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EFFECTIVENESS OF NEEDLE CAST FROM BURNT CONIFER TREES ON REDUCING EROSION

by

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Summary:
Wildfires in steep forest environments can often produce disastrous runoff and soil loss after rainstorms. There is often needle cast from partially burnt conifer trees that generally fall to the soil surface within several months after the fire. These needles offer protection from soil erosion that is not fully understood. A laboratory experiment was conducted using rainfall simulation to determine the interaction of needle type and percent cover on soil erosion. Results indicate that needle type and percent cover greatly impact soil erosion processes. A log-decay relationship provided a good fit of the data. These relationships will be useful for the assessment of erosion potential after forest fires from a practical as well as a modeling standpoint.

Keywords:
Residue cover, Forest, Surface runoff, Erosion, Fires

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Effectiveness of Needle Cast from Burnt Conifer Trees on Reducing Erosion

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ABSTRACT

Surface cover affects soil erosion by decreasing the area susceptible to raindrop impact as well as overland flow by reducing runoff velocities and causing sediment deposition in detention storage areas. After wildfires in steep forest environments, there is often needle cast from partially burnt conifer trees. These conifer needles generally fall to the soil surface within several months after the fire. The effects of the needles on reducing erosion were examined in an indoor rainfall simulation experiment by determining the interactions between needle type and percent cover on sediment yield.

A modified Purdue-type rainfall simulator with a constant rainfall rate of 34 mm hr^{-1} suspended over a soil box 4 m long and 1 m wide tilted to a 40 percent slope was used to quantify runoff and erosion. Runoff and sediment yield were measured from two soil types (granitic and volcanic), two needle types (Douglas fir and ponderosa pine) with four surface cover amounts (0, 15, 40, and 70 percent), and four inflow rates (0, 1.5, 2.4, and 3.9 L min^{-1}).

Results demonstrate that an increase in both Douglas fir and ponderosa pine needle cover decreases sediment yield for all inflow rates. The Douglas fir needles were more effective than the ponderosa pine needles on reducing sediment yield. Increasing inflow rates decreased the effectiveness of needle cover. The exponential relationship between sediment yield and needle cover had correlation coefficients of 0.75 for the Douglas fir and 0.99 for the ponderosa pine needles. These results suggest that the shorter length of the Douglas fir needles (24 mm) had greater soil surface contact compared to the ponderosa pine needles (143 mm) thus providing better protection of the soil. These relationships will be useful for the assessment of erosion potential after forest fires from a practical as well as a modeling standpoint.

INTRODUCTION

Fire is a natural and important part of the disturbance regime for forested ecosystems especially in the western USA (Agee, 1993). Wildfires, which burn both small and large land areas, are often associated with lightning strikes from thunderstorms during the dry seasons and human-caused ignition (Agee, 1990). Fire effects on erosion are related to the effects of ground cover destroyed by fire and any ground cover that can occur due to natural or human activities after the fire. During fire, the consumption of ground cover (i.e. duff) exposes mineral soil, which can be subject to overland flow and raindrop impact. Ground cover usually consists of duff, grasses and forest liter on the ground surface.

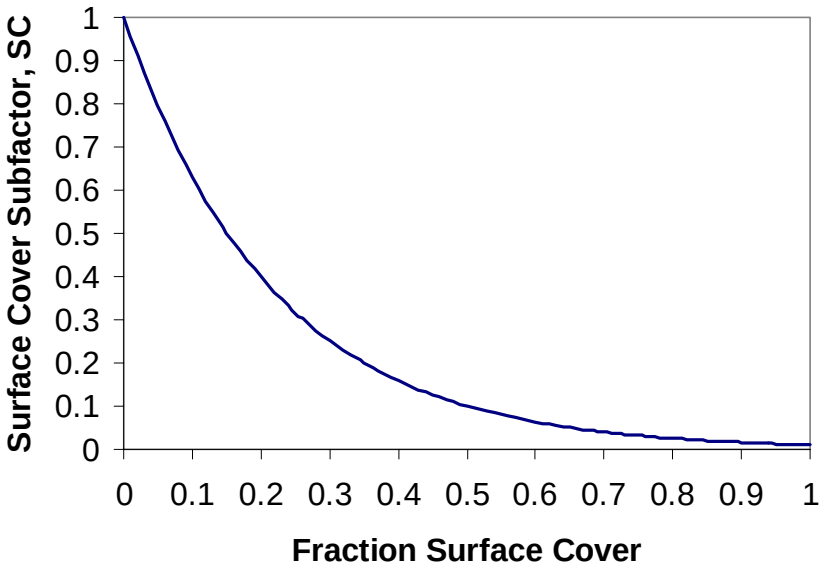
Surface cover affects soil erosion by decreasing the area susceptible to raindrop impact as well as reducing transport of runoff (Foster, 1982), and by causing deposition in ponded areas (Laflen, 1983). In current erosion models such as the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), or the Water Erosion Prediction Project (WEPP), cover is the most important factor in controlling erosion. In RUSLE, for example, a surface cover sub factor and three other sub factors are multiplied to calculate the effect of vegetation and management practices on the soil loss ratio (SLR), the ratio of soil loss from a condition determined by management or environment to that from a bare fallow condition (Wischmeier, 1975).

Surface cover (SC) relationships indicate a reduction in soil loss for a given fraction of surface cover (Equation 1).

$$SC = e^{(-b\ Fs)} \quad [1]$$

where b is the fitted coefficient and Fs is the fraction of surface cover. Data from an 8-year plot study at the Palouse Conservation Field Station near Pullman, WA indicate a b value of -4.6 (McCool et al., 1997) (Figure 1). Robichaud (1996) has shown similar relationships for post-fire conditions in forest environments.

Figure 1. Relationship of the fraction of surface cover and the surface cover subfactor developed for the Northwest Wheat and Range Region (McCool et al., 1997).



Wildfires generally burn in mosaic patterns with portions of the area burned in low, moderate and high severity conditions as described by Ryan and Noste (1983). There is often needle cast from partially burnt conifer trees within area of low or moderate fire severity. These needles generally fall to the soil surface within several months after the fire. There are primarily two types of conifer needles. The first types are long needles, usually bunched, and include species such as the ponderosa pine (*Pinus ponderosa*), coulter pine (*Pinus coulteri*), and whitebark pine (*Pinus albicaulis*). These are approximately 140 mm long, which curve and are generally in bundles of 2 to 5. This type of needle, because of the curved shape, tends to sit above the soil surface about 5 mm for the majority of their length. The second types are short and include Douglas fir (*tseudotsuga menziesii*), grand fir (*Abies grandis*), white spruce (*Picea glauca*), and tamarack (*Larix occidentalis*). These needles are approximately 25 mm, straight, and generally single which are in contact with the soil surface. Relationships between the diameter of the tree, scorch height, and density of the trees, to the mass of needles that fall to the soil surface after a wild fire are described by Moeur (1981) and Brown (1978).

Surface cover is measured in terms of a mass per unit area. This is a time consuming process and has been abandoned in favor of measuring percent cover. Models such as the WEPP and RUSLE use a relationship of soil loss to percent cover derived from the work done by Wischmeier and Smith (1978).

The USDA Forest Service and other land management agencies develop watershed rehabilitation plans with Burned Area Emergency Rehabilitation (BAER) teams after severe wildfires that intend to reduce the effects of soil erosion and flooding. Many factors are taken into consideration such as fire severity, climate, and values at risk during their assessment (Robichaud et al. In press). The effects of needle cast from partially burnt trees that may cover the ground, on reducing erosion has not been recognized during assessment of post-fire conditions. The objective of this study is to quantify effects of needle cover on sediment delivery for rain and upslope influences.

METHODS

Ponderosa pine and Douglas fir needles were collected from the Wenatchee National Forest in Washington State, in the fall of 1998 after the Twenty Five Mile Creek wildfire. In some areas after the fire, the trees were killed but the flames did not scorch the needles. The needles were collected from burnt trees by laying a tarp beneath the tree and raking or shaking the tree. Two surface soils were collected after wildfires from intensely burned sites where the entire forest floor (duff layer) was consumed by the fire. The first soil (Dystric Cryochrepts) was from the Salmon National Forest in Idaho State and the second soil (Alfic Vitrixerands) was collected from the Wenatchee National Forest in Washington State. Both soils were passed through a 10mm sieve to remove roots and large rocks then dried to approximately 10 percent gravimetric water content. The soil was placed into 4-m-long by 1-m-wide by 0.2-m-deep box on a porous soil filter fabric. The loose soil was then screed level, 10 mm from the top of the box frame. The soil was compacted to simulate a restrictive sub-surface zone and reach bulk densities found at the site the soil was taken from. This layer was then screed to 60 mm below the top of the box and compacted again. Additional sieved soil was placed on top and leveled with a double "U" shaped screed to form two channels or rills. The rill dimensions were approximately 30 mm at the sides and 50 mm in the middle from the top (slightly above the headwall) of the soil box, which corresponds to a 10 percent side slope. The division of the soil box was made to allow two rills to be formed side by side so that two treatments could be run simultaneously. The soil box was placed on an adjustable frame and a trough was placed at the lower edge to collect runoff from each side. The soil box was left in a level position and rained on at 18 mm hr^{-1} until ponding occurred (approximately 12 min for granitic soil and 25 min for volcanic soil), to consolidate loose aggregates and to bring surface soil water content to field capacity. The soil was then left to equilibrate for at least 12 but no more than 24 hours.

Following the equilibration period the soil box was adjusted to a 40 percent slope. Two inflow devices were positioned at the top of the soil box to introduce water at rates of 1.5, 2.4 and 3.9 L min^{-1}. The inflow simulates the effect of upslope contribution to the area investigated. To disperse the inflow evenly and reduce the cutting effect of the flow a dispersion mechanism was fixed at the top of the plot. The device was gravel glued to a metal plate that narrowed to a 100 mm outlet followed by a 50 mm length of nylon mesh screen.

Needles were weighed to approximate 15, 40 and 70 percent ground cover and spread evenly on the plot. The soil box was positioned under a modified Purdue-type rainfall simulator (Meyer, 1994). Rainfall was applied throughout the entire run at a rate of 34 mm hr^{-1}. For the first 10 minutes only rain was applied. Between 10 and 15 minutes 1.5 L min^{-1} inflow was added with continued rainfall. At 15 minutes the inflow was increased to 2.4 L min^{-1} and at 20 min the flow was increased to 3.9 L min^{-1}. The inflow and rain were stopped after 25 minutes or when

the plot began leaking from the bottom. Six timed runoff samples were taken during each rain and inflow combination to calculate sediment yield and inflow rate.

Statistical Design

The statistical design of the experiment is a balanced incomplete block (SAS Inst., 1989). Since the soil box cannot be of mixed soils the statistical analysis will not compare soil type. The basic treatments were 2 needle types (Douglas fir and ponderosa pine), and 4 cover amounts (0, 15, 40, and 70 percent). A balanced incomplete block design requires each treatment to appear with every other treatment thus, requiring 21 blocks or runs. The runs were also performed in random order and analyzed using SAS (1989).

RESULTS AND DISCUSSION

The results of this experiment indicate that needle cast decreases soil erosion. As needle cover increased so did their effectiveness at controlling erosion. As inflow increased the effectiveness of the needles decreased. Douglas fir needles protected both soils better than the ponderosa pine needles at the lower intensity inflow rates. However, on the volcanic soil at high inflow rates the ponderosa pine needles were more effective than the Douglas fir needle.

Main Effects - Granitic Soil

Sediment concentration, runoff, and sediment delivery for both soils were averaged for treatment main effects (Table 1). Note that significant treatment interactions occurred in all state variables and treatment effects may be masked or better explained through the interactions.

Sediment concentration was greater with ponderosa pine needle cover compared to Douglas fir needles however; runoff was greater with the Douglas fir cover. Sediment delivery is the product of sediment concentration and runoff; hence there was no difference in needle type for sediment delivered.

Percent needle cover affected sediment concentration and sediment delivery at every level, decreasing soil loss as needle cover increased. Runoff was significantly lower at the high cover, whereas at all other needle cover amounts, runoff was similar.

Infiltration rates did not change as inflow was added. The granitic soil had a mean infiltration rate of 26.6 mm hr^{-1} and the volcanic soil was 29.6 mm hr^{-1}.

The granitic soil eroded quickly at the highest inflow rate (3.9 L min^{-1}). Many soil boxes leaked during this inflow before the completion of the run. For this reason only inflow rates of 1.4 and 2.5 L min^{-1} were reported. Interrill erosion processes dominated the soil loss when only simulated rainfall was applied. This was visually verified during simulation when no rills were formed from the top to the bottom of the plot. Sediment concentrations were significantly higher when inflows were introduced, indicating that rill erosion dominated the erosion processes. Runoff increased significantly as inflow increased; hence sediment delivery also increased as inflow rates increased.

Main Effects - Volcanic Soil

The volcanic soil contained centimeter sized pumice gravel that had a density less than water (1.0 g cm^{-3}). During runoff this “popcorn” pumice floated and would interact with needle cover causing debris to form thus slowing runoff.

Sediment concentration, runoff, and sediment delivery were greater with Douglas fir needle cover compared to ponderosa pine needles. The ponderosa pine needles tended to trap more pumice than the Douglas fir, creating dams and pools and thus increasing infiltration.

As needle cover increased, sediment concentration decreased and runoff decreased but only at 70 percent cover. Sediment delivery was significantly lower only at 70 percent cover.

Inflow rates increased runoff and like the granitic soil, sediment concentration increased significantly with the addition of flow. Sediment delivery increased for every increase in inflow. Infiltration rates were 29.6 mm hr^{-1} and did not change at different inflow rates.

Table 1. Sediment concentration, runoff, and sediment delivery for the granitic and volcanic soils main effects, degrees freedom and levels of probability.

			Granitic Soil			Volcanic Soil		
			Sediment Concentration g L^{-1}	Runoff L min^{-1}	Sediment Delivery g min^{-1}	Sediment Concentration g L^{-1}	Runoff L min^{-1}	Sediment Delivery g min^{-1}
NEEDLE (N)								
Douglas fir			194b	1.83a	440	168a	2.32a	506a
ponderosa pine			213a	1.75b	441	145b	2.17b	392b
COVER (C)								
0%			307a	1.83a	623a	186a	2.32a	509a
15%			257b	1.85a	565b	186a	2.21ab	514a
40%			177c	1.82a	425c	153b	2.28ab	464a
70%			73d	1.66b	146d	101c	2.16b	309b
INFLOW (I)								
0 L min^{-1}			109b	0.56c	62c	44c	0.28d	18d
1.5 L min^{-1}			250a	2.05b	551b	187b	1.93c	398c
2.4 L min^{-1}			251a	2.75a	707a	187b	2.67b	512b
3.9 L min^{-1}			-	-	-	208a	4.09a	868a
	df-G	df-V						
N	1	1	***	***	NS	***	***	***
C	3	3	***	***	***	***	*	***
I	2	3	***	***	***	***	***	***
N*C	3	3	***	***	***	NS	*	**
N*I	2	3	NS	NS	NS	**	NS	**
C*I	6	9	***	***	***	***	***	***
N*C*I	6	9	***	***	***	***	*	**

*, **, ***, Significant at 0.1, 0.05, and 0.01 levels of probability, respectively.
Different letters within columns indicate significant differences at $\alpha = 0.05$ probability and less as tested by Fishers protected LSD.
Df= degrees freedom, NS = not significant, G = granitic soil, V = volcanic soil

Needle, Cover, and Inflow Interactions

There were differences ($\alpha = 0.01$) in the three-way interaction for both soils in sediment concentration, runoff, and sediment delivery; except runoff on the volcanic soil was only at the $\alpha = 0.05$ (Table 1). In order to evaluate the effectiveness of needle cover on soil loss it is necessary to examine the interactions between needle type, percent needle cover, and inflow rates. To facilitate evaluation of the data and compare these results with other studies, the sediment delivery was normalized and percent cover is presented as a fraction of cover. This was accomplished by dividing the sediment delivery values of all treatments by sediment delivery values for the no needle cover plot.

Generally increasing needle cover decreased sediment delivery (Figures 2-5). However, the same relationship did not hold for the Douglas fir needle on the volcanic soil at the 3.9 L min^{-1} inflow rate. In this case there was no difference in cover treatment and possibly a trend in greater erosion. This was due to the flow increasing incrementally. During a run the flow was increased incrementally. During the low inflow rates sediment and the "popcorn" pumice were trapped behind the ponderosa pine needles. When the flow was increased to 3.9 L min^{-1} the runoff carried the sediment that was previously deposited.

As flow increased for each combination of needle and soil type the effectiveness of cover decreased. On the granitic soil when no inflow was introduced, needle cover would be 15 and 30 percent for the Douglas fir and the ponderosa pine, respectively, to reduce soil loss by half of that with no needle cover. On the volcanic soil needle cover would be 10 percent for both the Douglas fir and the ponderosa pine to reduce soil loss by half of that with no needle cover.

Figure 2. Relationship of normalized sediment delivery and needle cover fraction for Douglas fir needles on a granitic soil.

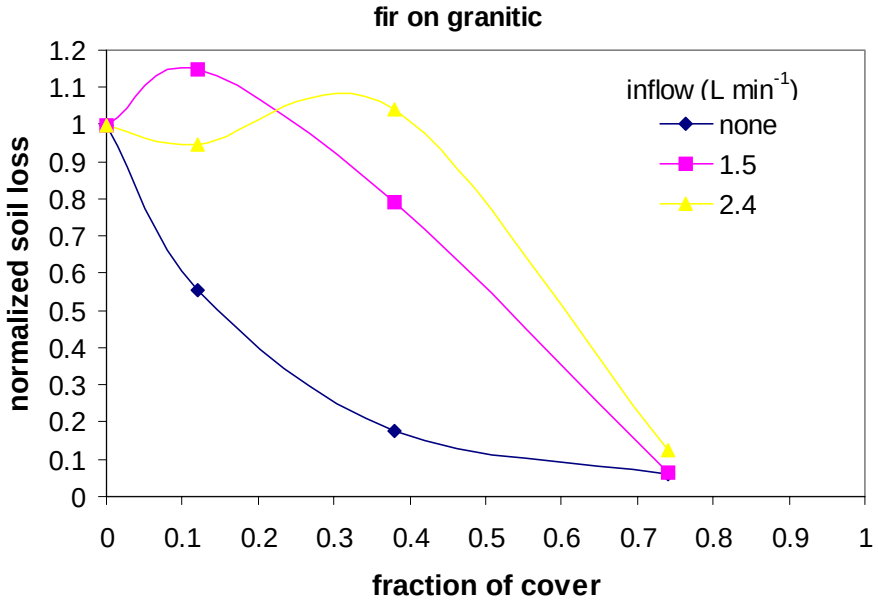


Figure 3. Relationship of normalized sediment delivery and needle cover fraction for ponderosa pine needles on a granitic soil.

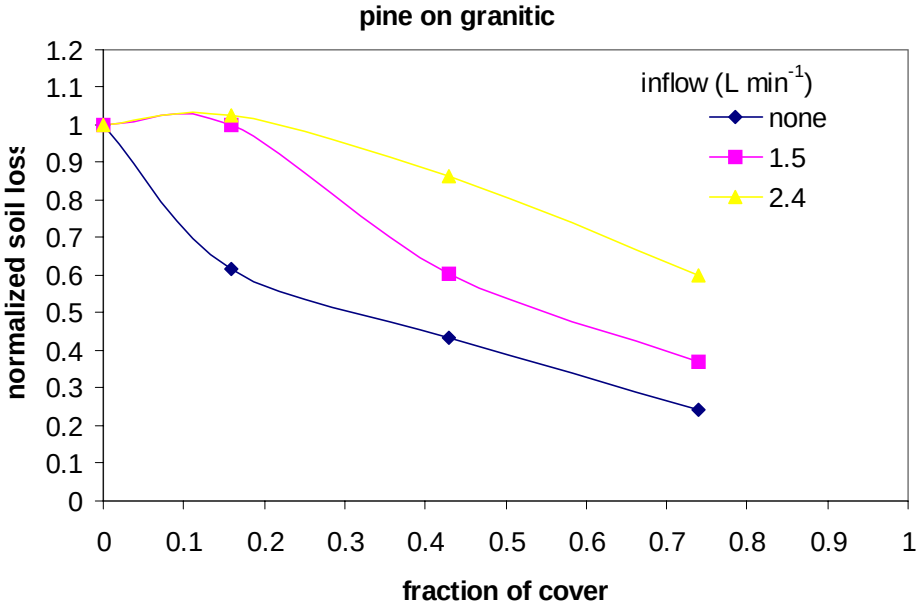


Figure 4. Relationship of normalized sediment delivery and needle cover fraction for Douglas fir needles on a volcanic soil.

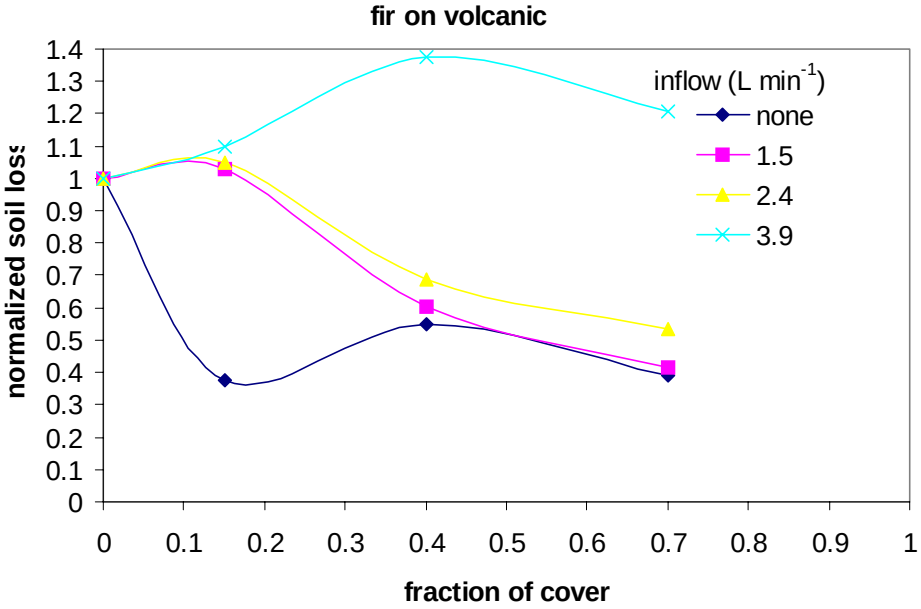
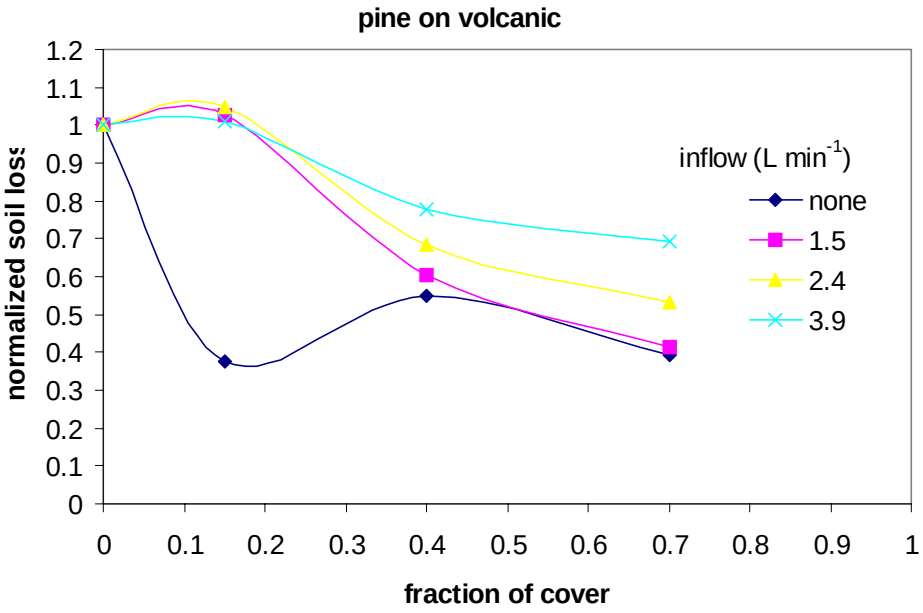


Figure 5. Relationship of normalized sediment delivery and needle cover fraction for ponderosa pine needles on a volcanic soil.



When rainfall only was used to produce runoff, there were differences at the low cover amounts in sediment delivery and less differences as the cover was increased on the granitic soil (Table 2). This has also been noted in other studies done comparing surface cover and soil loss (Wischmeier and Smith 1975, and McCool et. al 1997). Sediment concentration decreased significantly with increasing needle cover for all treatments except between 40 and 70 percent from Douglas fir cover, and between 15 and 40 percent ponderosa pine cover. Runoff amount did not change with needle cover. Sediment delivery decreased with increasing cover but not significantly. Observations verified that the Douglas fir needles were in closer contact with the soil surface than the ponderosa pine needles adding more protection both from raindrop splash as well as causing deposition in ponded areas.

The volcanic soil responded to needle cover much the same as the granitic soil under rainfall only. Sediment concentration decreased for each level of cover for the Douglas fir but not the ponderosa pine needles. Runoff only decreased under the fir needles at the 40 percent cover and decreased significantly at the 15 percent cover for the ponderosa pine needles. Sediment delivery decreased with increasing cover but not significantly (Figures 4 and 5).

Table 2. Sediment concentration, runoff, and soil loss for the granitic and volcanic soil with rainfall only.

	Granitic Soil						Volcanic Soil					
	Douglas Fir			Ponderosa Pine			Douglas Fir			Ponderosa Pine		
needle cover (%)	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}
0	223a	0.58a	128a	223a	0.58a	128a	77a	0.36a	34a	77a	0.36a	34a
15	108b	0.58a	64a	121b	0.57a	70a	47a	0.32a	19a	30c	0.16a	12a
40	34c	0.58a	20a	93b	0.53a	49a	21ab	0.22a	7a	52b	0.26a	18a
70	14c	0.56a	7a	59c	0.54a	31a	13b	0.25a	6a	32c	0.28a	12a

Different letters within columns indicate significant difference at $\alpha = 0.05$.

A rill formed during inflow of 1.5 L min^{-1} with 15 and 40 percent needle cover. At 70 percent cover the rill did not always form. Sediment concentration decreased with each increase in surface cover, except between 0 and 15 percent with Douglas fir needle cover on the granitic soil (Table 3). Runoff decreased as needle cover increased for all cover amounts except at 40 and 70 percent ponderosa pine needle cover where they were the same. Sediment delivery decreased with increasing cover except where 15 percent Douglas fir needles were compared with no needle cover.

Sediment concentration was greater for 15 percent Douglas fir needle cover than no cover on the volcanic soil (Table 3). Observations indicate that a "priming" effect occurred when the rain saturated the soil and then a subsequent addition of inflow caused an increase in the sediment concentration. Sediment delivery tended to decrease with increasing cover. However, when there was 15 percent Douglas fir needle cover, the sediment delivery increased compared to no cover.

Table 3. Sediment concentration, runoff, and soil loss for the granitic and volcanic soil with 1.5 L min^{-1} inflow.

	Granitic Soil						Volcanic Soil					
	Douglas Fir			Ponderosa Pine			Douglas Fir			Ponderosa Pine		
needle cover (%)	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}
0	389a	2.29a	935a	389a	2.29a	935a	262b	2.25a	638a	262a	2.25a	638a
15	399a	2.22a	909a	306b	2.10b	648b	300a	2.22a	680a	202b	1.69a	347b
40	171b	2.06b	364b	192c	1.79c	346c	174c	2.01a	385b	142c	1.71a	244b
70	21c	1.86c	39c	129d	1.79c	232d	49d	1.75a	86c	107c	1.60a	172b

Different letters within columns indicate significant difference at $\alpha = 0.05$.

As inflow increases there is less effect of cover on soil erosion as seen in figures 2-5. The ability of the needles to slow runoff becomes more a function of their contact with the soil surface or their ability to withstand the shear force of the rill water. Douglas fir needles have more soil contact for a given percent needle cover, whereas the ponderosa pine needles are longer and interact with each other to form a more stable cover. Sediment concentration was only different at 70 percent Douglas fir needle cover compared to other needle cover amounts on the granitic soil at an inflow rate of 2.4 L min^{-1} (Table 4). However, the ponderosa pine needles significantly reduce sediment concentration at 40 and 70 percent needle cover. Sediment delivery was lowest at 70 percent needle cover for both needle types. The erosion mechanics in the WEPP model assume that cover can resist a given amount of shear (Flanagan and Livingston, 1995). These data would tend to support that assumption.

Sediment concentration was lowest at the high cover for the Douglas fir needles on the volcanic soil and lowest for both 40 and 70 percent needle cover of the ponderosa pine needles (Table 4). This indicates the effectiveness of the ponderosa pine needles compared to the Douglas fir needles at higher inflow rates. Runoff tended to be the same for the ponderosa pine needles except at 70 percent cover where runoff was lower. The higher runoff rate for 70 percent Douglas fir needle cover indicates the ineffectiveness of cover on infiltration at the higher inflow rates. Sediment delivery was significantly lower only at 70 percent needle cover for both needle types.

Table 4. Sediment concentration, runoff, and soil loss for the granitic and volcanic soil with 2.4 L min^{-1} inflow.

	Granitic Soil						Volcanic Soil					
	Douglas Fir			Ponderosa Pine			Douglas Fir			Ponderosa Pine		
needle cover (%)	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}
0	308a	2.62b	807b	308a	2.62b	807ab	190b	2.66b	506bc	190b	2.66a	506ab
15	306a	2.70b	831b	301a	2.92a	869a	225ab	2.62b	594b	233a	2.71a	641a
40	322a	3.25a	1087a	251b	2.68b	686b	255a	2.93a	754a	147c	2.59a	393bc
70	32b	2.63b	85c	183c	2.60b	483c	144c	2.83a	437c	111d	2.38b	264c

Different letters within columns indicate significant difference at $\alpha = 0.05$.

At the highest inflow rate (3.9 L min^{-1}) Douglas fir needle cover did not affect sediment concentration on the volcanic soil (Table 5). However, ponderosa pine needle cover at 70 percent cover reduced sediment concentration by 36 percent. Needle cover did not affect runoff and sediment delivery only reflected the differences in sediment concentration.

Table 5. Sediment concentration, runoff, and soil loss for the volcanic soil with 3.9 L min^{-1} inflow.

	Douglas Fir			Ponderosa Pine		
needle cover (%)	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}	sed. conc. g L^{-1}	runoff L min^{-1}	sed. del. g min^{-1}
0	213b	4.01b	858b	213ab	4.01a	858ab
15	237ab	3.89b	925b	216a	4.09a	892a
40	257a	4.43a	1181a	177b	4.05a	728b
70	213b	4.36a	990b	129c	3.88a	509c

Different letters within columns indicate significant difference at $\alpha = 0.05$.

Exponential regression fits of normalized soil loss and fraction of cover are shown in Table 6. The granitic soil results indicate that as the inflow increased the relationship became more linear and the correlation coefficient became smaller. The fir needles provide the same amount of protection as seen in agricultural studies of crop residue cover that is generally short and flat (McCool et al., 1997 and Wischmeier and Smith 1978). The ponderosa pine needles are longer and form an arc that does not allow the entire length of the needle to be in contact with the soil surface. This lack of contact does not allow runoff to pond behind the needles thus slowing flow and increasing infiltration.

The volcanic soil results show that as inflow increased the relationship between soil loss and cover became more linear (less negative). Correlation coefficients were very low in some cases indicating that this may not be the best relationship for this soil type. The ponderosa pine needles proved more effective at lowering sediment delivery at the higher inflow rates compared to the Douglas fir needles. The interaction between the "popcorn" pumice and ponderosa pine needles may account for this.

Table 6. Exponential regression fits to fraction of cover and normalized soil loss for soil, needle type, and inflow rate.

	Granitic Soil				Volcanic Soil			
	Douglas Fir		Ponderosa Pine		Douglas Fir		Ponderosa Pine	
Inflow L min^{-1}	**Exponent**	**R^2**	**Exponent**	**R^2**	**Exponent**	**R^2**	**Exponent**	**R^2**
none	-4.00	0.98	-1.95	0.97	-2.36	0.89	-1.55	0.05
1.5	-2.98	0.76	-1.26	0.93	-1.25	0.41	-1.21	0.92
2.4	-2.15	0.69	-0.57	0.83	0.36	0.06	-0.87	0.89
3.9					0.41	0.37	-0.53	0.91

CONCLUSIONS

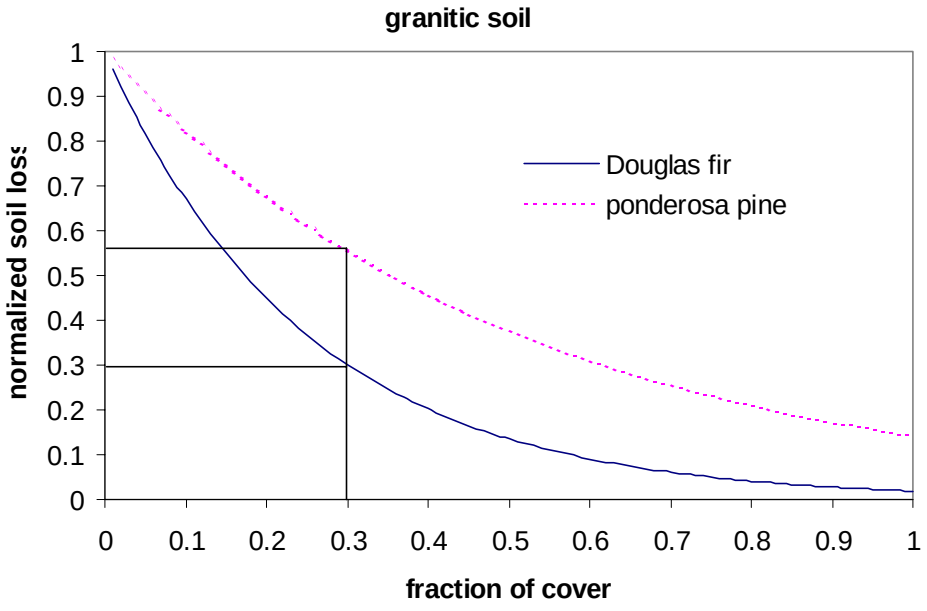
Under simulated rain conditions, needle cover protected the soil from erosion. The relationship between soil loss and percent cover for a granitic soil can be illustrated by equation 4 and 5 for the Douglas fir and ponderosa pine needles respectively:

$$SL = e^{-4.00x} \quad [4]$$

$$SL = e^{-1.95x} \quad [5]$$

Where SL is normalized soil loss and x is the fraction of needle cover on the soil surface. Graphically this relationship indicates at 30% cover of the fir and pine needles, only 30% and 57% respectively, of the erosion would occur had the soil been bare respectively.

Figure 6. Predicted relationship of soil loss and percent cover for Douglas fir and ponderosa pine on a granitic soil. The difference in normalized soil loss is shown for a 30 percent cover of Douglas fir and ponderosa pine needles.



Results from the volcanic soil were somewhat less clear. However, similar relationships do exist. Although the total sediment delivery was much less, the protection offered by conifer needles was not as apparent.

Forest managers, that make decisions concerning soil erosion after wildfires, may be able to use this information when evaluating onsite conditions as they design mitigation practices. When low and moderate fire severity conditions exist after a wildfire, there may be ample needle cast that may fall to protect the soil from erosion. Thus, the role of natural occurring events (needle cast) after the fire can now be quantified in reducing erosion. The BAER teams could use these findings with estimates of needle cast from other work to approximate the ground cover amounts that could occur and subsequent reduction in erosion.

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