time. A Pearson's correlation analysis was performed on the 31 observations to detect significant correlations. Dependent variables were tested by SAS GLM repeated measures procedures as functions of treatment effects for the 30-month study. Data were then organized in four 6-month, postconstruction study periods: 0 to 6 months, 12 to 18 months, 19 to 24 months, and 25 to 30 months. Individual treatment means were tested for between subject effects (α = 0.05) in cases in which repeated measures analysis of variance indicated significant differences.

DISCUSSION OF RESULTS

Precipitation

Precipitation, the majority of which was rainfall. showed differences between study periods and affected sediment yields in this experiment based on analysis of variance. Precipitation during the first 6-month study period was greater than in all other periods during the study (Figure 2). The third 6-month period received significantly less precipitation than all other study periods. This period occurred during the drier months in central Alabama (April-September). During the last 6-month study period, precipitation was 693 mm, consistent with amounts recorded during the first two study periods. The effect of precipitation differences among study periods was corrected by analyzing sediment yield per unit of precipitation as opposed to simply analyzing overall sediment yields.

Rainfall intensity has been reported to be a major influence on the detachment and transport (erosive) energy of storms (28,29). Observed sediment yields were greater in storms with higher intensities. Each treatment yielded greater quantities of sediment during higher intensity storms, although the effects can more easily be observed on the bare soil control used in the experiment. The higher intensity storms (Table 1) coincide with periods of accelerated sediment loss from both slopes.

Ground Cover

Ground cover from mulch immediately after installation and before study initiation on erosion control treatments was highest on the cutslope treatments. The cutslope had less slope than the fillslope, which permitted more efficient application of mulch. Exotic species treatments had 57 and 47 percent cover on the cutslope and fillslope, respectively. Native species treatments had a higher ground cover than the exotic species, with 80 and 61 percent cover on the cutslope and fillslope, respectively. The erosion mat treatment had 100 percent cover on both slopes immediately after treatment installation.

TABLE 1 Observed Precipitation for Shoal Creek Study Area

Study Period #	Elapsed Days (day)	Precipitation Amount (mm)	Intensity (mm/hour)
1 (0-6 month)	7	91.7	---
	27	13.5	9.1
	37	25.2	4.6
	42	35.8	10.9
	49	91.7	6.9
	54	41.9	7.1
	79	18.0	3.8
	84	24.9	5.8
	92	69.9	10.4
	115	62.0	3.1
	134	154.9	7.4
	143	69.9	5.3
	181	162.6	5.8
2 (12-18 month)	417	104.1	9.1
	437	80.0	5.3
	473	111.8	3.8
	480	44.7	6.9
	491	102.9	10.2
	498	26.9	5.1
	512	57.2	2.1
	519	66.5	10.2
	534	34.3	5.1
	554	90.7	17.5
3 (19-24 month)	625	287.0	7.9
	654	47.2	8.9
	729	206.8	20.8
4 (25-30 month)	779	137.2	5.3
	806	159.6	7.3
	828	73.7	3.3
	861	144.8	6.1
	890	177.8	2.5

Average ground cover for erosion control treatments for periods during the study ranged from 58 to 100 percent (Table 2). Ground cover was detected by a Pearson's correlation analysis procedure as moderately correlated with sediment yield from erosion treatments. Treatments with increased ground cover had reduced sediment yields from both slopes investigated in this study. A stronger correlation between ground cover and sediment yield was detected on the fill-slope than on the cutslope with correlation coefficients of 0.683 and 0.542, respectively. Reductions in sediment yields can be related to the effectiveness of ground cover in reducing storm energy, as discussed in the previous section of this paper. The relationship between ground cover and reduced sediment yields can also be observed by comparing erosion control treatments with the bare soil control. The control's excessive sediment yields during higher intensity storms was likely caused by the lack of the ground protection from storm energy found on the three study treatments.

Ground cover stayed relatively constant during the four study periods in this experiment. Grass establishment for the duration of the experiment increased with each study period. A noticeable shift was observed during the second study period as vegetation was estab-

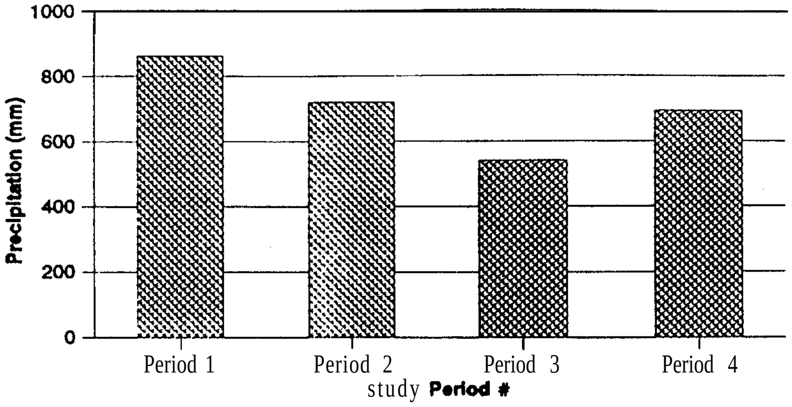

FIGURE 2 Precipitation observed during each study period.

lished and accounted for the majority of ground cover (Figure 3). Erosion mat treatments were shifted from 100 percent mulch cover at the beginning of the experiment to 96 percent vegetation cover within the first year after establishment. Similar shifts from mulch cover to vegetation cover were recorded for all three erosion control treatments in this study. Changes in cover type likely influenced sediment yields measured in this experiment, but could nor be tested in this experiment. Vegetation cover has been reported to provide greater reductions in soil erosion than mulch cover by (a) greater interception of raindrops, which decreases raindrop energy; (b) anchoring the soil with root systems, which reduces the detachment of soil particles; and (c) slowing runoff with increased roughness.

Sediment Yield

Repeated measures analysis of variance detected a significant treatment effect on sediment yield from both slope types. Contrast tests (a = .05) were used to test treatment means for between subject effects on the cutslope and fillslope. The test on the treatment means detected that sediment yield from the control was significantly different from treatments on both the cutslope and fillslope. Cutslope and fillslope native species grass, exotic species grass, and erosion mat treatments were statistically similar in sediment yield on the basis of repeated measures analysis of variance results of all observations during the study.

Data were categorized in distinct study periods to test for differences among treatments for individual study periods. The native species grass, exotic species grass, and erosion mat treatments provided great reductions in sediment yields during all four study periods compared with the control (Table 3). The erosion mat afforded the greatest protection of sediment and runoff yields on both slopes because of the reduction in sediment yields during the first study period, which covered the first 6 months after slope construction. The erosion mat produced less than 1 t/ha (0.4 ton/acre) on the cutslope during the first 6 months, which was 99 percent less than the untreated control and greater than 79 percent less thau the two grass treatments on the cutslope. Fillslope sediment yields from the erosion mat and grass treatments during the first study period, ranging from 5.1 to 3.3 t/ha (2.3 to 3.7 ton/acre), were more comparable. Sediment yield reductions of greater than 89 percent were observed on all treatments by the second study period for both slopes and continued through the next two study periods. The control had a decrease in yields as the slopes aged, but continued to yield excessive quantities of sediment and runoff throughout the 30-month study period. Cumulative sediment yield from the untreated controls on the cutslope and fillslope averaged 100.1 and 76.1 t/ha (44.6 and 33.9 ton/acre), respectively, by the end of the fourth study period.

Runoff

Repeated measures analysis of variance detected a significant treatment effect on runoff yield from both slope types. Contrast test (a = .05) were used to test treatment means for between subjects effects on the cutslope and fillslope. Cutslope erosion mat runoff was significantly different from the native species grass and the control in an analysis of all observations in the study. On the

TABLE 2 Average Ground Cover for Treatments During Study Periods

	Cutslope				Fillslope			
Period	Erosion Mat	Native Grass	Exotic Grass	Control	Erosion Mat	Native Grass	Exotic Grass	Control
1	100	78	75	0	98	67	58	0
2	96	93	a6	13	95	85	79	12
3	98	87	89	12	97	87	100	17
4	98	85	80	14	97	89	89	52

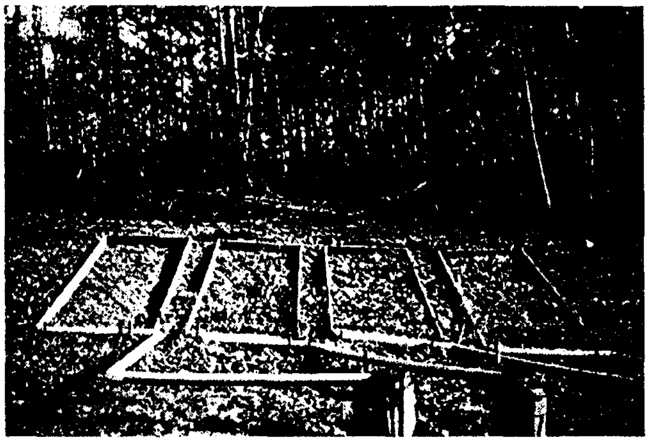

FIGURE 3 Typical ground cover on cutslope treatments 1 year after treatment (*left to right:* exotic grass, erosion mat, native grass, and control).

fillslope, no significant differences were detected between treatments and the control based on results from analysis of all observations in the study.

Analysis of individual study periods detected no significant differences in cutslope runoff during the first and fourth study period. The second study period had a significant difference in cutslope runoff between the erosion mat and the native species grass and the control. The cutslope erosion mat runoff was significantly different from the two grass treatments and the control during the third study period. On the fillslope, exotic grass runoff was different from the native grass and the control during the first period. In the second study period, the fillslope control was significantly different from all treatments in the experiment.

Time Effect

To investigate the effect of treatment age and time trends on sediment yield and runoff from road sideslopes, the data were categorized in four postconstruction periods (Table 3). Repeated measures analysis of variance detected a significant time and treatment-time interaction on both slopes in this investigation. The repeated measures analysis detected significant time effects on treatment ground cover. sediment yield, and runoff from the slopes. In addition to showing a change in ground cover, sediment yield, and runoff over time. tests detected the treatment effects as being significant over time for all three dependent variables. The treatment effects were detected as being significant for all comparisons of ground cover. sediment yield, and runoff, with the effect of time taken into account.

Sediment yields were highest for all treatments during the first few months after construction (Period I), when the slopes were vulnerable to erosion losses (Table 4). The native grass treatment had higher sediment yields, five times more on cutslopes and twice as much on fillslopes, than any other treatment during this first 6-month period. During the second fall-winter study period (12 to 18 months after establishment), sediment yields from all treatments decreased. The erosion mat and exotic species grass treatments had decreased to less than 0.3 and 0.5 t/ha (0. I3 and 0.22 ton/acre), respectively, on both the cutslope and fillslope. The native species grass sediment yield decreased to IO times less on the cutslope and 40 times less on the fillslope during the second fall-winter study period. The control treatment also had decreased sediment yields during the second fall-winter study period.

The third study period, which was a spring-summer period, had less precipitation and runoff and more ground cover than all previous periods of the study. Sediment yield during this period was higher than during the previous period for all treatments on the cutslope and fillslope. The control also yielded more sediment from the cutslope, but less from the fillslope. Storm intensity, averaging 12.5 mm/h (0.50 in./h), was greater during this period than during the previous period (Period 2). This increased storm energy allowed a greater potential for detachment and transport of sediment.

Sediment yield declined significantly during the fourth study period to less than 0.22 t/ha (0. IO ton/acre) for fillslope treatments. Sediment yields also significantly decreased on the cutslope treatments to less than 0.64 t/ha (0.29 ton/acre) by this period. The control continued accelerated sediment losses during the fourth study period, with 10.8 and 2.6 t/ha (4.7 and 1.2 ton/acre) on the cutslope and fillslope, respectively. By the fourth period, sediment yield from the fillslope control began to show strong signs of stabilization, with a 77 percent reduction in sediment yield from the previous period.

TABLE 3 Sediment Yield Reductions for Treatments on Cutslope and Fillslope

	Sediment Yield (t/ha)				Runoff Yield (mm)			
Treatment	Period 1	Period 2	Period 3	Period 4	Period 1	Period 2	Period 3	Period 4
Cutslope								
Erosion mat	0.81	0.24	0.34	0.29	178 (18%)	48 (75%)	41 (48%)	41 (61%)
Native species	18.0	1.8 (89%)	2.7 (85%)	0.64	241 (-	168 (13%)	69 (13%)	79 (24%)
Exotic species	3.8 (93%)	0.58	0.93	0.28	224 (-4%)	137 (29%)	69 (13%)	91 (12%)
Control	53.5	17.0	18.6	10.8	216	193	79	104
Fillslope								
Erosion mat	5.1 (88%)	0.11	0.20	0.01	145 (36%)	107 (52%)	53 (26%)	64 (47%)
Native species	8.3 (81%)	0.13	0.42	0.11	170 (26%)	97 (56%)	51 (31%)	53 (55%)
Exotic species	5.8 (87%)	0.27	0.68	0.22	104 (54%)	89 (60%)	53 (28%)	66 (45%)
Control	43.6	10.4	11.5	2.6	229	221	74	119

. (**) Percent reduction in comparison to the bare soil control.
1 t (metric ton) = 1 .1 ton; 1 ha = 2.47 acres; 1 mm = 0.039 inches

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