Post-treatment Hydrologic Response to Mechanical Shredding in a Juniper Woodland

by

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of a thesis submitted by

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ABSTRACT

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Juniper (*Juniperus* spp.) woodland expansion in the western United States is thought to result in increased wildfires throughout its range and has prompted land managers to search for effective fuel control methods. Recently, mechanical shredding (Bull Hog ®) has been used to reduce juniper trees to a mulch residue on or around the juniper mound. On hillslopes, tracking from rubber tires or steel tracks could potentially increase runoff and sediment yield while the tree mulch residue could decrease them. We investigated soil compaction and hydrologic responses from mechanical shredding on a gravelly loam soil with a 15% slope in the Onaqui Mountains of Utah. Rain simulations were applied on 0.5 m^2 plots at two rates: 64 $mm \cdot h^{-1}$ (dry run) and 102 $mm \cdot h^{-1}$ (wet run). Runoff and sediment were collected from 50 post-treatment plots: 20 control, 20 tire-tracked, and 10 mulch residue covered. Soil penetration resistance, canopy cover, ground cover, soil stability, and surface roughness were measured. Tracked soils were significantly more compacted (from 5 cm to 10 cm in soil depth) than untracked soils for interspace and shrub mound microsites. Infiltration rates of grass interspaces were significantly decreased ($P < 0.05$) by tire tracks but not on juniper mounds or bare interspaces. Mulch-residue-covered bare interspace plots had significantly higher ($P < 0.05$) infiltration rates and lower sediment yields compared to microsites without mulch residue. This study found little adverse hydrologic effect from mechanical shredding in these juniper woodlands at the patch-microsite scale. Effects of shredding at the hillslope or larger scales and on other sites should be quantified to best determine hydrologic response and guide management actions.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) woodlands have expanded into sagebrush (*Artemisia* spp.) steppe over the last 130 years and now occupy approximately 20-30 million ha in the western United States (Miller and Wigand 1994; Miller and Tausch 2002). A reduction in fine fuels and fire suppression have facilitated this expansion (Miller and Wigand 1994; Miller and Tausch 2002). Runoff and soil erosion may increase with woodland expansion on sites with steeper slopes, erodible soils, and high intensity thundershowers (Roundy and Vernon 1999; Petersen and Stringham 2008). Range managers employ tree reduction methods such as fire, chaining, felling, and crushing to reduce fuels and improve ecological function. These methods have varying effects on vegetation and surface hydrology (Williamson and Currier 1971; Roundy et al. 1978; Busby and Gifford 1981; Bates et al. 2000; Baker and Shinneman 2004). Recently, mechanical shredding (or Bull Hog ®) has become an increasingly popular method to control trees because it avoids the risks associated with prescribed fire and the resulting mulch residue is thought to protect soils from erosion.

Shredding vehicles use large rubber tires or steel tracks and are equipped with a horizontal mulcher, which has rapidly rotating metal teeth that shred material to a mulch residue (Hatchett et al. 2006). A shredding vehicle has the ability to maneuver with rubber tires or tracks to a standing juniper tree, and after mulching it, leave the residue on or immediately around the tree mound.

Mechanical shredding has been applied to rangelands in several western states as an alternative to other vegetation control methods. Between 2004 and September 2006, more than 9700 ha of woodland had been shredded in Utah, with future use expected to increase (B. Washa, personal communication, September 2008).

Researchers have measured the effects of compaction on infiltration rates, soil structure, plant (various species) cover, and sediment yields. In Midwestern agricultural pastures, Haan et al. (2006) found that penetration resistance was a key factor in the prediction of infiltration rates. Hamlett et al. (1990) found that infiltration rates were significantly reduced by construction vehicle traffic on agricultural lands. Also, compaction reduces soil aggregate strength by breaking down soil structure and disrupting soil porosity (Bruand and Cousin 1995, Sveistrup and Haraldsen 1997). Lipiec et al. (2006) investigated the effects of agricultural tillage on soil porosity and found that highest soil porosity was accompanied with highest infiltration rates. Compaction may also decrease root growth and thereby decrease overall plant growth (Sveistrup and Haraldsen 1997). Though site specific, many studies have found that vegetation cover is negatively correlated with sediment load (Linse et al. 2001; Pierson et al. 2001; Pierson et al. 2002; Haan et al. 2006). Raper (2005) provides five factors that result in compaction: heavy loads, soil disturbance, moist soils, multiple passes, and compactable soil textures. Shredding vehicles may weigh approximately 16 000 kg (R. Pentesco, personal communication, January 2007). The effects of the other four factors depend on vehicle driver skill and site conditions.

Mulch residues may also impact soil surface hydrology. Covering soils with organic matter, such as mulch, has generally been accepted as a method of increasing infiltration rates and decreasing sediment yields in agricultural soils and may have similar effects in juniper woodlands. In agricultural soils, these coverings are often straws or grasses (Zuzel and Pikul 1993; Blanco-Canqui and Lal 2007). In conifer forest, soils covered with pine mulch had similar sediment yields as grass microsites (Grismer and Hogan 2005). Wood and Javed (1992) show that leaving slash on a hillslope reduces runoff and sediment in pinyon (*Pinus edulis* Engelm.)-juniper (*Juniperus deppeana* Steud.) woodland.

No research has been reported on the soil and hydrologic effects of mechanical shredding in juniper woodlands. The objectives of this study were to quantify soil physical characteristics (soil resistance and stability) and hydrological responses to compaction and mulch residue from mechanical shredding in a juniper (*Juniperus osteosperma* [Torr.] Little) woodland in central Utah. We hypothesized that tracks from a shredding vehicle would increase soil compaction, decrease infiltration rates, and increase sediment yields at the patch scale (0.5 m^2). We further hypothesized that shredded mulch residue would elevate infiltration rates and decrease sediment yields.

METHODS AND MATERIALS

Study Site

This study was conducted 76 km southwest of Salt Lake City, Utah on the eastern slopes of the Onaqui Mountain range (lat 40°12'46"N, long

112°28'17"W). With a north facing aspect, the slope is approximately 15% and the site elevation ranges from 1 720 m to 1 738 m. The mean annual temperature is 7.5˚C with cold, wet winters and hot, dry summers. Annual precipitation ranges from 400 to 560 mm, mostly occurring as winter snow storms and late summer monsoons. The 1 500 m^2 study area is located on Bureau of Land Management (BLM) Land that is leased for livestock grazing, but has been free of livestock since the fall of 2005. The dominate soil type is Borvant gravelly loam series of loamy-skeletal, carbonatic, mesic, shallow Aridic Petrocalcic Palexerolls (USDA Soil Survey 2007). The plant community consisted of Utah juniper, Black sagebrush (*Artemisia nova* A. Nelson), Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), Sandburg bluegrass (*Poa secunda* J. Presl), cheatgrass (*Bromus tectorum* L.), bur buttercup (*Ceratocephala testiculata* [Crantz] Roth), ballhead ipomopsis (*Ipomopsis congesta* [Hook.] V.E. Grant), and pale madwort (*Alyssum alyssoides* [L.] L.).

Experimental Design

We used a randomized block design consisting of five blocks with three treatments: control, tire tracks, and mulch-residue covering. In comparisons with tracked plots, control plots are referred to as untracked plots; when compared with juniper residue plots, control plots are referred to as without-residue plots. Control and tire-tracked treatments were measured on four microsites in each block: juniper mound, shrub mound, grass interspace (> 5% grass cover on plot), and bare interspace. Mulch-residue-covered treatments were measured on one grass interspace microsite and on one originally-bare interspace microsite in each block. Plots were 0.5 m^2 galvanized steel frames with a horizontal lip on the down-slope end. The frames were pounded into the soil and disturbed soils on the borders of the frame were refilled with soil adjacent to the plot and a sealant applied. As part of a larger study, the control plots were installed in spring of 2006 and received simulated rainfall during the summer. In the fall of 2006, trees were mechanically shredded using a Tigercat M726E Mulcher® vehicle (Fig. 1a). This model uses large rubber tires. The tractor operator was asked to avoid disturbing previously installed plots which were marked by florescent paint on the plot frame. Two plots were disturbed and made unusable which resulted in two additional control plots installed in spring 2007. Tracked and residue plots were installed in spring 2007.

Using a Meyer and Harmon (1979) rainfall simulator, two rainfall events were simulated on all three treatments in late spring of 2007. We utilized a Veejet 80-100 nozzle to approximate the kinetic energy of a convective thunderstorm (Meyer and Harmon 1979). The two successive simulations, approximately 30 min apart, applied 64 mm•h^{-1} (dry run – soil initially dry) and 102 mm•h^{-1} (wet run – soil initially wet), for 45 min each. These rates were selected to achieve a steady state infiltration rate. During rainfall simulations, timed samples of surface water runoff were collected. Each sample was weighed, dried (105˚C), and weighed again to obtain runoff volume and sediment mass. The variables for this study were final infiltration rate (used as the steady state value), minimal infiltration rate (the lowest infiltration rate during the simulations), time to the start of runoff, time to the peak of runoff (highest measured runoff rate), cumulative runoff (total runoff during simulation), runoff-to-rain ratio, cumulative sediment (total sediment during simulation), and runoff-to-sediment ratio.

Soil and Vegetation

Ground cover, surface roughness (microtopographic variation), soil water content, and soil aggregate stability were measured in plots before rainfall simulations began. Using the point-frame method, 15 measurements were obtained along seven transects (105 points) to quantify canopy, ground cover and surface roughness. Surface roughness was measured and derived as described by Pierson et al. (2007b). Vegetation and ground cover was differentiated into lichens, mosses, grasses, forbs, shrubs, tree mulch residue, bare ground, litter, rock (≥ 5 mm), and standing dead. Soil aggregate stability was tested 0.5 m to the right of each plot using methodology developed by Herrick et al (2001; 2005). Soil samples were collected next to each plot and analyzed for gravimetric soil water content at the time of simulation.

Tree and understory vegetation cover were measured on three 30 x 33 m macroplots randomly-placed across the site. Trees were counted and tree canopy cover was calculated prior to the shredding by measuring the width and breadth of each tree canopy within the macroplot. After shredding, the cover of tire tracks and understory vegetation on the study site was recorded.

For an index of soil compaction from tire tracks, we used a cone penetrometer (FieldScout SC-900 Soil Compaction Meter®) to measure soil resistance at five depths (0, 2.5, 5, 7.5, 10 cm). The measurements were recorded in October of 2007 at the closest of each of the four microsites to 15 regularly-placed points along two transects (120 total points, 15 for each microsite type, both tracked and untracked) that spanned the length of the study site.

Data Analysis

We used mixed model analysis (Littell et al. 1996) to analyze infiltration rates, time to runoff, time-to-peak runoff, cumulative runoff, runoff-to-rain ratio, cumulative sediment, sediment-to-runoff ratio, soil water, canopy and ground cover, aggregate stability, and surface roughness. Blocks were considered random, while microsite and treatment were considered fixed factors. The arcsin square root transformation was performed to normalize data for time to runoff, time-to-peak runoff, cumulative sediment, and sediment-to-runoff ratio. For penetrometer measurements, the mean tracked and untracked microsites were compared at five depths using repeated measures analysis. Tablecurve ® 2D was employed to derive the best-fit non-linear equation describing the relationship between percent residue cover and sediment yield for bare and grass interspace plots that had runoff and residue cover.

RESULTS

Soils and Vegetation

After mechanical shredding, bare ground represented 78% of the surface whereas rock, moss, and lichen crust accounted for 15, 5, and 1% of the surface, respectively. Litter covered 26% (for site characterization, litter was not considered a surface layer). The dominant vegetation consisted of grasses, forbs, and shrubs with bluebunch wheatgrass, Sandburg bluegrass, and cheatgrass covering 11, 3, and < 1% of the site, respectively. Black sagebrush covered 3% while Wyoming big sagebrush covered < 1%. Bur buttercup covered 3% while ballhead ipomopsis, and pale matwort covered < 1%.

Prior to the shredding of juniper trees, tree canopy was estimated to be 23.1% with an average of 453 trees ha^{-1}. After shredding, the mulch residue was estimated to cover 35% of the study site. The shredding vehicle left behind tire tracks estimated to cover 15% of the hillslope. Mean rock cover on untracked plots (21.6% ± 1.9) was significantly higher ($F_{1,28} = 8.48$, $P = 0.007$) than that of tracked plots (13.5% ± 1.9) (Table 1). Untracked and without-residue bare interspace plots had significantly higher rock cover than tracked or residue-covered plots ($P < 0.05$). There was no statistical difference ($P \geq 0.05$) in surface roughness for any comparison. Aggregate stability tests indicated that soils under trees, grasses, and shrubs had the highest relative stability, while areas of bare ground and under juniper litter had the lowest.

Soils were coarse-textured loam. A calcic layer was observed approximately 10 cm beneath the surface. Also, $CaCO_3$ levels varied from 27.1% to 38.9% across the site. Volumetric soil water at 10 cm to 20 cm depth at the time of shredding at three nearby (< 1.6 km) soil moisture stations as measured by time domain reflectrometry (TDR) ranged from 20% to 22%.

Soil Resistance Measurements

For interspaces and shrub mounds, soil resistance (kPa) was significantly higher ($P < 0.05$) for tracked than untracked microsites at the 5 cm to 10 cm depths (Fig.2). Resistance did not significantly differ ($P \geq 0.05$) on juniper mounds. For all microsites, soil resistance increased as soil depth increased.

Infiltration Rates and Sediment Yield

Untracked vs. Tracked Soils. For the dry run, time to runoff ($F_{2,12} = 20.74$, $P < 0.0001$) and time-to-peak runoff ($F_{2,12} = 18.02$, $P = 0.0002$) for interspace plots were significantly higher than juniper mound plots. Cumulative runoff ($F_{2,12} = 4.44$, $P = 0.0360$) were significantly higher for bare interspace compared to grass interspace. Sediment-to-runoff ratio ($F_{2,11} = 7.04$, $P = 0.0107$) was significantly higher for bare interspace compared to juniper mound. Effects of tracking were significant for cumulative sediment yield ($F_{1,11} = 5.72$, $P = 0.0358$) and sediment-to-runoff ratio ($F_{1,11} = 9.30$, $P = 0.0111$). The interaction of tracking with microsite was not significant for any comparison ($P \geq 0.05$) (Table 2 and Fig. 3a). There was no measurable runoff from shrub mounds and therefore this microsite was not included in the dry run analysis.

For the wet run and across all microsites, tire-tracked plots had significantly lower final ($F_{1,25} = 7.52$, $P = 0.0111$) and minimal ($F_{1,25} = 7.99$, $P = 0.0091$) infiltration rates and higher cumulative runoff ($F_{1,25} = 5.38$, $P = 0.0288$), runoff-to-rain ratio ($F_{1,25} = 5.60$, $P = 0.0260$), and cumulative sediment yield ($F_{1,24} = 7.01$, $P = 0.0141$) than untracked plots (Table 3 and Fig 3b). As expected, microsites varied significantly in final ($F_{3,25} = 41.74$, $P < 0.0001$) and minimal

($F_{3,25}$ = 36.13, P < 0.0001) infiltration rates, time-to-peak runoff ($F_{3,25}$ = 28.85, P < 0.0001), cumulative runoff ($F_{3,25}$ = 35.48, P < 0.0001), runoff-to-rain ratio ($F_{3,25}$ = 34.96, P < 0.0001), cumulative sediment yield ($F_{3,24}$ = 30.16, P < 0.0001), and sediment-to-runoff ratio ($F_{3,24}$ = 8.87, P = 0.0004). Mean final and minimal infiltration rates of mounds were 0.5 to 1.5 times higher than those of bare interspace plots. Mean cumulative runoff, runoff-to-rain ratio, and cumulative sediment yield were two to six times higher for interspace than those of mound plots with bare interspaces significantly higher than those of grass interspaces in all cases (P < 0.05). Juniper mounds had the shortest time-to-peak runoff and the lowest sediment-to-runoff ratio during the wet run (Table 3). Although the interaction for all plots between microsite and tracking was not significant for final ($F_{3,25}$ = 1.72, P = 0.1882) and minimal ($F_{3,25}$ = 1.90, P = 0.1552) infiltration rates, tracking significantly (P < 0.05) reduced final and minimal infiltration rates by 40% and 42%, respectively, on grass interspace plots (Table 3 and Fig. 1b), but untracked and tracked infiltration rates were similar for the other microsites. The interaction between microsite and tracking was also not significant for time-to-peak runoff ($F_{3,25}$ = 1.22, P = 0.3247), cumulative runoff ($F_{3,25}$ = 1.08, P = 0.3750), runoff-to-rain ratio ($F_{3,25}$ = 1.07, P = 0.3788), cumulative sediment ($F_{3,24}$ = 0.22, P = 0.8833), sediment-to-runoff ratio ($F_{3,24}$ = 0.30, P = 0.8217). Time to the start of runoff was notability reduced by 83% for tracked plots compared to untracked plots on shrub mounds (P < 0.05).

Without-mulch residue vs. mulch residue. The dry run did not have any measurable runoff on almost all mulch-residue-covered plots and therefore was not analyzed. For the wet run, juniper residue significantly increased final ($F_{1,8}$ = 13.02, P = 0.0069) and minimal ($F_{1,8}$ = 8.74, P = 0.0182) infiltration rates and decreased cumulative sediment rates ($F_{1,8}$ = 18.67, P = 0.0025), runoff-to-rain ratio ($F_{1,8}$ = 9.91, P = 0.0137) , cumulative runoff ($F_{1,8}$ = 10.17, P = 0.0128), and sediment-to-runoff ratio ($F_{1,8}$ = 11.01, P = 0.0106) compared to without-residue plots. There were no significant differences ($P \geq 0.05$) between grass and bare interspace microsite infiltration rates. The interaction of microsite and mulch residue was significant with mulch affecting bare interspaces more than grass interspaces. Mulch on bare interspace plots increased final infiltration rates by 67% ($F_{1,8}$ = 11.99, P = 0.0085), and minimal infiltration rates by 69% ($F_{1,8}$ = 10.65, P=0.01). Mulch residue on bare interspace significantly decreased cumulative runoff by 40% ($F_{1,8}$ = 11.84, P = 0.0088), runoff to rain ratio by 75% ($F_{1,8}$ = 11.65, P = 0.0092), and cumulative sediment yield by 88% ($F_{1,8}$ = 9.1, P = 0.0166). Residue did not significantly ($P \geq 0.05$) affect these responses for grass interspaces. However, two of the grass interspace plots did not run off and there was a downward trend in infiltration rates with residue compared to without-residue plots (Table 3 and Fig. 3c).

There was a significant correlation ($F_{1,12}$ = 8.55, P = 0.0128) between percent cover of mulch residue and cumulative sediment yield for interspace plots (Fig. 4). As percent cover increased, cumulative sediment (g) decreased. The analysis included bare and grass interspace plots that had simulated rainfall runoff and shredded juniper residue.

DISCUSSION

Compaction and Infiltration from Tire Tracks

Does tire tracking from a heavy shredding vehicle increase soil compaction? Hatchett et al. (2006) measured soil resistance as an index of compaction. They found little effect from the shredding vehicle. In our study, it appears that juniper litter and duff layers act as a cushion to absorb the compression of the weight of the vehicle. As a result juniper mounds responded similarly to pine (*Pinus* spp. and *Calocedrus* spp.) needles on the site studied by Hatchett et al. (2006). On the other hand, tracking significantly increased soil resistance one to three fold for bare interspace, grass interspace, and shrub mound microsites. Litter fall in these microsites offers little protection from vehicle compacting. Compaction from agricultural vehicles has been well documented (Hamlett et al. 1990; Raper 2005). Although increased compaction from vehicular tracking is consistent with agricultural studies, rangeland shredding vehicles do not repeatedly pass over the same soil year after year. Rather, shredding of juniper woodland may not have to be repeated for several decades. Rangeland soils are highly variable temporally in anecedent soil water and highly variable spatially in texture, coarseness, and organic matter composition (Coronato and Bertiller 1995; Reeder 2002). Therefore, rangeland soils may respond very differently to tire or track-induced soil compaction.

Does compaction decrease infiltration? Compaction of soils from tire tracks did significantly decrease final and minimal infiltration rates when analyzed across all microsites. However when microsites were analyzed separately, tracking compaction was only found to significantly decrease the final and minimal infiltration rate on grass interspaces. Decreased soil porosity is presumably responsible for this and is consistent with agricultural findings that investigated compaction from vehicles (Berli et al. 2004). As the vehicle rolls over the grass it reduces the porosity created by the fibrous root system of the grass leaving the soil with less infiltration pathways. Bare interspaces lack the porosity of grass interspace, tree mounds, and shrub mounds and typically have lower infiltration rates than vegetated mounds and microsites (Blackburn 1975; Roundy et al. 1978; Reid et al. 1999). Wilcox et al. (2003) suggested that macropores under some juniper trees may provide for higher infiltration rates on mounds than bare interspaces. In our study, mounds had up to 300% higher infiltration rates than bare interspaces suggesting the presence of macropores. The difference between mounds and interspaces is consistent with previous research (Rau et al. 2005; Pierson et al. 2007a).

Eldridge and Rosentreter (2004) found that shrub mounds exhibited higher infiltration rates that that of interspaces. They attributed this to the presence of soil macropores. In our study, shrub mounds were likewise found to have significantly higher final and minimal infiltration rates compared to interspace plots. Tracking significantly decreased the time to initial runoff. Tracking flattened shrub canopies and probably reduced rainfall interception. Evidence of this is the downward trend in infiltration rates and the upward trend in cumulative runoff on tracked shrub plots. The lack of significance of these trends lends evidence that the macropores on shrub mound plots were, to some degree, still intact and permitting a high level of infiltration.

In our study, surface roughness was not significantly changed by tracking. This was an unexpected result. Large tire tracks observed across the site were thought to increase surface roughness and thereby either provide catchment run-in areas for tracks perpendicular to the slope or provide avenues for rills for tracks parallel to the slope. Untracked microsites had a significantly higher percentage of rock cover than tracked microsites. It is likely that rocks were pushed into the soil and possibly covered resulting in a smoother track and explain the lack of difference in surface roughness.

Mulch Residue

Does a mulch residue reduce sediment yields and increase infiltration rates? Bare interspaces have been found to have higher sediment yields than understory vegetated tree interspaces and tree canopies at a patch scale (1 m^2) (Reid et al. 1999). Hastings et al. (2003) found that leaving juniper slash on New Mexico watersheds can reduce sediment loads by one to three fold. Pine-needle mulch (various species) cover has been found to reduce sediment yields by half, an effect similar to that of vegetation restoration treatments (Grismer and Hogan 2005). In agricultural practices, Radcliffe et al. (1988) have suggested that the hydrologic benefits of the “no till” method are largely attributed to accumulation of ground debris disrupting rain drop impact which increased infiltration rates. They further indicated that the soil covering may have a repairing effect on compacted soils over time.

The results of this study are consistent with those of previous work. Mulch residue decreased sediment yield on bare interspace plots by approximately 87%, while increasing infiltration rates by approximately 67% (Table 3). We believe the reductions in sediment yields are a result of a reduction in raindrop impact associated with the mulch cover as also reported in laboratory experiments by Geddes and Dunkerley (1999) and Kramer and Meyer (1969). High infiltration rates are associated with lower sediment yields (Walker et al. 2007). Also, the nonlinear correlation between percent residue cover and sediment yield supports this idea of raindrop interception by showing a major reduction in sediment as percent cover increased to 20% (Fig. 4). It is also possible that mulch residue provides resistance to interrill flow similar to resistance provided by vegetation. Gutierrez and Hernandez (1996) show that grass cover is negatively correlated with sediment production and that grass may also resist interrill flow. Vegetation and residue resistance to interrill flow would allow sediment to settle out of runoff water and permit more time for infiltration to occur. Reid et al. (1999) point out that "intercanopy vegetation acts as a sink" (p. 1870). While Ernst et al. (1993) further suggests that slash material acts as an obstacle to prevent sheet erosion. We surmise that both raindrop interception and interrill obstruction play a role in the reduction of runoff and sediment yields.

Although there were some negative hydrological effects from compaction on grass interspaces, mulch residue increased infiltration and decreased sediment yield on bare interspaces. The Onaqui study site was estimated to have tire tracks that covered 15% of the study site, while mulch cover was estimated to cover 35%. Juniper cover before shredding was estimated to be as high as 23%. This suggests that approximately 12% of the residue was being spread beyond the confines of the canopy into interspaces. Amounts are likely to vary depending on the vehicle, the methods of maneuvering by the driver, and site characteristics.

For mechanical shredding, the generated mulch residue has a positive impact on infiltration rates and sediment yields for bare interspaces. The process of surface cover from litter or residue interfering with rainfall impact and providing obstacles to the interrill flow appeared to be the overriding influence on sediment production and infiltration rates. Soil penetration resistance was significantly higher at all microsites except for juniper mounds thus demonstrating that compaction did occur from tracking.

IMPLICATIONS

Mechanical shredding (or Bull Hog®) is a viable method of vegetation control where juniper trees have excluded understory vegetation and had limited effects on infiltration and erosion under high-intensity simulated rainfall at the patch-microsite scale. Site and temporal characteristics should always be considered when applying mechanical treatments as specific soil conditions may be associated with low infiltration. Therefore, land managers should be aware of factors that promote soil compaction such as wet soils, heavy loads, repeated passes, soil disturbance, and the generation of fine sediments (Raper 2005). Sites with coarser-textured soils and higher infiltration rates or finer-textured soils with lower infiltration rates may respond differently to tracking and shredded residue than soils at the Onaqui site. Managers should watch for evidence of rills and coalescing of rills before and after treatments to best evaluate hydrologic responses at the hillslope and larger scales. Where possible, vehicle drivers should shred trees to spread the mulch residue as much as possible.

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Table 1. Mean (± SE) ground and vegetation cover (%) in shredded Utah juniper woodland by microsite.

	Control				Track				Mulch	
	Juniper	Shrub	Grass	Bare	Juniper	Shrub	Grass	Bare	Grass	Bare
Perennial grass	14.1 ± 4.63	25.7 ± 4.63	34.3 ± 4.63	0.76 ± 4.63	8.57 ± 5.17	16.2 ± 4.63	18.4 ± 4.22	0.76 ± 4.62	19.8 ± 5.17	1.67 ± 5.17
Perennial forb	3.24 ± 2.36	7.81± 2.36	6.86 ± 2.36	0.38 ± 2.36	3.46 ± 2.62	2.29 ± 2.36	2.14 ± 2.19	0.57 ± 2.36	2.50 ± 2.62	0.21 ± 2.62
Shrub	0.19 ± 2.62	50.7 ± 2.62	0.19 ± 2.62	0.00 ± 2.62	0.00 ± 2.93	17.9 ± 2.62	1.11 ± 2.39	0.00 ± 2.62	0.00 ± 2.93	0.00 ± 2.93
Standing dead	0.00 ± 0.54	1.52 ± 0.54	0.00 ± 0.54	0.19 ± 0.54	0.00 ± 0.60	0.00 ± 0.54	0.00 ± 0.49	0.38 ± 0.54	0.71 ± 0.60	0.00 ± 0.60
Annual forb	0.00 ± 1.24	0.00 ± 1.11	0.38 ±1.11	0.57 ± 1.11	2.10 ± 1.11	0.76 ± 1.11	0.79 ± 1.01	0.19 ± 1.11	0.00 ± 1.24	3.57 ± 1.24
Total foliar cover	24.8 ± 5.50	94.3 ± 5.50	47.8 ± 8.76	3.43 ± 5.50	12.5 ± 6.15	59.6 ± 5.50	31.6 ± 5.03	3.24 ± 5.50	23.0 ± 6.15	5.15 ± 6.15
Litter	58.7 ± 8.12	48.8 ± 8.12	19.6 ± 8.12	1.90 ± 8.12	56.5 ± 9.02	46.7 ± 8.12	17.9 ± 7.53	3.62 ± 8.12	17.9 ± 9.02	3.05 ± 8.12
Rock	0.95 ± 3.74	10.9 ± 3.74	31.4 ± 3.74	43.2 ± 3.74	1.67 ± 4.18	12.38±3.74	15.1±3.42	24.8 ± 3.74	6.42 ± 4.18	7.43 ± 3.74
Bare	2.37 ± 6.40	30.7 ± 6.14	37.7 ± 6.14	46.7 ± 6.14	7.86 ± 6.86	25.5 ± 6.14	47.0 ± 5.60	67.4 ± 6.14	20.5 ± 6.86	12.2 ± 6.14

Table 2. Dry run (soil initially dry) infiltration, runoff, and sediment rates on a shredded Utah juniper woodland in Utah. Different letters within a row indicate significantly different means by the Tukey-Kramer test ($P < 0.05$).

	Tire tracks					
	Juniper mound		Grass interspace		Bare interspace	
	Untracked	Tracked	Untracked	Tracked	Untracked	Tracked
Number of plots out of five with runoff	3	3	3	3	5	5
Time to runoff (min)	6.0 b	4.1 b	24.8 a	16.2 a	13.8 ab	18.8 a
Time-to-peak runoff (min)	17.6 b	25.6 ab	41.3 a	39.8 a	42.6 a	39.0 a
Cumulative runoff (mm)	6.97 a	9.61 a	2.98 a	10.6 a	13.3 a	12.8 a
Runoff/Rain ratio ($mm•mm^{-1}$)	0.15 a	0.21 a	0.06 a	0.23 a	0.28 a	0.27 a
Cumulative sediment ($g•m^{-2}$)	29.2 a	37.6 a	16.1 a	77.7 a	62.0 a	83.5 a
Sediment/Runoff ratio ($g•m^{-2}•mm^{-1}$)	3.77 b	3.81 b	4.38 ab	7.07 ab	4.88 ab	7.07 a

Table 3. Wet run (soil initially wet) infiltration, runoff, and sediment rates on a shredded Utah juniper woodland in Utah. Different letters within a row and treatment indicate significantly different means by the Tukey-Kramer test ($P < 0.05$).

	Tire tracks								Juniper residue			
	Juniper mound		Shrub mound		Grass interspace		Bare interspace		Grass interspace		Bare interspace	
	Untracked	Tracked	Untracked	Tracked	Untracked	Tracked	Untracked	Tracked	No residue	residue	No residue	residue
Number of plots out of five with runoff*	5	5	3	4	5	5	5	5	5	3	5	4
Final infiltration ($mm{\bullet}h^{-1}$)	85.7 a	74.2 a	85.0 a	79.3 a	66.1 a	39.8 b	26.7 b	24.2 b	66.1 a	67.3 a	26.7 b	81.9 a
Minimum infiltration ($mm{\bullet}h^{-1}$)	71.7 a	62.6 a	83.0 a	77.0 a	65.4 b	37.7 a	24.0 b	20.1 b	65.4 a	62.7 ab	24.0 b	78.1 a
Time to runoff (min)	3.55 bc	3.64 bc	25.5 a	4.5 b	1.86 bcd	2.91 cde	1.02 e	1.22 de	1.86 a	12.5 a	1.02 a	7.66 a
Time-to-peak runoff (min)	8.30 b	8.24 b	40.3 a	31.9 a	36.6 a	40.4 a	43.3 a	31.9 a	36.6 a	22.4 a	43.3 a	29.5 a
Cumulative runoff (mm)	14.3 c	20.2 bc	4.66 c	12.2 c	22.5 bc	38.3 ab	52.1 a	52.7 a	22.5 b	24.1 ab	52.1 a	11.1 b
Runoff/Rain ratio ($mm{\bullet}mm^{-1}$)	0.19 c	0.27 bc	0.06 c	0.16 c	0.30 bc	0.51 ab	0.68 a	0.69 a	0.30 b	0.32 ab	0.68 a	0.15 b
Cumulative sediment ($g{\bullet}m^{-2}$)	48.8 c	75.0 bc	20.9 c	70.5 bc	133 bc	211 ab	313 a	403 a	133 b	83.8 b	313 a	38.6 b
Sediment/Runoff ratio ($g{\bullet}m^{-2}{\bullet}mm^{-1}$)	3.40 b	3.38 b	4.96 ab	5.77 ab	5.46 ab	5.51 ab	6.08 ab	7.68 a	5.46 b	1.61 b	5.30 a	1.08 b

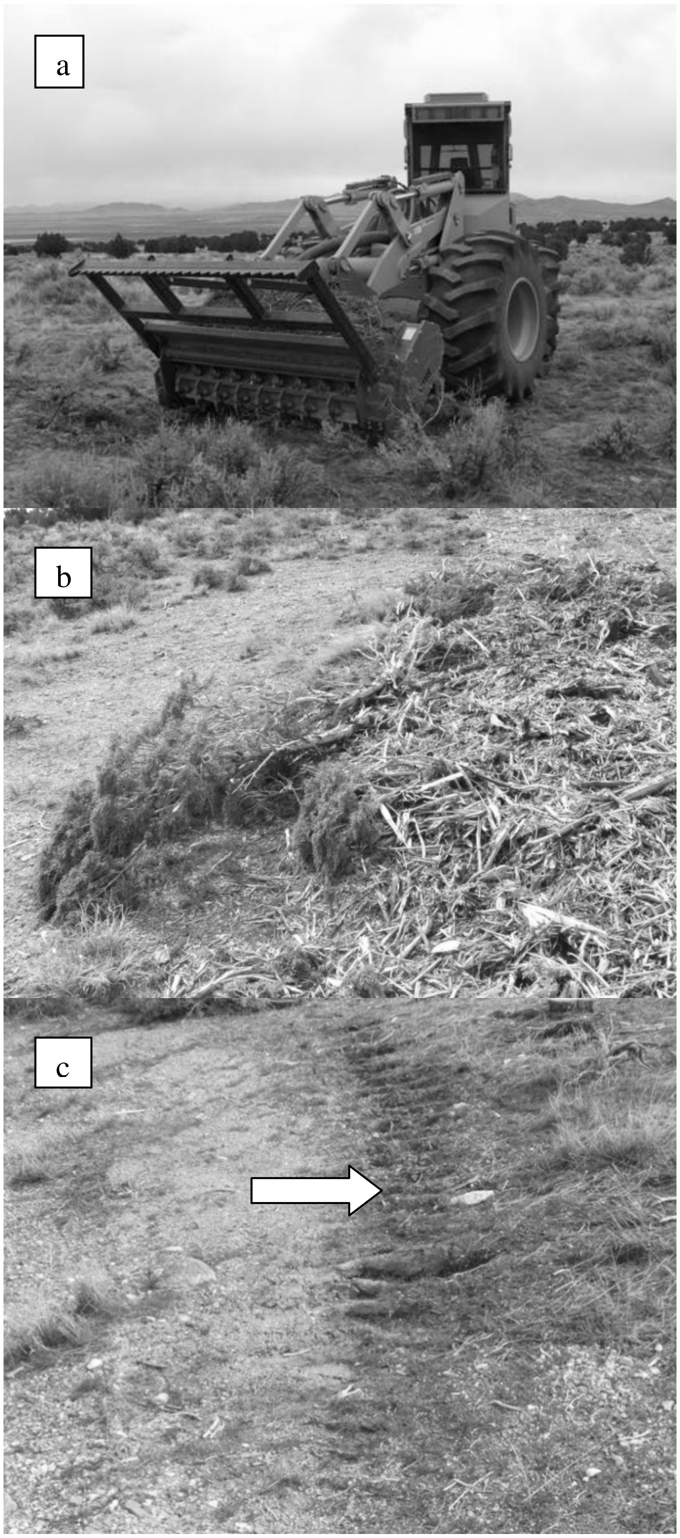

Figure 1. Tigercat M726E Mulcher® (a), Utah juniper mulch residue (b), and tire tracks (c) at Onaqui Mountains, Utah.

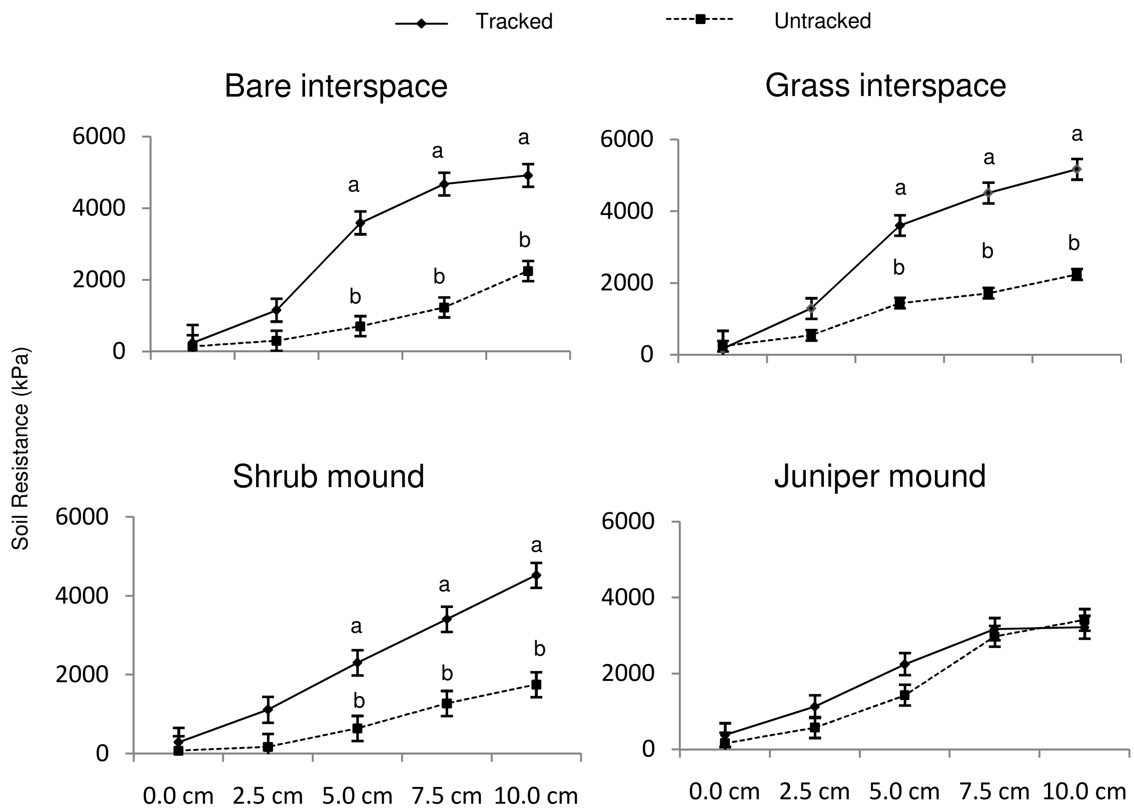

Figure 2. Soil resistance by microsite with and without tracking from a rubber–tired tree shredder. Graphs indicate soil resistance from cone penetrometer as depth increases. Letters "a" and "b" above standard error bars indicate significant differences between untracked and tracked soils at that depth as determined by the Tukey-Kramer test ($P < 0.05$).

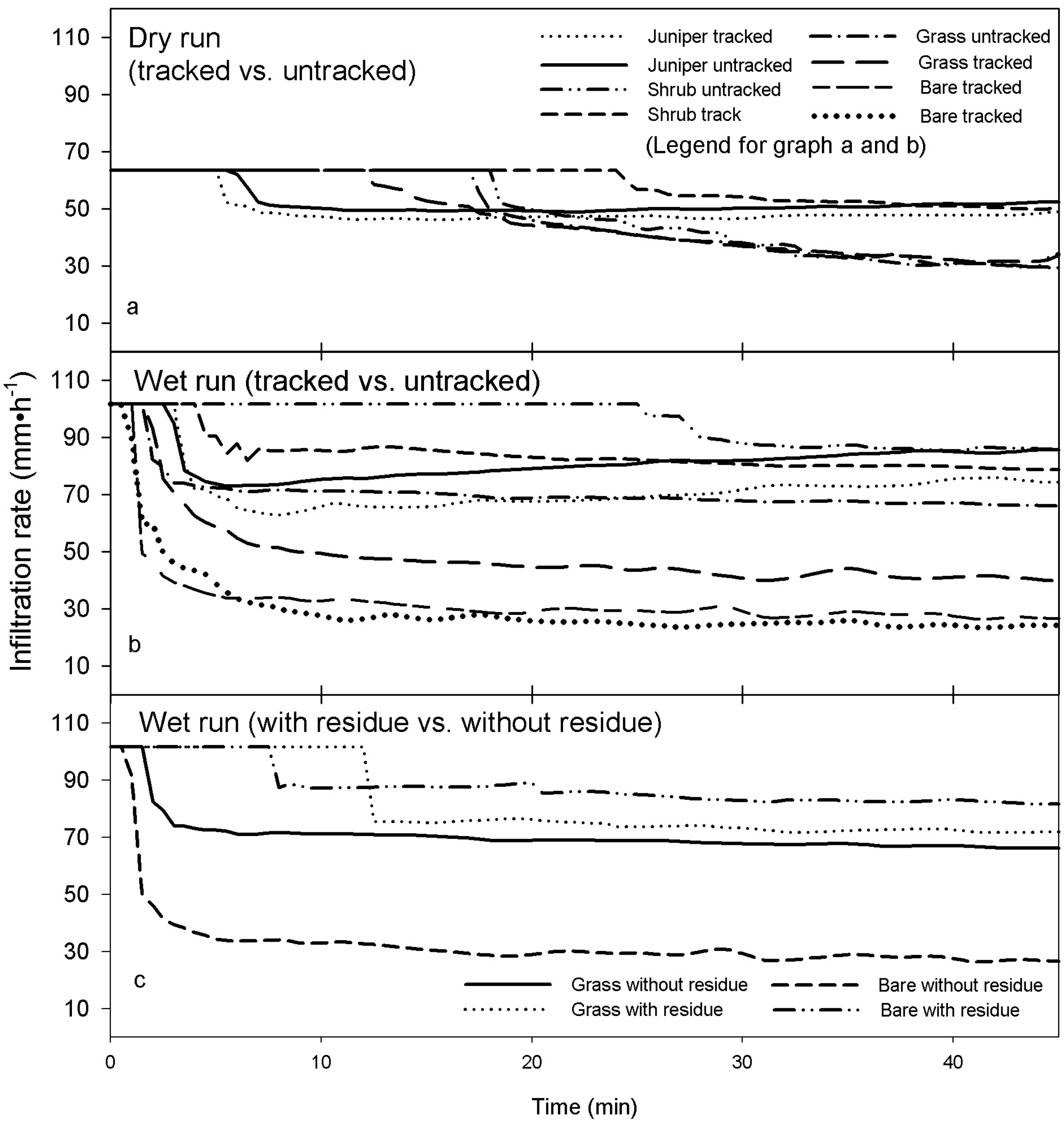

Figure 3. Infiltrations rates for tracked and untracked microsites for initially dry (a – dry run) and initially wet (b – wet run) soils and c – bare and residue – covered interspaces in a Utah juniper woodland after tree shredding.

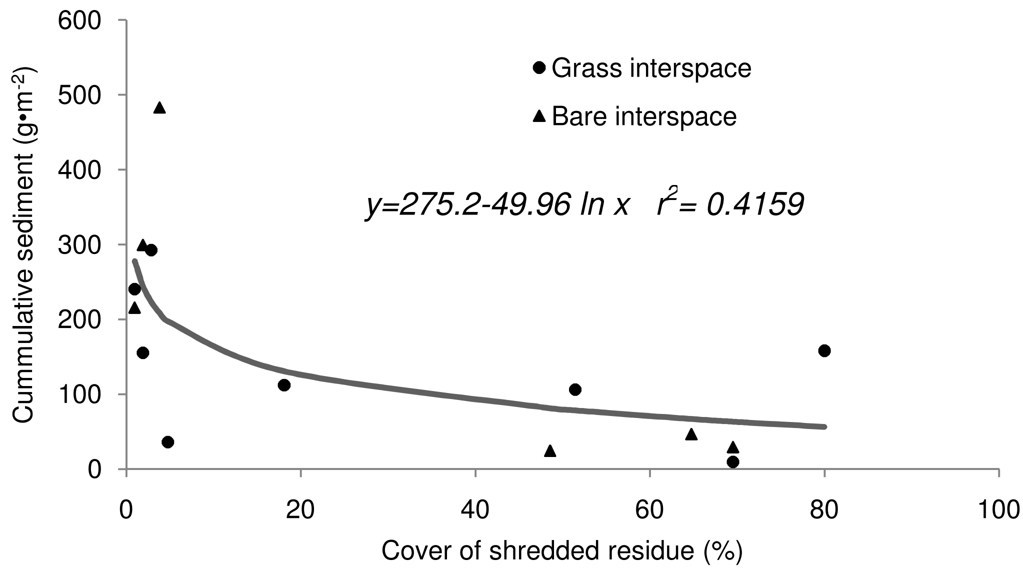

Figure 4. Sediment (g•m^{-2}) as a function of percent cover of shredded juniper residue from interspace and grass interspace microsites measured on 0.5 m^2 runoff plots.