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Evaluating the effectiveness of wood shred and agricultural straw mulches as a treatment to reduce post-wildfire hillslope erosion in southern British Columbia, Canada

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ABSTRACT

After the 2009 Terrace Mountain fire near Kelowna, BC, Canada, wood shred and agricultural straw mulch effects on post-fire runoff and sediment yields were compared using three experimental techniques: rainfall simulations on 1-m^2 plots, concentrated flow (rill) simulations on 9-m long plots, and sediment yields from natural rainfall on 30-m^2 plots. All experimental plots were located on and along a planar hillslope burned at high severity. Experiments were conducted once a year for three consecutive years beginning in Sep 2009, except for the rainfall simulations which only were conducted the first two years. Although results varied by experiment and time since fire, both agricultural straw and wood shred mulch treatments performed similarly for reducing runoff and sediment; thus were combined into a single "treated" class for analyses. The mulch treatments were effective in reducing sediment yields as compared to the controls in all three experiments in 2009. In the rill simulation experiment, the mulch treatments significantly reduced overland flow velocity and increased the proportion of overland flow that infiltrated the soil before reaching the plot outlet. The elapsed time since the fire, which was strongly related to the increase in vegetative ground cover, was a significant factor for predicting sediment yields in the statistical models. Favorable spring rainfall in 2010 and 2011 supported rapid regrowth of vegetation, which recovered similarly on all plots regardless of treatment. The runoff and sediment yields on the treated plots were similar to those measured on the control plots a year later; we concluded that the mulch was, in effect, a surrogate for a year of recovery. Given that agricultural straw mulch is an established and effective post-fire hillslope treatment, it was important to find that wood shred mulch was similarly effective in reducing post-fire runoff and sediment yields. Thus, the choice of agricultural straw or wood shreds for a post-fire mulch treatment may be based on the performance characteristics (longevity, potential to carry invasive species seeds, cost, etc.) that best fit the needs of the site.

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1. Introduction

Forested slopes that have been burned at high severity can experience significant increases in post-fire runoff, flooding, and erosion that may put human life and safety, infrastructure, buildings, drinking water quality, aquatic habitat, and valued natural and cultural resources at risk for damage or loss (Kunze and Stednick, 2006; Lane et al., 2006; Shakesby and Doerr, 2006; Moody et al., 2008; Moody and Martin, 2009; Silins et al., 2009). Although wildfires are fairly common in the inland forests of south-central British Columbia (BC), Canada, no large post-fire responses had been documented prior to the severe wildfire season of 2003 when debris flows and other erosion events caused significant damage to highways, houses, and aquatic habitat (Jordan and Covert, 2009). Given the warmer temperatures, earlier spring snow melt, the large and expanding area of beetle-killed trees, and other effects of climate change, the number and severity of wildfires in the southern interior of BC is likely to continue to increase (Haughian et al., 2012). In addition, the number of people living in and around forested areas continues to increase (Peter et al., 2006). Land managers in BC, like their counterparts in other fire prone areas around the world, are expanding and systematizing post-fire assessment and use of treatments to reduce runoff, flooding, and erosion from burned areas (Jordan, 2011).

Studies conducted over the past decade have identified key factors that influence the magnitude of the potential post-fire hydrologic response: 1) the amount of ground cover or, conversely, the amount of bare soil exposed (Benavides-Solorio and MacDonald, 2005); 2) the rainfall intensity (Benavides-Solorio and MacDonald, 2005; Moody and Martin, 2009); 3) the amount and degree of soil water repellency (DeBano, 2000; Shakesby and Doerr, 2006; Doerr et al., 2009); and 4) the time since the fire (Gimeno-García et al., 2007). Many of these factors have been incorporated into the soil burn severity classification system—a designation of soil disturbance based on residual ground cover, ash color and depth, effects on soil structure and fine roots, and changes in soil water repellency

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(Neary et al., 2005; Parsons et al., 2010). Several studies have correlated the degree of soil burn severity with the magnitude of the post-fire response (e.g., Doerr et al., 2006; Moody et al., 2008).

The relative effect of individual factors on post-fire hydrologic response is not well understood and may vary between regions, sites, vegetation, and soil types. Yet, understanding these relative effects is needed to predict where post-fire erosion will likely occur and design effective hillslope treatments to mitigate the post-fire responses. Despite the interrelationships among the factors related to post-fire responses, the importance of ground cover seems the least ambiguous in its effect in reducing post-fire hillslope erosion rates. Areas burned at low and moderate burn severity have greater residual cover and lower post-fire erosion rates than areas burned at high severity. Given that mulches (agricultural straw, wood products, hydromulch, etc.) can provide immediate ground cover for exposed soil, they are increasingly being applied as post-fire hillslope treatments to reduce rain drop impact, runoff, and erosion (Wagenbrenner et al., 2006; Bautista et al., 2009; Robichaud et al., 2010a). Some short-term (12–24 months) post-fire treatment effectiveness studies have reported 48–99% lower sediment yields from research hillslope plots or swales treated with agricultural straw mulch as compared to untreated controls (Badia and Marti, 2000; Dean, 2001; Wagenbrenner et al., 2006; Rough, 2007; Groen and Woods, 2008).

Aerial application techniques for agricultural straw mulch have made it possible to apply mulch more efficiently and to treat inaccessible burned areas (Napper, 2006). With increasing use of agricultural straw mulch as a post-fire hillslope treatment, some of the drawbacks have become apparent. These include redistribution by wind, possible hindrance of native vegetation regrowth, and weed contamination (Robichaud et al., 2003; Beyers, 2004; Bautista et al., 2009). Other dry mulches made from native forest materials, have been developed, tested, and in some cases, applied as post-fire hillslope treatments. However, agricultural straw remains the most commonly used post-fire mulch because it is generally available from agricultural lands near many fires, less costly than wood-based mulches, and lighter-weight and therefore, less expensive to transport and aerially apply than wood-based mulches.

Wood mulches have been developed from wood manufacturing waste (e.g., wood strands such as WoodStraw®, Forest Concepts, Inc., Auburn, WA), wood shreds or wood chips made from burned trees or forest thinning operations, and shredded forest floor material from nearby unburned areas (Bautista et al., 2009; Robichaud et al., 2010a). Although these wood-based mulches are unlikely to harbor non-native seeds, their greater density can increase the cost of transportation to the site and aerial application as compared to straw mulch (i.e., necessitate more round trips from the staging area and/or the use of aircraft with larger payload capacities). Laboratory studies established that wood strands have greater resistance to wind displacement as compared to agricultural straw (Copeland et al., 2009), and both wood strands and wood shreds provide equal or greater protection from erosion as compared to agricultural straw mulch at equal areal coverage rates (Yanosek et al., 2006; Foltz and Wagenbrenner, 2010). Foltz and Wagenbrenner (2010) reported that a 50% cover of wood shred mulch, with small (<25 mm length) pieces removed by sieving, reduced sediment yields nearly as well as 70% cover when it was tested using indoor rainfall and overland flow simulations.

In a recent field study, manufactured wood strands and agricultural (wheat) straw were tested on burned hillslope plots at two sites—the Colorado Front Range and south-central Washington (Robichaud et al., 2013). Although both mulch treatments increased total ground cover to more than 60% immediately after application, the wheat straw mulch cover decreased nearly twice as fast as the wood strand mulch. Wood strand mulch significantly reduced sediment yields at both sites and the wheat straw mulch significantly reduced sediment yields at the Washington site but not at the Colorado site. In addition, wood strands reduced sediment yields for up to 4 years (Robichaud et al., 2013).

Given that the post-fire erosion potential is greatest immediately after the fire and decreases over time, field tests of post-fire treatments are best accomplished immediately after a wildfire. Yet results from post-fire experiments can be inconclusive if the natural rainfall characteristics during the first few years of the experiment are significantly below normal—a common occurrence as drought cycles often coincide with increases in wildfire ignitions. The use of simulated rainfall and concentrated flow (rill) experiments to field-test post-fire treatments provides opportunities for researchers to garner comparable runoff and erosion information while controlling the timing of the experiments and the characteristics of the rainfall and/or overland flow applied to the plots (Robichaud et al., 2010b). In addition, the inter-rill and rill erodibility parameters (K_i and K_r, respectively) of the burned soil can be calculated from rainfall and rill simulations and these values are used in predictive post-fire erosion models (Robichaud et al., 2007; Wagenbrenner et al., 2010). Although the information from simulations is useful, runoff and erosion from natural rainfall cannot be fully captured in simulations. Thus we used two simulation experiments (rainfall and rill) to individually evaluate treatment effects on inter-rill and rill erosion. We also examined treatment effectiveness on the combined processes of hillslope erosion by measuring sediment yields from natural rainfall on hillslope plots.

This study was initiated immediately following the 2009 Terrace Mountain wildfire in southern British Columbia to compare the effects of wood shred and agricultural straw mulches on post-fire hydrologic responses on hillslopes with high soil burn severity. Specific objectives were to determine the effects of wood shred and agricultural straw mulches on post-fire: 1) runoff and sheet erosion rates generated from rainfall simulations on small plots; 2) runoff velocities, rill geometry, and rill erosion rates generated from simulated concentrated flow experiments; 3) sediment yields from natural rainfall on planar hillslope plots; and 4) discern changes in post-fire responses, treatment effectiveness, and the characteristics of the wood shred and straw mulches over time for 2 years after the fire.

2. Methods

2.1. Site description

The Terrace Mountain fire in south-central BC started on 18 Jul 2009 and was deemed contained (15 Sep 2009) in the same week we established our study site (14–18 Sep 2009) on a 2-ha area classified as mostly high soil burn severity (Fig. 1, based on the criteria of Parsons et al., 2010). Plots for rainfall simulation, rill simulation, and natural rainfall (hillslope silt fence plots) experiments were established in close proximity, but not overlapping, on a large planar west-facing hillslope at an elevation of 1000 to 1200 m (mean of 1070 m) with slopes of 25–50% (Fig. 1).

The continental climate that dominates south-central BC is generally mild in the summers with cold winters at higher elevations where the study plots are located. The annual average precipitation at the Kelowna Airport weather station (20 km away and 600 m lower than the study site) is 381 mm, which is divided fairly equally between summer and winter with maxima occurring in the months of June (rain) and December (snow) (Fig. 2). The study area is usually snow covered from late October to late April. The dominant forest overstory species are Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and trembling aspen (*Populus tremuloides*) with an understory dominated by pinegrass (*Calamagrostis rubescens*) and birch-leaved spirea (*Spiraea betulifolia*) (Lloyd et al., 1990; Meidinger and Pojar, 1991).

The soil in the study area was derived from a shallow glacial till of mainly granitic origin—predominantly Eutric Brunisols of the Connaly soil series (BC Ministry of Environment, 1978), which corresponds to Eutrocryept in the USDA soil classification system. In 2009, when the experimental sites were established, nine core samples were taken at each of two depths (0–5 and 5–10 cm) at four locations near the rill plots. The mean soil bulk density measured at the control plots