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Evaluating the effectiveness of agricultural mulches for reducing post-wildfire wind erosion

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ABSTRACT

Post-wildfire soil erosion can be caused by water or aeolian processes, yet most erosion research has focused on predominantly water-driven erosion. This study investigates the effectiveness of three agricultural mulches, with and without a tackifier, on aeolian sediment transport processes. A wind tunnel was used to simulate post-wildfire wind erosion at three wind speeds (6, 11 and 18 m s^{-1}). Shallow trays containing soil collected after a wildfire were treated with chopped rice, wheat or chopped wheat mulch; mulch treatments were also compounded with liquid treatments, tackifier to water ratios of 1:6, 1:3 and water. The mulch treatments were generally easily moved at all wind speeds with cover reductions greater than 90% at the highest wind speed. As expected, sediment loss was greatest for the bare soil treatment, ranging from 6.5 g m^{-2} at the lowest wind speed which increases to 6258 g m^{-2} at the highest wind speed. Adding wheat or chopped wheat mulch significantly reduced sediment loss by an order or magnitude (698 and 298 g m^{-2}, respectively) at the highest wind speed. Adding chopped rice straw reduced sediment loss by a half to 3573 g m^{-2} at the highest wind speed, but the effect was not significant due to mobilization of the mulch. The most effective sediment loss mitigation was achieved with liquid tackifier treatments when applied to bare soil and when compounded with various mulch treatments, particularly at the highest wind speed. These results may aid management decisions when mitigating aeolian sediment transport after wildfires.

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1. Introduction

Over four million hectares burned in the United States in 2015, the most wildland area burned since 1960 (National Interagency Fire Center, 2016). Wildfires are likely to continue increasing in regions affected by fluctuating hydrologic regimes and other climate-change related phenomena (Liu et al., 2010; Miller et al., 2009; Westerling et al., 2006). Since post-fire watershed responses such as soil erosion and downstream sedimentation (i.e., deteriorated water quality from ash and sediment) tend to have a farther reaching impact than the actual burned area (Moody et al., 2013), it is necessary to consider the most successful and cost effective strategies for mitigating the widespread secondary effects of wildfire. Soil erosion may be driven by wind or water and its associated impacts are a high priority concern in the post-fire environment.

Burned landscapes are more susceptible to erosion, which can have dramatic effects on water quantity and quality (Smith et al., 2011), downstream infrastructure (Robichaud and Ashmun, 2012), and air quality (Sankey et al., 2009). While much attention has been given to determining appropriate strategies to control post-fire erosion from hydrologic processes (e.g., Robichaud et al., 2013a,b), treatments specific to addressing the consequences of wind erosion through aeolian sediment transport have received markedly less consideration (Field et al., 2009; Miller et al., 2012; Wagenbrenner et al., 2013). Wind erosion plays a major role in burned landscapes as a result of lower threshold velocities needed to transport sediment (Ravi et al., 2007), which negatively impacts nutrient availability and water-holding capacity (Field et al., 2010; Lyles and Tatarko, 1986). Additionally, increases in dust flux measured after wildfires can persist for years (Whicker and Breshears, 2006). Such increases have been known to impact snowpack melting regimes by altering the timing and availability of water resources (Painter et al., 2010) and change the natural biogeochemical balance in a given ecosystem (Field et al., 2010).

Management practices designed to moderate wind erosion include the use of windbreaks (e.g., Fryrear and Skidmore, 1985; Woodruff et al., 1972); and conservation tillage (Mannering and Fenster, 1983; Sharratt and Feng, 2009a,b). There is also substantial evidence that surface cover, such as surface residues and mulches,

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reduces wind erosion (Armbrust, 1977; Bilbro and Fryrear, 1994; Fryrear and Skidmore, 1985; Horning et al., 1998). Additionally, vegetative recovery after wildfire (Wagenbrenner et al., 2013) and vegetation cover and soil crusting can reduce wind erosion (Hupy, 2004; Sharratt and Vaddella, 2012). Although there have been recent investigations of the effectiveness of wind erosion control treatments, much of the literature is not specific to post-fire circumstances. For example, soil bonding agents such as polyacrylamides (PAM) have a demonstrated ability to reduce aeolian sediment transport (Armbrust, 1999; Genis et al., 2013; He et al., 2008), but most studies research PAM efficacy on unburned agricultural or pasture lands. Two notable exceptions have contrasting results in regard to PAM efficacy in reducing hydrologic erosion in post-fire environments (Inbar et al., 2015; Prats et al., 2014).

Few studies have focused on treatments to reduce wind erosion via land management after wildfires. For example, Miller et al. (2012) investigated the effect of seeding perennial plants on wind erosion in Utah after the 2007 Milford Flat Fire and found that decreases in sediment flux observed three years after the fire were primarily attributed to the establishment of exotic plants and not intentionally seeded perennials. Copeland et al. (2009) evaluated wood strands and agricultural wheat straw treatment efficacy in controlling wind erosion of an agricultural (Ritzville) silt loam soil. Results from their study demonstrated that both treatments reduced wind erosion when compared to bare soil at moderate wind speeds (11 m s^{-1}). At higher wind speeds (18 m s^{-1}), no difference was found between agricultural straw treatment (131 g m^{-2}) and bare soil (126 g m^{-2}), whereas wood strands (13.6 g m^{-2}) continued to reduce the amount of eroded soil. This suggests that wind erosion treatments should be tailored to anticipated wind events with consideration for local topography. While these studies contribute to needed investigations specific to wind erosion treatment effectiveness in an agricultural context, there is still a deficiency of studies focused on testing burnt soils and alternative treatment combinations.

Thus, the purpose of this study was to examine three mulch-cover treatments (wheat straw, chopped wheat straw, and chopped rice straw), a new soil-bonding agent PineBind™ tackifier (National Land Management, Phoenix, AZ; http://www.ecodustcontrol.com; accessed 27 March 2017), and mulch-tackifier combinations to determine their efficacy at reducing soil loss from post-fire aeolian processes. The PineBind™ tackifier was originally designed to decrease dust transport on unimproved native material roads (National Land Management, 2016).

2. Methods and materials

2.1. Experimental design and equipment

Experimental trials with a portable wind tunnel were conducted at the US Department of Agriculture, Agricultural Research Service, Palouse Conservation Field Station in Pullman, Washington. The wind tunnel had working dimensions of 7.3 m long, 1.0 m wide and 1.2 m tall (Pietersma et al., 1996). Because soil moisture affects aeolian sediment transport (Mulumba and Lal, 2008) and the facility was not climate regulated, the experiment was conducted only when atmospheric humidity was <65%. Relative humidity was not expected to influence threshold friction velocity until liquid water bridges formed in the soil; these bridges can form at 65% relative humidity (Ravi et al., 2006) or soil water potentials of > −25 MPa (Sharratt et al., 2013).

A 1.4 m diameter Joy Series 1000 axivane fan powered via a Ford industrial gasoline engine generated winds from 2 to 20 m s^{-1}. Airflow into the tunnel was constricted using a bell infuser. Curvilinear guiding vanes were located immediately downwind of the fan blades to minimize vortices or swirling. Airflow then passed through a diffuser and honeycomb-screen to decrease flow turbulence. Upon entering the working section of the tunnel, the airflow passed through a shear-grid to generate shear boundary layer flow. Fully developed shear flow was achieved at a distance of about 3.6 m downwind of the shear-grid (Pietersma et al., 1996).

Plywood platforms were constructed and installed to form the floor of the wind tunnel. Cutouts to accommodate soil trays in these approach platforms were made 5 m downwind from the shear grid, which allowed the top of the trays to be flush with the plywood surface. The approach plywood platforms created a fixed surface roughness specific to each of the three mulch types and allowed for the establishment of an upwind boundary-layer prior to airflow reaching experimental plots. To achieve the desired experimental surface roughness, 70% cover for each mulch type – rice, wheat, and chopped wheat – were glued to three unique approach platforms, which were sequentially installed and specific to the treatment used within experimental runs. To create the bare soil approach platform, sand was glued in lieu of mulch.

To simulate soil in a post-fire environment, we used previously burned soil from the 2010 Jefferson Fire (43° 40′ N, 112° 35′ W) located in southeastern Idaho on the Snake River Plain. Soils in this region are predominantly loamy sand (USDA-NRCS Web Soil Survey, 2016). Soil samples were collected in 2010 from the top 5 cm of the soil and were classified as sand (sand 88%, silt 10%, and clay 1%). The soil was air-dried and stored in a climate-regulated facility until 2015, when the soil was then sieved to 2 mm and organic materials >2 mm were removed by hand. During experimental trials, aluminum trays (1 meter long, 40 cm wide, 1.5 cm deep) were overfilled with soil and leveled with a screed until soil was flush with the tray. Treatments were then applied at random to experimental trays.

In total, 19 different treatment combinations were applied to the experimental trays and consisted of: 1) control (bare soil); 2) three types of ground cover (chopped rice straw hereafter referred to as "rice straw", wheat straw, chopped wheat straw) at two cover percentages (10% and 70%); and 3) three liquid applications (PineBind™ tackifier agent at dilutions of 1:6 and 1:3; and water) (Table 1). Wheat and rice straw were selected for study because of their common or growing use in burned areas to mitigate hydrologic erosion (Napper, 2006; Robichaud et al., 2010). Baled rice straw is commonly chopped before aerial application because its high starch (amylopectin) content causes the rice to stick together

Table 1
Surface ground cover treatment types and combinations (19 total). Each of the 19 treatments was replicated four times at each of the three wind speeds (12 repetitions of each plot treatment, 228 total experimental runs).

Cover type	Ground cover (%)	Plot treatments
Bare soil (no cover)	0	Tackifier:water ratio (1:6 and 1:3), water only, and dry
Chopped rice straw	10	Tackifier:water ratio (1:6) and dry
	70	Tackifier:water ratio (1:6 and 1:3), water only, and dry
Wheat straw	10	Tackifier:water ratio (1:6) and dry
	70	Tackifier:water ratio (1:6 and 1:3), water only, and dry
Chopped wheat straw	70	Tackifier:water ratio (1:6), water only, and dry