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Sediment Production and Runoff from Forest Road Sideslopes

by

John M. Grace III
Research Engineer

Bob Rummer
Research Engineer

Bryce J. Stokes
Project Leader

USDA Forest Service
Southern Research Station, SRS-4703
Auburn, Alabama

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Summary:

Sediment and runoff production from three erosion control treatments were investigated on a newly constructed road during a two-year study period. The treatments included a wood excelsior erosion mat, native grass species, and exotic grass species. Sediment and runoff production were significantly reduced on both the cutslope and fillslope by the treatments. Grass treatments showed more than a 90 percent reduction in sediment production between the two study years. The erosion mat treatment showed relatively insignificant sediment production for both years during the study.

Keywords:

Forest roads, Soil Erosion, Conservation Practices, Slopes, Surface. Runoff

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Introduction

Forest roads are recognized as a major source of erosion from forested lands across the United States (Patric, 1976; Swift, 1984a). Forest roads are reported to account for as much as 90 percent of all sediment produced from forest land (Patric, 1976; Anderson et al., 1976; Hoover, 1952; Megahan, 1972). Roads accelerate erosion by increasing slope gradients, interrupting normal drainage patterns, and concentrating overland flow into ditches and channels. Erosion losses from forest roads require special attention since sediment from roads can be carried directly to waterways and streams.

The key to reducing the amount of sediment delivered to waterways is to identify the source of erosion losses. The greatest mitigation of erosion losses can be achieved through careful planning, location, construction, and maintenance of forest roads. Sediment is produced from all aspects of the road prism: traveledway, cutslope, fillslope, and ditching. Considering the impact roads have on the forest ecosystem, quantifying erosion and sedimentation resulting from forest roads is elemental in designing sustainable, aesthetically pleasing forest systems.

Previous Work

Pioneer work in road bank stabilization was done in the southern Appalachians during the mid- 1930's. Hursh (1935) explored bank stabilization after 6 to 12 inches of bank soil were lost from steep banks. Experiments showed that the most practical and simplest procedures for road bank erosion control were: sod strips along the contour, root clumps of honey suckle along the contour, grass seed, stake and brush wattles, and wood litter and debris. Hursh (1938, 1939,1949) recommended mulching as a minimal requirement for road bank stabilization. Mulches were found to be the simplest and least expensive method for stabilization. Hursh (1942) found that slopes were stable during most of the year but could be unstable during the winter months due to sloughing and erosion caused by alternate freezing and thawing. The investigator stated that a slope has to be made stable by vegetation or some mechanical means to prevent surface soil movement.

Swift (1984b) also investigated soil loss from roadbeds and cut and fillslopes in the southern Appalachian mountains. The roadbed accounted for 54 percent of the roadway with cut and fillslopes accounting for the other 46 percent of the road construction disturbed area. During a 23 month study period, the total roadway yielded 139 and 169 t/ha of sediment at two different sites.

Application of erosion control practices can reduce sediment yields from the forest road prism. In a study by Cline et al. (198 1), the onsite sediment reductions suggested a partitioning of total sediment production of 60 percent from fillslopes, 25 percent from traveledways, and 15 percent from the cutslope and ditch. This partitioning was based on comparisons between erosion reduction factors given by this research and the amount of erosion reduction reported for individual components of the road prism. The amount of reduction that can be achieved with various erosion control treatments on cut and fillslopes was also estimated by Burroughs and King (1989). Six treatments were identified as erosion control treatments: straw with asphalt tack, straw with net, straw, erosion control mats, wood chips or rock, and hydromulch.

Sediment production decreased with increasing ground cover. Hydromulch was least effective in reducing sediment production unless used with some type of fiber tackifier.

Eight mulching treatments were evaluated on fillslopes for their effectiveness in promoting grass establishment by Dudeck et al. (1970). Mulch treatments evaluated included an emulsified polymer, compost, wood cellulose, jute netting, excelsior, and asphalt-anchored mulches of excelsior, wood shavings, and bark dust. The treatments with an excelsior mat or jute netting yielded the best grass coverage. The investigators reported poorer performance from treatments with asphalt tackifier. In another study by Grace et al. (1996), treatment with wood excelsior erosion mat proved to be most effective in reducing erosion from cut and fillslopes immediately after construction. Erosion mats resulted in a 98 and 88 percent reduction in sediment production from cutslopes and fillslopes, respectively.

The effect of surface cover on soil loss was studied using a rotating boom rainfall simulator by Benkobi et al. (1993). The treatments evaluated included different combinations of rock and surface litter. The investigation concluded that 100 percent coverage with combinations of rock and surface litter offered the best protection of the soil against erosion. Research has shown that some type of cover has to be utilized in order to control road bank erosion and establish permanent vegetation, although timing of application will determine success of erosion controls.

Research evaluating sediment production from road sideslopes has shown that sediment production is greatest immediately following construction. Sediment production has been reported to exponentially decrease over time (Bethlahmy and Kidd, 1966; Burroughs and King, 1989; King, 1984; Megahan, 1974; Swift, 1985; Megahan et al., 199 1). The first few rainstorms after construction were reported by King and Gonsior (1980) to cause 100 to 10,000 times the normal sediment loadings into streams, representing 45 to 450 kg of sediment loss.

Objectives

Previous research has concentrated on sediment production from forest roads in various geographical areas in the USA, but research has not focused on specific conditions encountered in the South. Unique climatic factors, soil characteristics, and topographic factors found in the southern USA could necessitate variations in treatment methods used to control road erosion. The purpose of this study was to obtain better understanding of the effect of treatment and slope age on sediment production. This study investigates road sideslope erosion from erosion control techniques commonly used in the southern USA and assess the effectiveness of various erosion control treatments on sediment and runoff production from road sideslopes over a two-phase study period.

Shoal Creek Study

A field experiment was conducted to assess road sideslope erosion control techniques on a typical forest road in the southern USA. The study site was located on the Shoal Creek District of the Talladega National Forest in Clebume County near Heflin, Alabama. The study was initiated immediately after construction of a forest access road in the fall of 1995 and was intensively monitored for the critical fall-winter 1996 season after road construction (September 2 1, 1995 to March 18, 1996). Monitoring was re-initiated during the fall of 1996 and intensively monitored for the second critical fall-winter 1997 season (October 10, 1996 to April 8, 1997). Plot design is described in previous work by Grace (1996). Plots were maintained during the inactive period in order to protect against washouts. Minor modifications were made to gutter structure to allow flexibility during winter freeze-thaw cycles.

The road was constructed during the summer of 1995 and completed on September 9, 1995. The road was constructed with a 15 percent grade with 2.2: 1 and 1.5: 1 west-facing cutslopes and fillslopes, respectively. The road design was a mid-slope half-bench crowned road with inside ditching. The road was constructed on a Tatum soil series, a member of the fine loamy mixed thermic family of Typic Halpudult. A more detailed description of test soil characteristics and experimental design is given by Grace et al. (1996).

Hand seeding and mulching of all erosion control treatments was installed on September 16, 1995, one week after road completion. Mulching was applied at a rate of 4.5 t/ha. Fertilizer and lime applications were applied at a rate of 1 .O t/ha of 13-13-13 fertilizer and 4.5 t/ha of agricultural limestone. Native grass plots were seeded with a mixture of big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scuparius),* and Alamo switchgrass *(Panicum virgatum),* each at a rate of 11.2 kg/ha. Exotic species seeding was accomplished with a mixture of Kentucky 3 1 tall fescue (*Festuca arundinecea)* at 28.1 kg/ha, Pensacola bahiagrass *(Paspalum notatum)* at 22.5 kg/ha, annual lespedeza (*Lespedeza cuneata)* at 5.6 kg/ha, and white clover (*Trifolium repens*) at 11.2 kg/ha. Erosion mat treatments were composed of the same seeding and mulching regime as the exotic grass treatment in combination with a wood excelsior erosion mat anchored in place with six-inch staples. The erosion mat is a machine produced mat with a photo degradable plastic net over the top side of the mat.

Plots were bounded to insure that runoff and rainfall within each plot was isolated from the surrounding slope. Plot area was 4.65 m^2 with dimensions of 1.5 m x 3.1 m. A gutter was placed at the bottom of plots to convey runoff to 130-L storage containers for sample collection.

Analvsis

Plot runoff volume was directly measured as the amount of runoff collected in storage containers. Suspended and deposited sediment samples were taken from collected runoff for each sampling period Suspended sediment samples were collected by taking 500 ml grab samples. Deposited sediment samples were obtained by dipping off runoff top water and rinsing the remaining deposited sediment into 13 L sampling buckets. The depth of runoff in the storage containers was measured to determine total plot runoff. Rainfal! intensity and amounts were recorded with a Universal recording rain gauge located on site.

Suspended sediment samples were processed by gravimetric analysis using methods defined by Greenberg et al. (1992), and the average of three suspended sediment replicates was calculated. Deposited sediment was determined by oven drying collected runoff at 105 °C and weighing dried material. Total sediment yield was a composite of suspended and deposited sediment for each plot.

Independent variables that were measured included rainfall amount, rainfall intensity, and percent cover. The fillslope and cutslope sediment production data were analyzed as a repeated measures randomized complete block design. Dependent variable measurements, runoff volume and sediment yield, were repeated over time. Runoff volume and sediment yield, were tested as functions of treatment effects, rainfall amount and intensity, percent cover, and treatment age. Individual treatment means were tested for within subjects effects (a = 0.05) where repeated measures analysis of variance indicated significant differences.

Results and Discussion

Second Year Analvsis (1997)

Rainfall intensity and amount are strong factors in sediment production from any slope. High rainfall intensity means higher detachment energy and transport capacity due to increased runoff. High intensity storms in combination with high rainfall amounts generally present a problem in erosion control due to greatly increased event energy. During the second study period, sediment production from both slopes was higher for three observation points (Figures 1 - 3). These observation periods characterized events of higher rainfall amounts and intensities (Figure 4). Observation periods, 1, 5, and 10, had a large percentage of the total sediment yield for each of the erosion treatments. The erosion mat treatment produced 49 percent of its total soil loss, while the native grass, exotic grass, and the control treatments yielded 66, 75, and 80 percent of their total soil loss, respectively, during these three periods. Sediment yield may have increased for these observations because rainfall intensity exceeded the infiltration rate of the soil, causing greater runoff.

During the second year after establishment, cutslope sediment yield from control plots averaged 8.02 kg/plot (17.2 t/ha) with runoff of 889 L. In comparison to the cutslope control, the erosion mat and exotic grass treatments, at 0.101 and 0.271 kg/plot or less than 1.0 t/ha, had the largest reductions in sediment yield at 99 and 97 percent, respectively. The native grass treatment at 0.838 kg/plot, had a 90 percent reduction in sediment losses in comparison with the cutslope control. Runoff from erosion treatments during the second year after establishment followed the same trend as sediment yield from treatments. The erosion mat, exotic grass, and native grass resulted in reductions in runoff of 75, 25, and 13 percent, respectively.

Fillslope sediment yield from control plots during the second year averaged 8.54 kg/plot (18.4 tonnes/ha) with runoff of 1021 L. The fillslope erosion mat, native, and exotic grass treatments were effective in reducing sediment yield in comparison with the control, with a 99 percent reduction. Runoff production on the fillslope for the exotic grass, native grass, and erosion mat treatments with 60, 56, and 52 percent reductions in runoff, respectively, was similar for all treatments.

Cutslope and fillslope data were analyzed as a repeated measures randomized complete block design. The repeated measures analysis of variance ($\alpha = 0.05$) gave no significant slope type effects, therefore slopes were analyzed together. Analysis showed significant treatment effects on the dependent variable of sediment loss. Mean sediment losses from the erosion mat, native grass, and exotic grass treatments were not significantly different with sediment losses of 7.6, 45, and 20 g, respectively (Table 1). The control treatment had significantly higher sediment loss than all other treatments with a mean loss of 828 g.

Runoff production from the two slopes followed the same trend as sediment losses from both slopes. Runoff production from the control had a significantly higher runoff volume with a mean of 95 L. The erosion mat and exotic grass treatments were not significantly different in runoff volume on the slopes. The native grass treatment had a significantly higher runoff volume than the erosion mat treatment on the slopes.

Table 1. Means and statistics for second study period (1997).

	Sediment Production			Runoff Volume		
Treatment	**Mean (g)**	**N**	**Std. Dev.**	**Mean (L)**	**N**	**Std. Dev.**
Erosion Mat	7.6b*	60	18	36c	60	26
Native Grass	45b	60	111	62b	59	41
Exotic Grass	20b	60	31	54bc	60	38
Control	828a	60	1272	95a	60	40

* Means with same letter are not significantly different (a = 0.05).

Surface cover is reported to decrease sediment loss and runoff production because it intercepts raindrops, slows runoff, and filters runoff (Burroughs and King 1989). Second year data shows that sediment loss was influenced by the amount of cover on the surface (Table 2). Treatments with high percent cover exhibited the greatest mitigating effects on both sediment loss and runoff on the cutslope. Cutslope sediment losses and runoff decreased with increasing percent cover for all treatments. The control treatments, which were allowed to naturally re-vegetate to examine the true effect of mitigation treatments, had the lowest percent cover and the highest runoff and sediment losses. The erosion mat treatments had the greatest percent cover during the study period and the lowest runoff and sediment losses.

The same trend is noted with fillslope sediment losses, but not for fillslope runoff. Fillslope runoff was highest for the treatment with the lowest percent cover, the control treatment. The erosion mat treatment had the highest percent cover, but it yielded more runoff than the two grass treatments which had lower percent covers. The fillslope native grass treatment had a higher percent cover than the exotic grass treatment, but it yielded a greater runoff. Fillslope runoff could have been influenced by subsurface flow, but subsurface hydrology was not considered in this study.

Table 2. Surface percent cover for treatments during second year.

	Average Percent Cover (%)	
Treatment	**Cutslope**	**Fillslope**
Erosion Mat	96	99
Native Grass	69	81
Exotic Grass	78	77
Control	6	19

Mitigation with Time

Sediment and runoff production changes created from road construction have been reported to dramatically decrease with time (Burroughs and King, 1989). These large reductions can be attributed mainly to vegetative establishment. Large reductions in sediment and runoff production were observed from the second year data from the Shoal Creek road (Figures 5 and 6). The largest reductions in sediment production from the first year (1996) to the second year **(1997) was** found on the native grass treatments with 90 and 98 percent reductions on the cutslope and fillslope, respectively. Sediment production from native grass plots during the second year dropped to levels near those of the erosion mat and exotic grass treatments. This result was expected based on slower establishment rates of native grass. During the second year native grass treatments had increased grass establishment which reduced sediment yield and runoff.

Exotic grass treatments had reductions of 84 and 95 percent from initial sediment production rates for the cutslope and fillslope. The cutslope erosion mat treatment showed a 70 percent reduction, while the fillslope erosion mat treatment had a 98 percent reduction in sediment production during the two study periods. A reduction in sediment production was also noted on the control treatments for the cutslope and fillslope, with 68 and 58 percent reductions, respectively. Less precipitation (17 percent less) during the second study period could have had an effect on sediment yield reductions. Precipitation was 862 mm for the first study period and 7 19 mm for the second study period.

To account for the different precipitation for the two study periods, the data was analyzed on the basis of sediment loss per depth of rainfall (Table 3). Repeated measures analysis of variance (a = 0.05) on both slopes for the two study periods indicated treatment effects and treatment age were significant variables in sediment yield and rur f. ests on individual treatment means for within subjects effects (a = 0.05) showed that sediment production from the native grass and control treatments during the second study period (1997) was significantly lower than the first study period, with the erosion mat treatments showing the lowest sediment yield during both study periods. Runoff production from the native grass and control treatments was also significantly higher during the first study periods. The second year erosion mat treatments had significantly lower runoff production from all other treatments, with a mean of 22 L.

Table 3. Sediment and runoff production means for both study periods (1996 & 1997).

Treatment	Sediment Yield (g/mm)	N	Runoff Volume (L)	N
Cutslope				
Erosion Mat %	1.50	39	60	39
Native Grass 96	35.0	39	83	39
Exotic Glass 96	7.20	39	77	39
Control 96	78.0	39	74	39
Erosion Mat 97	0.50	30	22	30
Native Grass 97	3.80	30	80	30
Exotic Grass 97	1.20	30	66	30
control 97	36.0	30	89	30
Fillslope				
Erosion Mat %	8.50	39	51	38
Native Grass 96	16.0	39	59	38
Exotic Grass 96	12.0	39	37	37
Control 96	81.0	39	81	38
Erosion Mat 97	0.30	30	49	30
Native Grass 97	0.30	30	45	30
Exotic Grass 97	0.60	30	41	30
Control 97	42.0	30	102	30

The trends in fillslope sediment yield and runoff were different from those for the cutslope. Fillslope control treatments had significantly higher sediment yield and runoff than all other treatments, with the first study period control treatment having the highest sediment loss. During the second study period, sediment yield was significantly lower than the first study period. The control treatment runoff was significantly higher during both study periods than all other treatments with the second year production the greatest. Decreased runoff during the second study period for the erosion mat and native grass treatments could be due to increased infiltration and evapotranspiration resulting from increased vegetation.

Conclusions

Sediment losses from all erosion control treatments decreased during the second study period. Runoff production decreased on all erosion treatments except the fillslope exotic grass treatment. The erosion mat was most effective in reducing soil losses from both slopes during the second study period. The native grass treatment was found to be more effective in mitigating soil losses during the second study period than during the first study period. This is due to increased vegetative establishment during this period. The fillslope erosion mat and native grass treatments showed greater capacity to reduce sediment and runoff production with significantly lower losses. The control (bare) continued to lose large amounts of sediment during the second study period.

The native grass treatment was found to be more effective in mitigating losses during the second study period than during first study period. Also, sediment yield from the native grass treatment was not significantly different from that of the fillslope erosion mat treatment during the second study period. Fillslope runoff from treatments was significantly less than from the cutslope treatments. Fillslope stabilization is being accomplished at a faster pace than stabilization of the cutslope based on the data from the two study periods (1996 and 1997).

Precipitation had an effect on sediment yield differences during the two periods under investigation but analysis did show significant treatment effects. Sediment yield from erosion treatments during the second study period was significantly less than from all treatments during the first period. Fillslope runoff was significantly less for the erosion mat and native grass treatments during the second period than during the first period. Significant reductions in both sediment and runoff production were found on both slopes during the second year which shows the effect of time on erosion control treatments.

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Figure 1. Cutslope Sediment Production -- Mitigation Treatments (1997).

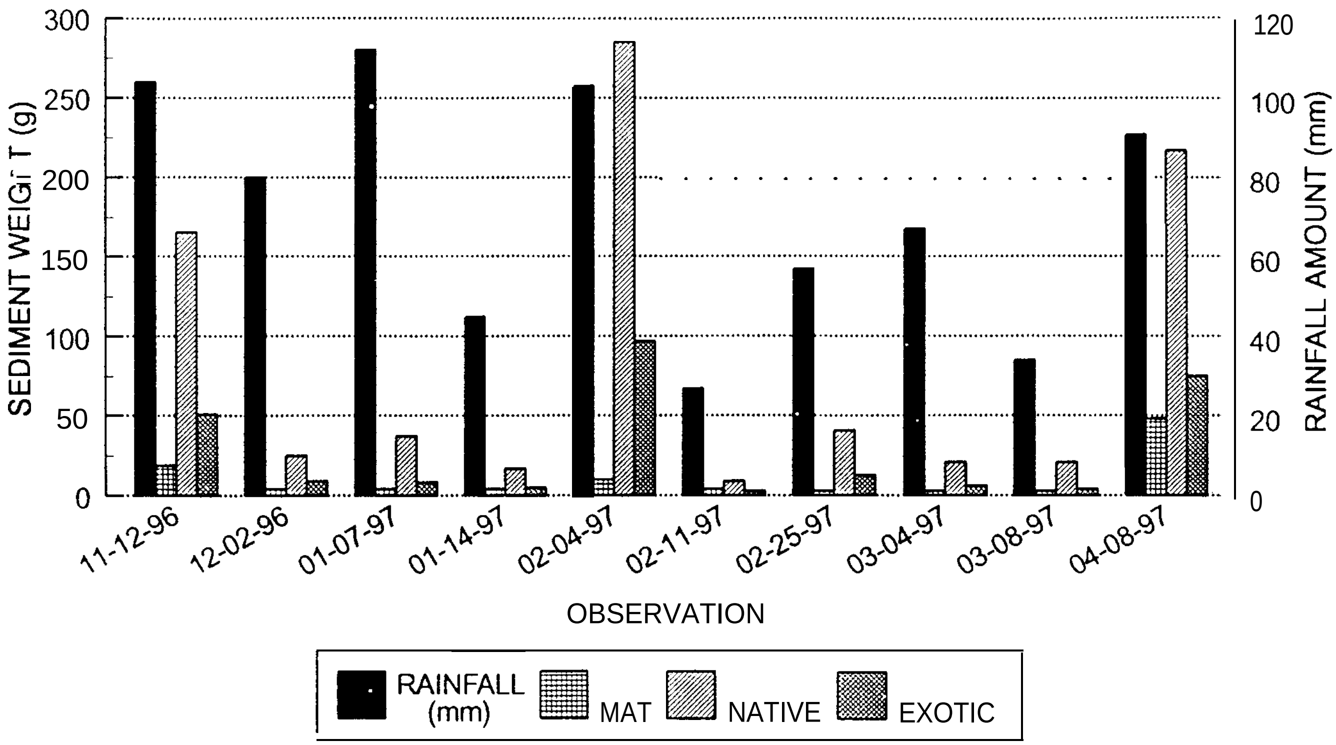

Figure 2. Fillslope Sediment Production -- Mitigation Treatments (1997).

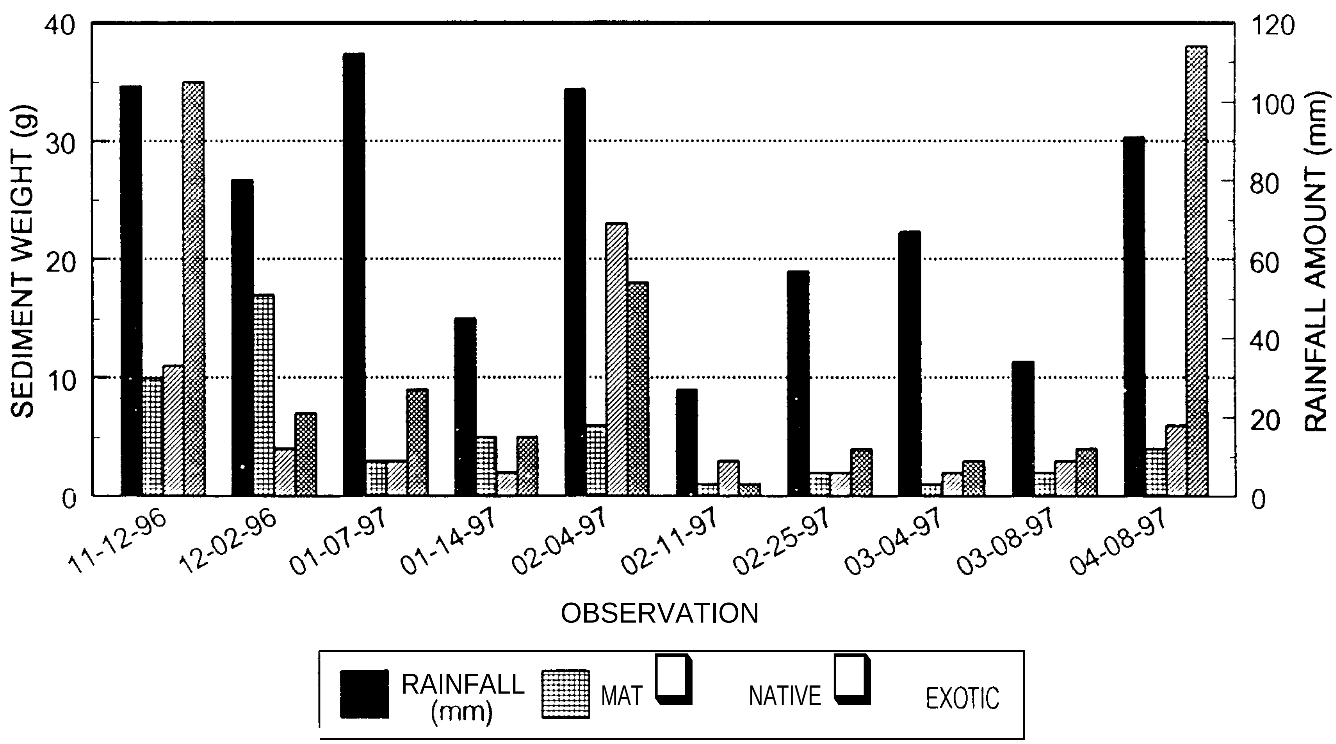

Figure 3. Control Sediment Production (1997).

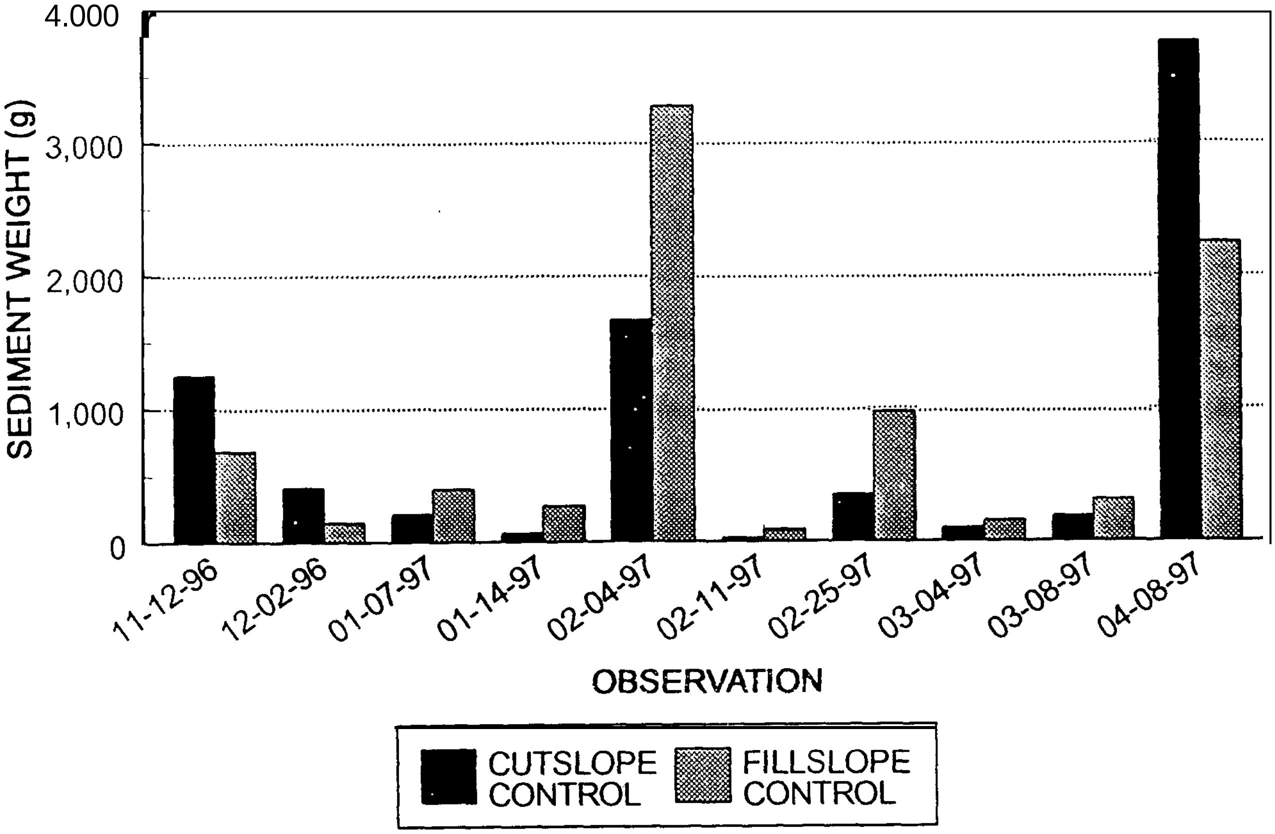

Figure 4. Precipitation during second study period.

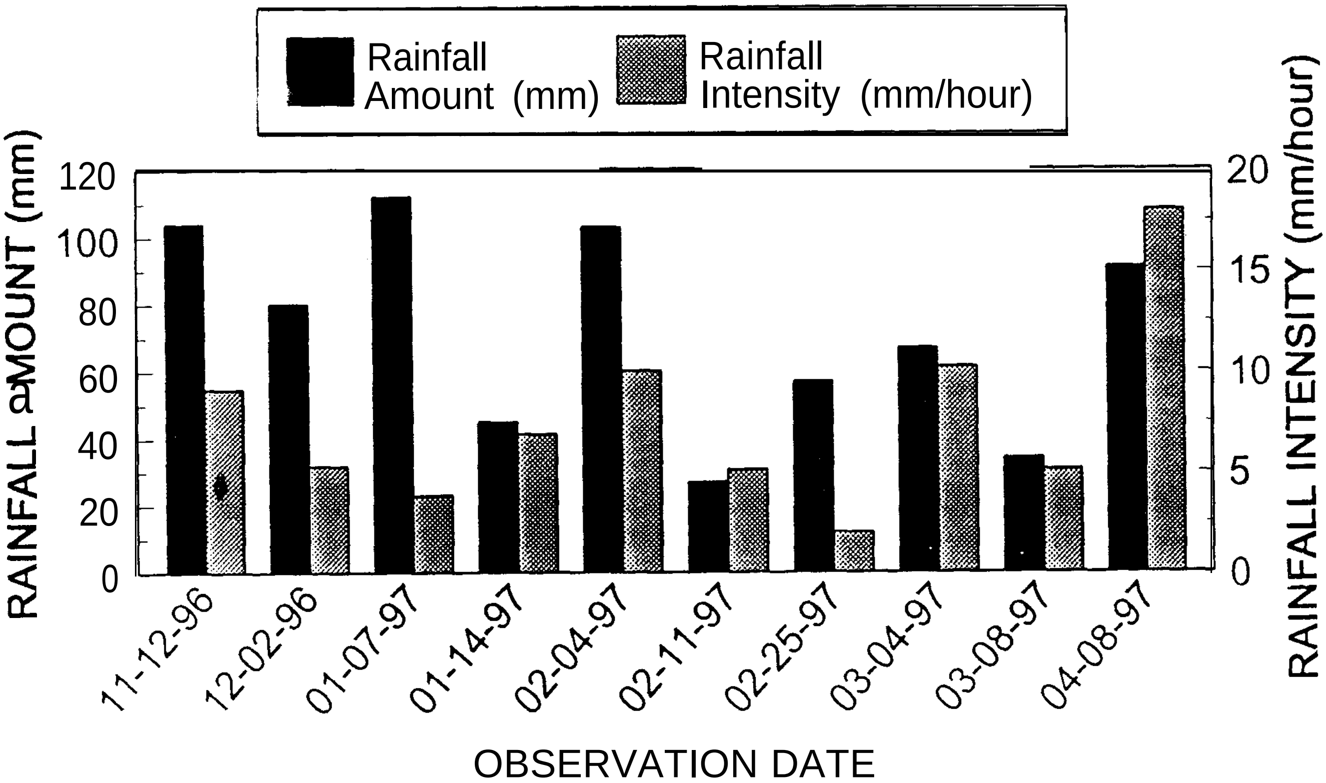

Figure 5. Average sediment production 1996-97

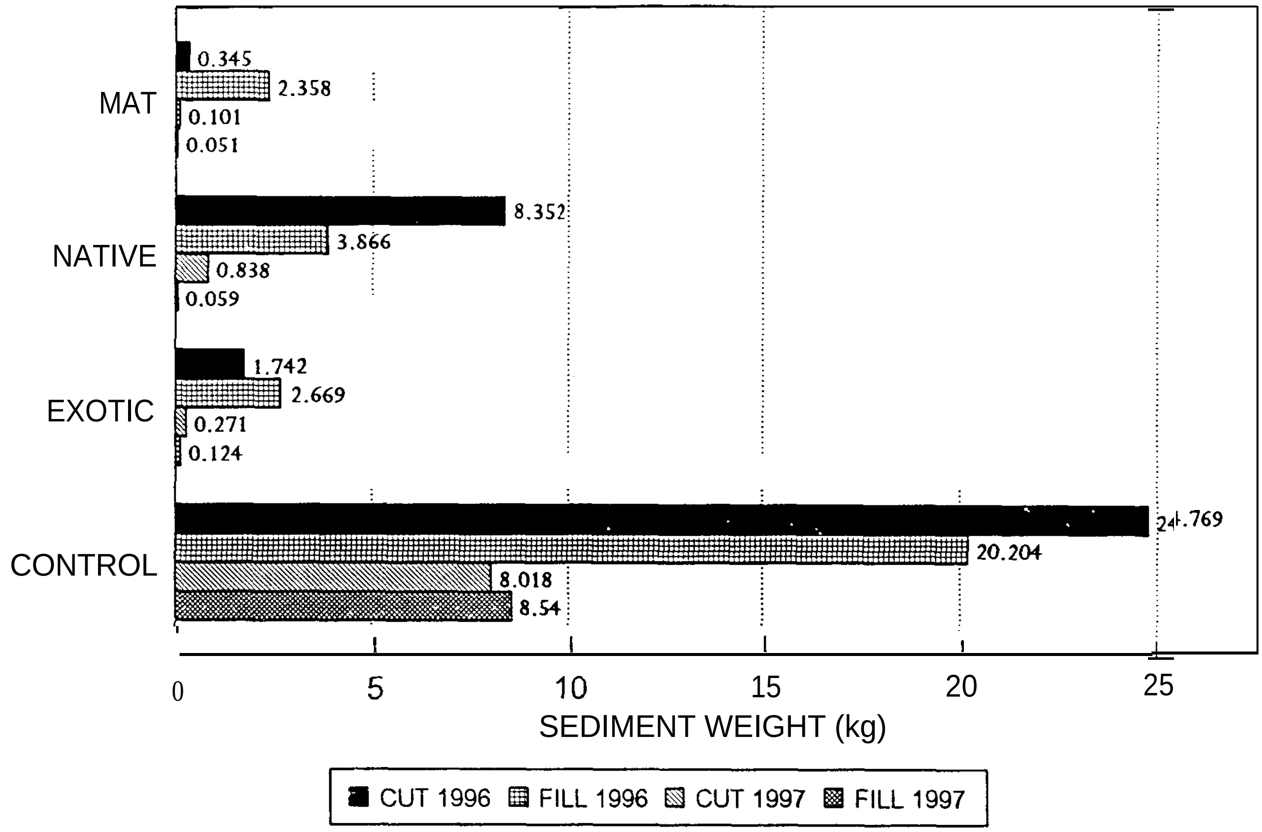

Figure 6. Average runoff volumes 1996-97