Influence of Llamas, Horses, and Hikers on Soil Erosion from Established Recreation Trails in Western Montana, USA

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ABSTRACT / Various types of recreational traffic impact hiking trails uniquely and cause different levels of trail degradation; however, trail head restrictions are applied similarly across all types of packstock. The purpose of this study was to assess the relative physical impact of hikers, llamas, and horses on recreational trails. Horse, llama, and hiker traffic were applied to 56 separate plots on an existing trail at Lubrecht Experimental Forest in western Montana. The traffic was applied to plots at intensities of 250 and 1000 passes along with a no-traffic control under both prewetted and dry trail conditions. Soil erosion potential was assessed by sediment yield and runoff (using a Meeuwig type rainfall simulator), changes in soil bulk density, and changes in soil surface roughness. Soil moisture, slope, and rainfall intensity were recorded as independent variables in order to evaluate the extent that they were held constant by the experimental design. Horse traffic consistently made more sediment available for erosion from trails than llama, hiker, or no traffic when analyzed across wet and dry trail plots and high and low intensity traffic plots. Although total runoff was not significantly affected by trail user, wet trail traffic caused significantly greater runoff than dry trail traffic. Llama traffic caused a significant increase in sediment yield compared to the control, but caused erosion yields not significantly different than hiker traffic. Trail traffic did not increase soil compaction on wet trails. Traffic applied to dry trail plots generally resulted in a significant decrease in soil bulk density compared to the control. Decreased soil bulk density was negatively correlated with increased sediment yield and appeared to result in increased trail roughness for horse traffic compared to hiker or llama traffic. Differences described here between llama and horse traffic indicate that trail managers may want to consider managing packstock llamas independent of horses.

Recreational use of mountainous areas has increased greatly over the past half century. Much of this use occurs on a trail system that both facilitates access to the mountains and reduces resource damage caused by recreation use. Over time, many trail segments deteriorate by natural processes (gradual or cataclysmic) and by wear from recreation traffic (Summer 1986, Tinsley and Fish 1985). Substantial sums of money are spent every year maintaining, rebuilding, and relocating damaged trails.

The magnitude of trail deterioration is determined by characteristics of the trail, its environment, and the recreation use that the trail receives (Cole 1987). Leung and Marion (1996) provide a comprehensive review of the influence of environmental factors. The influence of use intensity on trail deterioration has also been frequently studied. Less is known about how the type of trail use influences magnitude of deterioration.

On an established trail in Great Smoky Mountains National Park, Whittaker (1978) found that horse use caused more pronounced increases in trail width, trail depth, and litter loss than hiker use. This partially corroborated the finding of Dale and Weaver (1974) that horse trails in Montana are deeper but equivalent in width to hiker trails. In Rocky Mountain National Park, however, Summer (1980) was unable to detect differences in erosion rates between trails used by horses and those used only by hikers.

In the most rigorously controlled study of impact to existing trails, Wilson and Seney (1994) measured the effect of hiker, horse, motorcycle, and bicycle traffic on

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sediment yield following simulated rainfall. Sediment yield following horse use was significantly greater than sediment yield following hiker or bicycle use, on both prewetted and dry trails, and greater than sediment yield following motorcycle use on dry trails. However, sediment yield prior to treatment was significantly lower on hiker trails than on horse trails. Consequently, when before-and-after treatment differences in sediment yield did not differ between horse and hiker trails, there was some doubt left about what affected impact more—the treatments or the type of trails.

The somewhat equivocal nature of these findings regarding the relative impact of horses and hikers on trails suggests the need for further investigation. In addition, trails are increasingly being used by nontraditional types of packstock, particularly by llamas. For example, 57% of the wilderness areas in the United States with packstock use have some use by llamas (McClaran and Cole 1993). Proponents of llama use argue that llamas have less impact on trails than traditional packstock (Markham 1990, Harmon and Rubin 1992), a sentiment echoed by trail users in Yellowstone National Park (Blahna and others 1995).

The primary objective of this research, therefore, was to assess the relative impact of horses, llamas, and hikers on established trails, primarily by evaluating their effect on sediment yield following a simulated rainfall event. To determine whether results are consistent under wet and dry conditions, relative impacts were assessed on trails that were both prewetted and dry. Wilson and Seney (1994) found that sediment yields following the application of traffic were greater on prewetted trails than dry trails.

A secondary objective was to better understand the mechanisms by which trail traffic leads to increased erosion. Erosion potential should increase if trail traffic increases the detachability of soil particles or the ability of water or wind to move detached particles. Trail traffic can increase erosion by loosening soil (increasing detachability of particles), compacting the soil (increasing runoff and sediment transport), or concentrating water flow into channels and thereby increasing down-trail sediment transport and yield. Soil bulk density was measured to assess which of these mechanisms could explain variations in sediment yield. We also measured soil roughness, as increased roughness could be indicative of increased loosening (detachability) or increased ponding of water (and therefore reduced runoff and transport) (Dixon 1995).

Materials and Methods

The study was conducted at the University of Montana's Lubrecht Experimental Forest near Greenough, Montana (lat. 44° 53′ 24″N, long. 113° 25′ 49″W). Trail segment selection was based on consistent slope, historic use, and ease of closing the trail to visitor use.

The recreational trails used in this study consisted of 300-m segments of two parallel trails that were closed to all traffic immediately following snow melt in March 1995. The two parallel trails allowed us to apply traffic simulations to each trail simultaneously and thus reduce the overall length of trail, minimizing slope and soil variability.

The section of trail selected is located on a Winkler gravely loam, which is a loamy skeletal, mixed, frigid, Udic Ustochrepts (Nimlos 1986). The native soil is 50% sand, 38% silt, and 12% clay, is about 35% coarse fragments by weight, and has an average pH of 4.4 (1:2 soil to 0.01 M $CaCl_2$). The parent material for this soil type is colluvium that is composed of metamorphosed Precambrian sedimentary rock (Belt series). The trail resides on a 4%–8% slope (average of 6%) and the gravelly loam texture provided an intermediate to high level of resistance to soil compaction and erosion.

The width of individual trails range from 1 to 1.5 m and had little entrenchment. Trail segments with observed entrenchment were eliminated from use in study plots. The elevation is 1250 m (4100 ft), and the trail has an east aspect. Based on samples from the control plots, the pretreatment bulk density of the trail's surface 5 cm is 1.5 g/cc. It is located in a *Pseudotsuga menziesii/ Arctostaphylos uva-ursi* habitat type (Pfister and others 1977). The location receives approximately 460 mm of precipitation annually, about 40% of which falls as snow (Nimlos 1986).

Plots were arranged in a randomized complete block design with each of eight blocks (four wet trail and four dry trail) containing seven separate plots: (1) control (no traffic); (2) 250 hiker passes; (3) 1000 hiker passes; (4) 250 llama passes; (5) 1000 llama passes; (6) 250 horse passes; and (7) 1000 horse passes. Each plot was 1 m wide and 3 m long with a 3-m-long buffer zone between plots for turning, this allowed animals and hikers to reach a normal stride upon entering the plot.

Trail traffic was applied and data collected during June and July of 1995. To create wet trail conditions, plots and buffer zones received 10 mm of water per unit area applied by a gas-powered pump through a low-pressure, fine-spray nozzle. Immediately after each plot was wet, seven composite soil moisture samples were taken across the plot to a depth of 5 cm, stored in a sealed container, and later dried in an oven at 110°C. Percent soil moisture was determined on a gravimetric basis (Gardner 1986). Following wetting the soils were about 25% soil moisture or about 50% of soil water holding capacity.

Traffic was applied continuously on plots until the specified number of passes was accumulated. Sediment yield by rainfall simulation, soil bulk density, and surface roughness were measured immediately following completion of the traffic applications. Equal numbers of uphill and downhill passes were made on each plot. Horses and llamas were led in such a way that the person leading the animals stayed out of the plots. No animals carried packs and any manure from the animals was removed from the trail before further traffic application.

Hikers wore non-lug-sole hiking boots and weighed between 55 and 75 kg. The two horses with cleated shoes weighed around 400 and 500 kg each and the two llamas (with freshly clipped toenails) weighed 160 and 190 kg each. In all cases, the traffic conditions represent conservative estimates of what could occur with loaded horses, llamas, or people on steeper or wetter trails. Traffic application required variable lengths of time ranging from 20 min for the 250 hiker passes to 2.5 h for the 1000 llama passes, and 6 h to complete the 1000 horse passes. Average soil moisture content following traffic application was 10.5% for dry trail traffic and 21.9% following wet traffic application, but was not significantly different for types of trail user.

Simulated rainfall was produced with a modified Meeuwig drip-type rainfall simulator. This simulator produces a drop size of 2.8 mm, with a kinetic energy roughly one half that of natural rain when suspended from a drop height of 2.0 m (Meeuwig 1971). The maximum historic hourly precipitation rate recorded for a single rainfall event during the months of June or July for Lubrecht was 61 mm/h for a 15-min interval (NOAA 1971–1994). To be consistent with previous research and to ensure generation of adequate volumes of runoff, a 120 mm/h simulated rainstorm event was applied to all plots for a 15-min period.

Most rainfall simulation studies use intensities of about 120 mm/h, which is far in excess of normal rainfall rates (Wischmeier and Mannering 1969, Bryan 1969, Johnson and Bescheta, 1980, Quinn and others 1980, Quansah 1981, Wilson and Seney 1994). High intensity is necessary for two reasons: to produce adequate runoff to make up for limited overland flow; and to make up for the low kinetic energy associated with the rainfall simulator.

Each rainfall simulation was applied to a 0.66-m × 0.66-m plot, and all runoff was funneled into polyvinyl collection bottles. Total volume of runoff collected was measured and analyzed as runoff as a percent of total water applied as rainfall [% runoff = (liters runoff/liters water applied)$*$100]. The sediment in the runoff was allowed to settle for at least one day. The water was then siphoned off the top, and the remaining sediment dried at 110°C for 48 h. The total mass in grams of sediment collected from each rainfall simulation plot was used as a measure of the relative erosion potential of different trail user types.

Bulk density was measured by an excavation and volume measurement method. Briefly, a 12-cm-diameter circular hole was dug to a depth of 5 cm, all soil materials removed, and their dry mass determined. The volume of the hole was determined by refilling it with a measured volume of 0.25–0.84-mm quartz sand and the bulk density determined as mass of soil removed divided by hole volume.

Surface roughness was determined using a method adapted from Beckman and Smith (1974). A grid of six flexible, cotton crochet threads were attached to a 70-cm × 70-cm frame and the thread fitted to the soil surface following treatment application. The presence of vertical variation from a level surface creates a more tortuous pathway for the thread to follow, which increases the length of thread required to span the frame. Threads were run both parallel and perpendicular to the direction of traffic and the six values averaged for each plot. An average value of 70 cm would reflect a perfectly smooth surface.

Wet and dry treatments were applied in two separate experiments along the same trail instead of being randomly assigned within blocks. Therefore it is most appropriate to consider wet and dry treatments as separate experiments and evaluate them separately. To clarify the importance of soil moisture within the experimental design, a three-way analysis of variance (ANOVA) was performed with moisture, user type, and traffic intensity as independent factors. If moisture was a significant factor or if there were significant interactions between moisture and other factors, then the wet and dry trails were analyzed separately, otherwise the plots were pooled for subsequent analysis.

Factors judged to be significant ($P \leq 0.05$), were then assessed using Tukey's multiple-range test to determine which treatments were significantly different. We also used single or two-tailed Dunnet's tests, which compared individual treatment means to the control treatment. Finally, Pearson correlation coefficients were used to determine the relationship between sediment yield and bulk density or surface roughness. All analyses were performed using PC-SAS (SAS Institute, Cary, North Carolina).

Results

Sediment yield from trails following simulated rainfall, our primary indicator of trail deterioration, varied significantly with user type and traffic intensity (Table

Table 1. Three-way analysis of variance for sediment yield, runoff, bulk density, and surface roughness (control excluded to allow comparison of levels) for high and low traffic applications applied to wet or dry trails

	Sediment yield			Runoff			Bulk density			Surface roughness		
Factor	*df*	MS	*P*	*df*	MS	*P*	*df*	MS	*P*	*df*	MS	*P*
Model	6	32,437	0.000	6	851	0.000	6	0.030	0.813	6	12.4	0.000
User (llama, horse, hiker)	2	51,695	0.000	2	331	0.189	2	0.086	0.093	2	33.8	0.000
Level (250 or 1000 passes)	1	26,895	0.032	1	117	0.446	1	0.000	0.919	1	3.63	0.158
Trail (wet or dry)	1	11,560	0.151	1	6283	0.000	1	1.212	0.000	1	0.01	0.930
User * level	2	241	0.956	2	159	0.440	2	0.007	0.803	2	0.36	0.815
User * trail	2	8,240	0.229	2	98	0.600	2	0.033	0.389	2	3.57	0.142
Level * trail	1	9,213	0.198	1	24	0.726	1	0.054	0.214	1	1.69	0.331
User * level * trail	2	1,923	0.701	2	43	0.794	2	0.053	0.219	2	1.83	0.360

†MS = mean square.

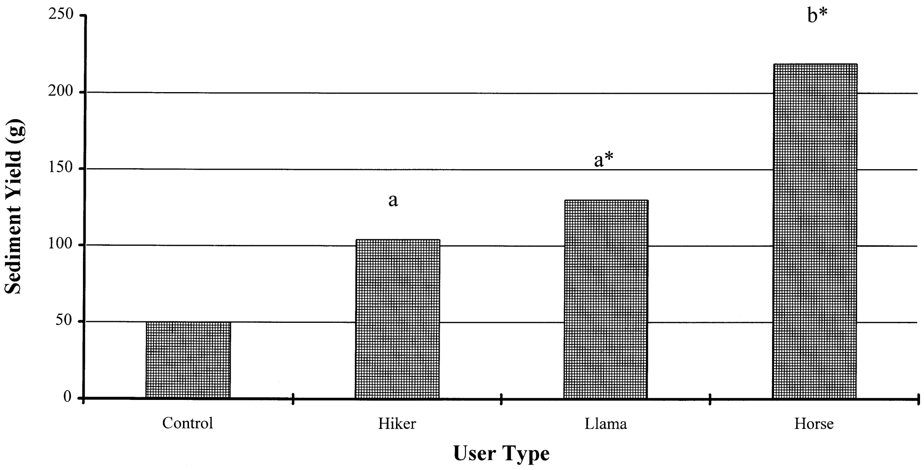

Figure 1. Sediment yield under rainfall simulation following hiker, llama, or horse traffic averaged across two levels of traffic application intensity and wet and dry trail moisture conditions. Bars with asterisks are significantly different than the control ($P \leq 0.05$) by Dunnet's analysis and bars without similar letters are significantly different ($P \leq 0.05$) by Tukey's test.

1). Sediment yield did not vary significantly between dry and prewetted trails, and none of the interactions between factors were significant. Consequently, we concluded that pooling the sediment yield data from the dry and prewetted trails was appropriate.

Runoff measured as a percent of total water applied as rainfall was greater on trails exposed to wet traffic (average of 82%) compared to that on dry (average of 59%) traffic (Table 1). Although runoff was not significantly affected by the trail user type, runoff was consistently higher under horse traffic than under llama or hiker traffic.

Horse traffic on trails resulted in significantly more sediment yield than either llama or hiker traffic, which did not differ significantly from each other (Figure 1). Both horse traffic and llama traffic resulted in significantly more sediment yield than controls, but hiker traffic did not. Mean sediment yield for all user types following 1000 passes (174 g) was significantly greater than the yield following 250 passes (127 g, $P < 0.003$). Both traffic intensities resulted in statistically significant ($P < 0.003$) increases in sediment yield compared to the control (50 g, data not displayed in Table 1).

Although sediment yield from dry and prewetted plots was not significantly different for the whole data set (Table 1), the yields from the traffic application on dry trails were greater than the traffic applications on prewetted trails for six of the seven treatments. The most pronounced difference in sediment yield was observed following 1000 horse passes, resulting in an average sediment yield of greater than 300 g on dry trail plots compared to an average of 183 g when horse traffic was applied to a prewetted trail.

Soil bulk density was measured because changes in bulk density can be precursors of increased erosion from trails. Bulk density differed significantly between the dry and prewetted trails, and there was substantial evidence of interaction between trail moisture and other factors; consequently, we analyzed dry and prewetted trails separately.

On dry trails, bulk density varied significantly with both user type and traffic intensity (Table 2). Traffic application to dry trails significantly reduced soil bulk density, with both horse and hiker plots having posttreatment bulk densities that were significantly less than on control plots. Among the user types, bulk densities following horse traffic were significantly lower than densities following llama or hiker traffic (Figure 2). Mean soil bulk density after 1000 passes (1.03 g/cc) was significantly less than after 250 passes (1.15 g/cc). Both traffic intensities resulted in bulk densities that were lower than those on controls (1.50 g/cc).

Bulk densities were generally higher after treatment when traffic occurred on prewetted trails than when they were dry. However, treatments did not cause a significant change in bulk density on prewetted trails, and bulk density did not vary significantly with either user type or traffic intensity (Tables 1 and 2). The lower bulk density on the dry trails is also reflected in the significantly lower runoff rates from the dry trails compared to the prewetted trails (Table 1).

It is likely that bulk density would increase from the compacting effect of trail use on soil and that an increase in bulk density might result in decreased infiltration, increased runoff, and increased sediment yield (Lull 1959, Lal 1994). However, on dry trails, bulk density declined with trail traffic, apparently reflecting a loosening of soil on the trail when traffic was applied. A highly significant negative linear relationship between bulk density and sediment yield ($r^2 = 0.59$; $P < 0.001$) suggests that soil loosening increased the detachability of soil particles and thus increased sediment yield.

Soil roughness was also measured as a possible precursor to increased sediment yield and erosion. Roughness varied significantly with user type, but not with traffic intensity or soil moisture (Table 1). Interactions between factors were not significant, so the data from dry and prewetted plots were pooled. None of the user types or traffic intensities resulted in surface roughness measures that were significantly different from controls. However, roughness measures were higher than controls after horse traffic and lower than controls after llama and hiker traffic (Figure 3). The roughness values on horse plots were significantly greater than those on either llama or hiker plots. These results validate field observations that llama and hiker traffic tended to smooth the trail surface while horse traffic left a more churned up and rough surface. A significant positive linear relationship between surface roughness and sediment yield ($r^2 = 0.24$; $P < 0.05$) suggests that increased roughness is associated with a loosened soil surface, with more detachable soil particles and more potential for erosion.

Discussion

The principal finding of this study is that horse traffic on trails resulted in substantially more sediment yield following simulated rainfall than either hiker or llama traffic. The relative erosion potential of horse, llama, and hiker traffic was consistent at traffic intensities of 250 and 1000 passes and on both dry and prewetted trails. This result adds to the evidence from a number of earlier studies (Whittaker 1978, Dale and Weaver 1974, Wilson and Seney 1994) that horse traffic tends to cause more trail erosion than hiker traffic. It also extends this earlier work by showing that horse traffic is likely to cause more trail erosion than llama traffic. Differences in erosion potential between hikers and llamas were not substantial or consistent enough to be statistically significant.

Table 2. Two-way analysis of variance for soil bulk density on dry and wet trail treatment plots

Factor	*df*	MS[a]	*P*
Dry trail traffic applications			
User type (llama, horse, hiker)	2	0.082	0.014
Traffic level (1000, 250)	1	0.031	0.162
User type * traffic level	2	0.016	0.362
Wet trail traffic applications			
User type (llama, horse, hiker)	2	0.037	0.545
Traffic level (1000, 250)	1	0.022	0.546
User type * traffic level	2	0.046	0.470

[a] MS = mean square.

Sediment yields were higher on the dry trail plots than on the prewetted trail plots, suggesting that dry trail conditions made the trail more vulnerable to sediment detachment. Bulk density of dry plots was decreased by traffic applications, suggesting that the trail surface aggregate was partially disrupted due to the trail traffic. Conversely, levels of runoff were significantly greater on prewetted trail plots compared to dry trail plots. Traffic applied to prewetted trails apparently resulted in increased armoring of the trail, which increased runoff rates. Traffic applied to dry trails may increase the potential for erosion by increasing sediment detachment, whereas traffic applied to wet trails may result in increased runoff resulting in greater down slope channeling of water and greater potential for sediment transport (Lal 1994).

A number of reasons can be advanced for why horses have more erosion potential than llamas or hikers. Horses are heavier and their weight is carried on a shoe with a small bearing surface. Moreover, horses' shoes are typically metal and frequently cleated. Horses are also less careful and deliberate than llamas or humans about where they place their feet.

Our results confirm what has been found in a number of studies (Cole 1987), that the relationship between the amount of traffic and amount of impact is curvilinear. When we increased trail traffic by a factor of 4, from 250 passes to 1000 passes, sediment yield increased by only a factor of 1.4 (from 127 g to 174 g).

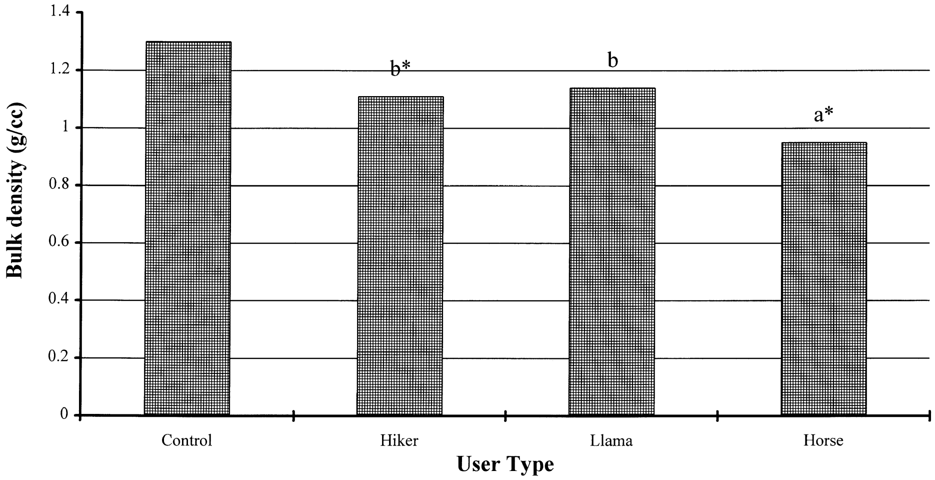

Figure 2. Soil bulk density following hiker, llama, and horse traffic averaged across two levels of traffic application intensity to dry trail segments. Bars with asterisks are significantly different than the control ($P \leq 0.05$) by Dunnet's analysis and bars without similar letters are significantly different ($P \leq 0.05$) by Tukey's test.

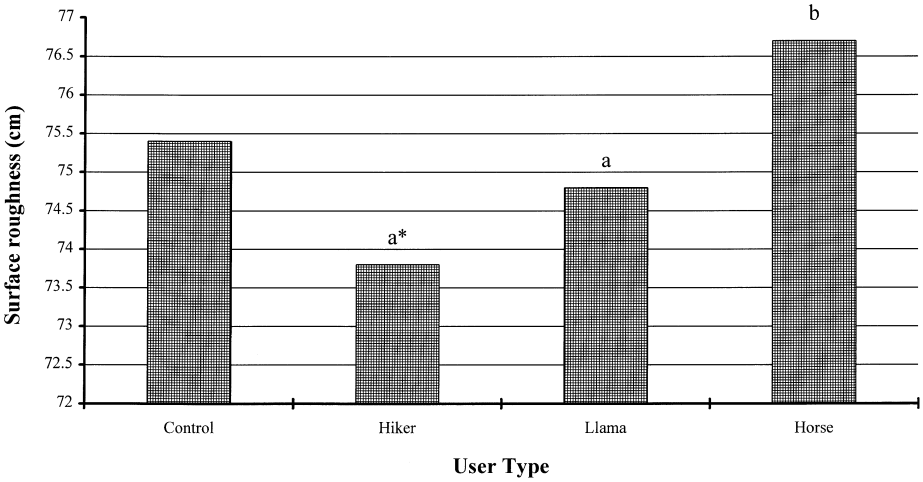

Figure 3. Mean roughness of soil surface as measured by total vertical variation (70 cm = level) across the hiking trail following hiker, llama, or horse traffic averaged across two levels of traffic application intensity and wet and dry trail moisture conditions. Bars with asterisks are significantly different than the control ($P \leq 0.05$) by Dunnet's analysis and bars for without similar letters are significantly different ($P \leq 0.05$) by Tukey's test.

Kuss (1983) also found that when hiker traffic was increased by a factor of 4 (from 600 to 2400 passes) sediment yield increased by a factor of only 1.4–1.7. This suggests that initial trail traffic is much more damaging than subsequent traffic.

Our results also provide some insight into the mechanisms by which trail traffic leads to accelerated erosion. Accelerated erosion greatly results from increased runoff, increased channel flow of water, increased detachment of soil particles, and increased transport of detached soil particles. Decreased bulk density and increased roughness should generally be indicative of soil loosening and therefore increased detachment (Gabriels and Moldenhauer 1978). Conversely, increased bulk density should be indicative of increased transport capability because increased compaction should result in decreased infiltration and increased runoff (Lal 1994). Decreased roughness should also be indicative of increased transport capability because flows across smoother surfaces will have higher velocities and there will be less ponding (Ruttimann 1995).

Our findings that bulk density was negatively correlated with sediment yield and that surface roughness was positively correlated with sediment yield suggest that soil loosening was the primary mechanism by which trail traffic caused increased soil erosion on our experimental trail plots. This supports Wilson and Seney's (1994) conclusion that sediment yield from experimental trail plots is detachment-limited rather than transport-limited. Detachment of particles by horse traffic appeared to be the most important mechanism in increasing sediment yield on our plots. We observed similar runoff rates with all three trail users, but a significantly higher sediment load in the runoff with horse traffic. Horses appear to cause more trail erosion than either llamas or hikers on dry trails because they loosen the soil to a greater degree, making soil particles easier to detach. In future studies, however, larger trail plots would have to be used to adequately address the effect of trail traffic on erosion due to increased runoff.

The importance of soil loosening also helps explain the somewhat unexpected finding that sediment yield following trail traffic was usually greater on dry trails than on prewetted trails. This finding is contrary to that of Wilson and Seney (1994), who generated greater sediment yields on prewetted trails. It also is counter to the general principle that moist soils are particularly vulnerable to trail problems (Hammitt and Cole 1987).

Since soil loosening was the primary mechanism of increased sediment yield on our plots, anything that increases soil cohesion should decrease erosion potential. The water that we added to the relatively coarse-grained soils of our experimental trail clearly increased soil cohesiveness and, therefore, decreased vulnerability to detachment. We might have obtained the opposite result, however, if we had added much greater quantities of water or if the soils were clayey, with a tendency to adhere to boots when wet or to harden when dry. Wet trails also might have been more problematic if the trail was steep and more of the forces of trail traffic involved smearing and shearing.

Finally, there are a number of the trail problems other than erosion that are aggravated most by traffic during wet conditions that were not considered in this study including: (1) multiple trailing; (2) trail widening, and (3) puddling (Cole 1987). Although traffic during periods of high soil moisture or in locations with chronically high moisture often causes problems on trails, soil erosion can also be a serious problem even on dry trails.

Various options exist for incorporating divergent impact potential into management programs. At one extreme, types of use with high impact potential (e.g., horse use) can be entirely prohibited. Alternatively, these uses can be allowed in some management zones and not allowed in others. Places where these uses are allowed could be selected on the basis of their resistance to impact. Trails where these uses are allowed could be specially designed and maintained to tolerate substantial disturbance. Our results, as well as the results of a study of visitor attitudes about encounters with horses, llamas, and hikers (Blahna and others, 1995) suggest that when zoning on the basis of use type, llamas are more closely allied with hikers than with horses.

In a number of parks and wilderness areas, amount of use is limited in order to control user impacts. Several scientists have suggested that managers should allocate a limited numbers of permits on the basis of the environmental expense of different user groups (Hendee 1974, Stankey 1977, Weaver and others 1979). These individuals argue that one's access to limited permits should be inversely related to one's impact potential. This approach would make it more difficult for horse groups to obtain a permit than for llama or hiker groups.

In conclusion, trail users are not equivalent in the extent to which they contribute to accelerated erosion. Horse traffic is capable of causing several times as much erosion as an equivalent amount of traffic by llamas or hikers. Managers concerned about trail problems may want to consider this difference when devising trail management strategies.

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