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An evaluation of three wood shred blends for post-fire erosion control using indoor simulated rain events on small plots

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ABSTRACT

The assessment teams who make post-fire stabilization and treatment decisions are under pressure to employ more effective and economic post-fire treatments, as wild fire activity and severity has increased in recent years across the western United States. Use of forest-native wood-based materials for hillslope mulching has been on the rise due to potential environmental, erosion control efficacy, and economic incentives. One concern regarding use of woody materials prepared on or near burned sites is the wide range in the size distribution of the shredded materials. We tested three blends of shredded woody materials, each blend containing different amounts of fine (less than 2.5 cm in length) woody particles. The blends (AS IS with 24% fines, MIX with 18% fines, and REDUCED with 2% fines) were applied at 50 and 70% ground cover to 5-m^2 plots containing burned soil placed at 40% slope and evaluated through simulated rain events which consisted of a rain only, a rain plus low flow, and a rain plus high flow period. The REDUCED blend was the optimum for both runoff and sediment concentration reduction under conditions of rainfall and rainfall plus concentrated flow. There was no difference between application rates of 50 and 70% for either of the rainfall plus concentrated flows tested. Our recommendation was that 50% ground cover of the REDUCED blend was adequate for both rainfall and sediment reduction compared to a bare soil. The other two blends were effective in reducing runoff but not sediment concentration compared to a bare soil. The wood shred manufacturing and blending process resulted in two statistically different relationships between application rate and ground cover; relationships were controlled by the amount of fines.

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1. Introduction

Wildland fires have become larger and more severe in the western United States, with the 2004–2007 fire seasons being the largest on historical record in terms of acres burned, total number of fires, and suppression costs (USFS, 2008). Unlike undisturbed forest soils, burned forest soils are highly susceptible to runoff and erosion. Forest fires remove both above ground vegetative cover and below ground small roots, destroy the protective duff layer, and often induce soil water repellency, all of which contribute to lower infiltration rates, increased runoff, and increased sediment production (Benavides-Solorio and MacDonald, 2001, 2005; Johansen et al., 2001; Robichaud et al., 2000; Smith and Dragovich, 2008).

Burned Area Emergency Response (BAER) teams are responsible for estimating post-fire risks and, when necessary, administering post-fire rehabilitation treatments to mitigate these effects. Increased fire activity puts more pressure on BAER teams to employ the most effective and economically viable post-fire rehabilitation treatments available. Prompt application of protective ground cover is perhaps the most effective rehabilitation treatment available and studies have shown the efficacy of various types of ground cover materials (Cerda and Doerr, 2008; Foltz and Copeland 2009; Wagenbrenner et al., 2006). Cover materials protect the exposed soil from wind and raindrop impact, help to retain moisture at the soil surface by reducing evaporative heat transfer, slow and divert runoff, and trap erodable material entrained in runoff. If a cover material is to be used on a large scale, such as for post-fire rehabilitation, it must be: (1) cost-effective, (2) ecologically sustainable and environmentally benign, (3) widely available and easily transported, and (4) durable and stable enough to provide protection until natural ground cover has been reestablished. The current challenge is to identify effective ground covers that maximize these criteria.

Mulch application is an effective post-fire rehabilitation method that provides immediate ground cover to exposed burned soil. Agricultural straw is currently the most common mulching material for BAER treatments. It is reasonably effective in reducing erosion; however, straw is (1) not native to forested areas and may introduce non-native vegetation and residual pesticides, (2) not stable under high wind conditions, and (3) less effective for severe storms (Copeland et al., 2009; Robichaud et al., 2000; Wagenbrenner et al., 2006). Also, the increasing cost and decreasing availability of straw may impact its use as a post-fire treatment (Gorzell, 2001). There is a growing consensus

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among land managers that a mulch product derived from native forest materials would be preferable to agricultural straw.

Work has recently been done to evaluate forest-native mulching materials (Foltz and Copeland, 2009; Foltz and Dooley, 2003; Yanosek et al., 2006). Yanosek et al., (2006) found wood strands, an engineered material produced from veneer waste, to be a good alternative to agricultural straw. The wood strands reduced erosion by over 90% compared to bare soil from two different soil types during rainfall simulation tests (Yanosek et al., 2006). These results were comparable to those from agricultural straw treatments (Burroughs and King, 1989). Additionally, mulches made from woody materials may offer other benefits such as nitrogen immobilization which reduces the adverse impact on water quality (Homyak et al., 2008). Wood strands are currently manufactured at a single facility and are a more expensive treatment than agricultural straw.

Mulch derived from on-site woody materials could reduce manufacturing and transportation costs, and thus, provide a more cost-effective alternative. Wood shreds are one such product and have shown promise as an effective mulching material (Foltz and Copeland, 2009). Wood shreds are created by shredding on-site woody materials such as tree limbs and small-diameter trees. Wood shreds were developed by the USDA Forest Service Missoula Technology and Development Center to provide an alternative to traditional mulching materials such as agricultural straw, hydromulch, and wood chips. Groenier and Showers (2004) discussed the advantages of using portable shredding equipment to produce wood shreds for on-site erosion control.

While wood shreds have demonstrated operational promise as an erosion control alternative, further evaluation is necessary to optimize wood shreds for large-scale post-fire erosion control. Wood shreds have not been evaluated on burned soils and their post-fire erosion reduction efficacy is difficult to extrapolate from studies done on unburned soil, as erosion and runoff mechanics differ for burned and unburned soils (Cerda and Doerr, 2008; Robichaud et al., 2007; Robichaud, 2000; Smith and Dragovich, 2008). For example, fire activity can alter hydrologic structure through deposition of a wettable ash layer at the soil surface and creation or enhancement of soil water repellency due to volatilization of organic compounds just below the soil surface.

Additionally, standard shred manufacturing produces a mixture that contains a large proportion of fine (less than 2.5 cm in length) material (Foltz and Copeland 2009). We hypothesize that these fine materials have little effect on erosion and are likely to be washed downslope during the first runoff event. Further, application costs may increase because the fines add to the overall weight of the material and more weight must be applied in order to achieve an effective ground cover. A material with fewer fines may be more cost-effective for large-scale application if (1) it can be produced with little extra cost or alteration to existing equipment and (2) a low fines shred material is equally effective in reducing erosion.

The purpose of this study was to test several blends of wood shreds through small-scale laboratory rainfall simulation experiments to determine the most appropriate blend for use in post-fire BAER treatments. This study served as a preliminary step to identify the optimal wood shreds blend for further testing in a larger field experiment at the hillslope scale. The goals of this study were to (1) determine differences in the material size distribution of three wood shred blends and the impact of those differences on the required mass application rates to achieve a desired ground cover, (2) determine the statistical significance of each wood shred blend in reducing runoff, sediment concentration, and rill formation from a burned soil, and (3) determine which wood shred blend best reduces runoff and sediment concentration.

2. Methods and materials

Rainfall events were simulated with an indoor simulator between August 2007 and April 2008 at the U.S. Department of Agriculture (USDA) Forest Service, Rocky Mountain Research Station in Moscow, Idaho. We tested the erosion control efficacy of three blends of wood shreds applied at 50 and 70% ground cover. The study used a completely randomized design with six replications of each treatment combination, including a bare soil treatment as a control, which gave a sample size of 42 rainfall simulations. Wood shreds effectiveness was assessed based on runoff, sediment concentrations, and rill formation during the simulated storms.

2.1. Simulations: plot preparation

A burned sandy loam soil collected from the Tripod Fire Complex near Winthrop, Washington, USA was used for the simulations (Table 1). The soil was collected from an area of high burn severity six months after the fire. The top 20 cm of surface soil included a layer of ash approximately 4 cm thick, and had neither duff nor small roots. The parent material was granitic-based glacial till that was overlain with volcanic ash. The collected soil was sieved through a 3/8-in mesh screen, well-mixed, and air-dried prior to simulations.

A steel-framed plot 1.24 m wide, 4 m long, and 0.2 m deep was filled with the burned soil and leveled with a trapezoidal-shaped screed (80 mm wide and 5% side slopes) to eliminate edge effects. Drainage of the plot was achieved with a metal screen with 12-mm openings covered by geotextile fabric that allowed water to penetrate the bottom face of the plot. Soil bulk density was measured prior to rainfall using a Troxler Model 3440 nuclear gauge. Gravimetric soil water content was measured before and after rainfall by oven drying soil samples at 110 ºC for 24 h (ASTM Standard D4959, 2007).

The plots were pre-wet using a rain intensity of 51 mm h^{-1} for 5–10 min, until the soil surface became saturated, but before ponding occurred. The plots were pre-wet at a slope of 0% to facilitate settling of the soil and to prevent mass failure due to the steep slope used for the simulations. Prepared soil plots were attached to a steel frame at 40% slope for rainfall and overland flow simulations (Fig. 1). This slope was chosen to be representative of the steep hillslopes commonly found in forested areas of the western U.S.

A pre-determined mass of wood shreds, based on trial cover count experiments for each blend, was applied to the plot by hand to achieve the desired cover amount of either 50 or 70% cover. Actual wood shred coverage was determined from point-count measurements made with a clear grid that contained 605 points spaced 25 mm apart. Wood shreds were then added or removed as necessary to ensure that the actual cover amount on the plot was within five percentage points of the desired cover amount. A relationship of the form

$$F_c = 1 - e^{-A_m M} \qquad (1)$$

was predicted from the observed data based on Gregory (1982), where F_c is the fraction of soil covered, M is the application rate, and A_m is the area covered by one average wood shred per mass of one average wood shred.

Table 1
Soil physical properties.

Parameter	Units	n	Mean	s
Sand fraction	%	9	66	3.0
Silt fraction	%	9	35	3.1
Clay fraction	%	9	0.18	0.32
D_{84}	mm	9	1.1	0.17
D_{50}	mm	9	0.14	0.02
D_{16}	mm	9	0.02	0.00
Bulk density	g cm^{-3}	42	1.1	0.03
Gravimetric water content (pre-rain)	%	42	12	2.8

s = standard deviation, n = sample size.
Soil particle size analyses performed by wet sieving (ASTM Standard D422-63 (2007)).