INITIATION AND EVOLUTION OF CONCENTRATED FLOW INDUCED EROSION ON A PINYON-JUNIPER WOODLAND

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Abstract Upland soil erosion and sedimentation is a serious global problem. Extensive research has been completed on erosion mechanics on croplands and these processes are well-understood. However, we only have limited knowledge of the processes on native rangelands and almost no knowledge on the process of concentrated flow induced erosion formation and evolution. There are numerous theories as to why these flow paths develop. One theory is that the critical shear stress of the soil is exceeded. Differences in bulk density of the soil may also be indicative of why these concentrated flow paths develop where they do. There are a number of factors that contribute to the complexity in predicting the evolution of these flow paths. Often times, a soil detachment capacity threshold is met and the soil armors itself. Also, there are nuances of the landscape such as large amounts of litter that can create dams that also contribute to this complexity. Experimental design consisted of twelve unbounded plots at two slope steepness (30% and 10%), six plots at each slope steepness, and 3 concentrated flow water application rates. Water was applied from a specially designed flow meter calibrated to rates of 15, 30 and 42 L min^{-1} for 12 minutes. Three replicates for each treatment-slope-water application rate were performed.

INTRODUCTION

Upland soil erosion is divided into raindrop detachment and splash sheet flow and into concentrated flow. Concentrated flow paths are an important component of surface runoff in rangelands as they are the largest source and delivery of sediment (Nearing et al., 1997) and the location of these flow paths is determined solely by the microtopography of the landscape (Toy et al., 2002). Flow in these flow paths are significantly deeper and faster than that found in the surrounding sheet flow zones (Abrahams et al., 1995) typically on the order of a few centimeters in depth.

There are a variety of factors that influence the soil erosion process and sediment transport on rangelands. Foster (1982) hypothesizes that flow contains a finite amount of energy that can either be used to detach soil particles or to continue transporting previously detached sediment. Energy is preferentially used for the continuation of movement of sediment and any excess energy is available for the detachment of new sediment (Merten et al., 2001). Bjorneber et al. (2000) notes that with continuous detachment of soil aggregates begin to breakdown the surface begins to armor itself. When the aggregates breakdown**,** the soil infiltration and detachment capacities are greatly inhibited (Bosch and Onstand, 1988). The largest influence on the soil armoring itself is the runoff or the rainfall intensity (Assouline, 2004).

Bare soil in Pinyon-Juniper woodlands can approach 95% (Pierson et al., 2007) which can have up to 24 times more sediment loss than in the canopy zones in Pinyon –Juniper woodlands (Reid et al., 1999). These large areas of bare ground provide more opportunities for water to concentrate in to flow paths. There is an inverse relationship between ground cover and erosion

(Wilcox, 1994); the more ground cover the less susceptible to erosion the site is. With the addition of slash to these bare interspaces, soil erosion can be greatly reduced (Stoddard, 2008). Increased vegetation cover in the form of slash is one of the largest influences on soil erosion in Pinyon-Juniper woodlands (Wood and Javed, 2001).

There has been extensive research on cropland rills, but there is limited research done on these concentrated flow paths (Parsons and Wainwright, 2006). A distinction between concentrated flow paths and cropland rills must be acknowledged. In current and past literature, areas of concentrated flow have often erroneously been identified as rills (Abrahams et al., 1996). Rills are created through artificial means as functions of disturbances on croplands whereas concentrated flow paths occur naturally on rangeland hillslopes and woodlands after a rainfall event typically when infiltration capacity is exceeded.

METHODS

Study Area This research was conducted in the Desatoya Mountains in Lander County, 260 km east of Reno, Nevada. The site is a Clanalpine soil where the top 1-11 cm is very friable and is a Pinyon-Juniper woodland ecological site (NRCS site F024XY050NV). The site receives approximately 36 cm of precipitation, primarily in the winter as snow.

Concentrated Flow Simulations There were a total of twelve unbound plots at two slope steepnesses of 10% and 30% with six plots at each slope steepness. Water was applied using pressure compensating flow regulators calibrated to rates of 15, 30 and 42 L min^{-1}. To find where the concentrated flow paths were going to develop, the hillslope was pre-wetted at a rate of 5 L min^{-1}. Once it was found where the flow paths were likely to develop, two cross-sections were installed two and for meters downslope of where the water was first introduced. At these cross-sections**,** a roughness meter with pins every centimeter for one meter in width was used to determine the geometry of the concentrated flow paths. Between each application rate**,** there was a brief hiatus for collection of the roughness data at each cross-section. A roughness measurement was also recorded just after the pre-wet.

Slash Treatment Slash was added to three plots at each slope steepness. The slash was arranged to mimic windrows, a common way that people hand fell trees to dry them out, perpendicularly to the predominant slope. If slash was not added perpendicularly**,** the water could actually concentrate along the tree and accelerate erosion. With the cross-sections, there was one installed both above and below the slash piles to determine the impact of the slash on the concentrated flow path formation and evolution.

Soil Samples Bulk density of the soil (g cm^{-3}) was taken in the concentrated flow paths and in the surrounding interspaces. These samples were conducted approximately four weeks after the concentrated flow simulations. The Volumeasure Model CN-980A device was used for determining the bulk density.

Statistical Analysis Analysis of variance was used to determine significance.

RESULTS AND DISCUSSION

Formation of concentrated flow paths Horton (1945) first proposed that concentrated flow path incision occurs when a threshold of shear stress is exceeded. Hydraulic shear stress, τ (Pa), is calculated by using the traditional Chezy equation:

$$\tau = \gamma_w RS \tag{1}$$

where γ_w is the specific weight of water (Nm^{-3}), R is the hydraulic radius (m) and S is the effective slope gradient (mm^{-1}). Hydraulic shear stress was calculated for every concentrated flow path. The critical shear for these flow paths do not indicate that when the concentrated flow paths develop they have a significantly higher shear stress. Critical shear stress values found for this study vary greatly. Additionally, there was not a consistent value for critical shear stress indicating when these flow paths develop. These flow paths were allowed to develop naturally and were not in predefined areas. Therefore, the concentrated flow paths were quite dynamic and their geometries changed, with these changes in geometry the hydraulic radius of the flow paths changed quite frequently.

The bulk densities of the concentrate flow paths were slightly lower than those from the surrounding interspaces (Table 1).

Table 1 Bulk Density Readings.

% Slope	Flow Path Bulk Density(g cm^{-3})	SE	Interspace Bulk Density (g cm^{-3})	SE
10	0.90	0.12	1.02	0.11
30	0.76	0.07	0.93	0.11

Lower bulk densities are indicative of soil that is more easily removed. Because the flow path bulk densities were consistently lower, it is reasonable to assume at the differences in bulk density can be indicative of where these flow paths develop where they do.

Evolution of Concentrated Flow Paths With the roughness meter, the concentrated flow path geometries were extracted (Figure 1).

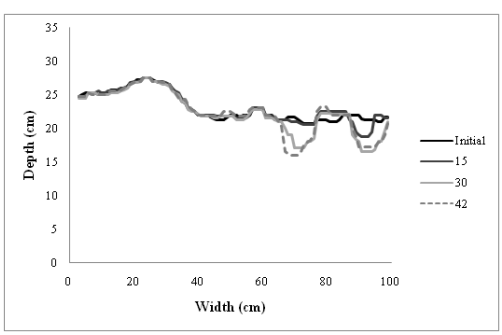

Figure 1 An example of the roughness meter data used to extract concentrated flow path geometries.

The maximum number of flow paths per cross-section is three. In Figure 1 it is clear that between the 30 and 42 L min^{-1} application rate there is not a significant difference in the concentrated flow path geometries. This limited change in geometries is indicating that the soil is beginning to armor itself or that a detachment capacity is met. Often times in this study, the detachment rate threshold was not met until the 30 L min^{-1} application rate. Pierson et al. (2007) also noted that soil begins to armor itself or that a detachment capacity threshold is met with increasing application rates. If the rates were increased even more, it is possible that this detachment capacity would be met and that the concentrated flow paths would become dynamic once again.

Effect of Slash on Concentrated Flow Formation and Evolution Slash has a profound impact on the concentrated flow paths' ability to deepen (Figure 2).

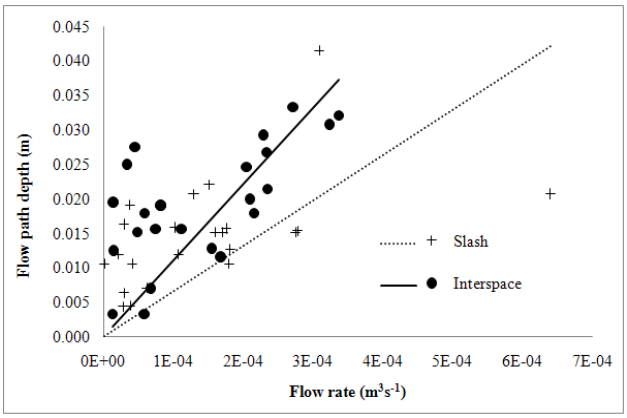

Figure 2 Concentrated flow path depths (m) versus flow rate (m^3s^{-1}).

With the addition of slash it is clear to see that the flow paths deepen at a much slower rate than those in the interspace zones. The addition of slash also has an impact on the concentrated flow paths' width (Figure 3).

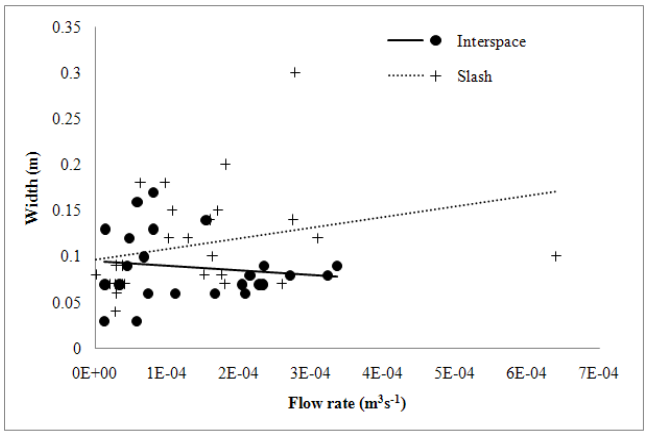

Figure 3 Concentrated flow path widths (m) versus flow rate (m^3s^{-1}).

The addition of slash results in the concentrated flow paths widening. From Figures 2 and 3 we see that the addition of slash does not allow the concentrated flow paths to scour as deep as that is seen in the interspace zones. In fact, the concentrated flow paths are shallower and wider. The addition of slash has been known to reduce soil movement by creating physical barriers. (Jacobs and Gatewood, 1999; Wood and Javed, 2001; Stoddard et al., 2008). Dunne and Foster (1978) note that the addition of slash reduces the effective length of the flow paths**,** which limits their ability to erode.

CONCLUSIONS

Inferences of this study are limited to Pinyon-Juniper woodlands in central Nevada. Concentrated flow erosion is highly variable which makes estimating erosion amounts and locations difficult. Results indicate that the use of critical shear stress for unbounded plots where the concentrated flow paths were allowed to develop naturally cannot define when the concentrated flow paths will develop. However, differences in the soil bulk density may be able to indicate where the concentrated flow paths develop. During runoff events, the geometries of the concentrated flow paths are dynamic. Therefore, for these 'natural' flow paths**,** it is unreasonable to assume that shear stress can be in indicator of when and where a concentrated flow path will develop.

Reported values for critical shear stress vary greatly**,** which also indicates that this parameter is difficult to estimate. Shear stress is also a function of a number of soil properties such as texture, salt content, dispersion ratio and plasticity index (Ariathurai and Arulanandan, 1978). These soil properties vary quite rapidly through the soil column, further adding to the complexity of estimating this parameter. The differences in bulk density in the interspace zones and within the concentrated flow paths may be an indicator of where the flow paths will form.

Since the flow paths are actively widening and deepening during the event, the soil begins to armor itself. This armoring occurs when the concentrated flow path reaches a detachment capacity threshold**,** and if this threshold is not met then the flow paths will not change much. However, if this threshold is met then the concentrated flow paths become quite dynamic. Defining this threshold is complex. There are a number of factors that influence the formation and evolution of these concentrated flow paths. On these Pinyon-Juniper woodlands litter dams are often created. When these dams break**,** there is a large pulse of water and a new concentrated flow path may subsequently develop.

The addition of slash to these plots also has an impact on the formation and evolution of these concentrated flow paths. The slash widens out the channels and does not allow for them to scour as seen in the interspace zones. Slash also has an impact on the runoff of the plot. At the 15 L min^{-1} application rate at the lower slope (10%), there was no run off for the plots that had slash added to them. From a managerial standpoint, the addition of slash can assist in soil loss reduction. One thing that must be considered is the length between the windrows. There are less opportunities for these concentrated flow paths to develop on bare interspaces less than 4.6m (Foster et al., 1981; Liu et al., 1994).

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