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Soil water repellency and infiltration in coarse-textured soils of burned and unburned sagebrush ecosystems

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ABSTRACT

Millions of dollars are spent each year in the United States to mitigate the effects of wildfires and reduce the risk of flash floods and debris flows. Research from forested, chaparral, and rangeland communities indicate that severe wildfires can cause significant increases in soil water repellency resulting in increased runoff and erosion. Few data are available to document the effects of fire on the spatial and temporal variability in soil water repellency and potential impacts on infiltration and runoff on sagebrush-dominated landscapes. Soil water repellency, infiltration and runoff were assessed after two wildfires and one prescribed fire in three steep, sagebrush-dominated watersheds with coarse-textured soils. Water repellency was generally greater on unburned hillslopes and annual variability in water repellency had a greater impact on infiltration capacity than fire effects. The most significant impact of fire was canopy and ground cover removal on coppice microsites. Infiltration rates decreased on coppice microsites after fire even though soil water repellency was reduced. Fire-induced reduction in infiltration resulted from the combined effect of canopy and ground cover removal and the presence of naturally strong water repellent soils. Removal of ground cover likely increased the spatial connectivity of runoff areas from strongly water repellent soils. The results indicate that for coarse-textured sagebrush landscapes with high pre-fire soil water repellency, post-fire increases in runoff are more influenced by fire removal of ground and canopy cover than fire effects on soil water repellency and that the degree of these impacts may be significantly influenced by short-term fluctuations in water repellent soil conditions.

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1. Introduction

Soil water repellency has been well documented in burned and unburned soils on semi-arid rangeland (Salih et al., 1973; Pierson et al., 2001, 2008), chaparral (Hubbert et al., 2006), and forested environments (Robichaud, 2000; Huffman et al., 2001; MacDonald and Huffman, 2004; Doerr et al., 2006; Lewis et al., 2006). Wildfires have often been associated with the formation of water repellent soil conditions thought to decrease infiltration and increase runoff and soil erosion (DeBano et al., 1998; Robichaud, 2000). During combustion hydrophobic organic compounds in litter and topsoil are volatized and released upwards to the atmosphere and downwards into the soil profile along a temperature gradient. Downward translocated hydrophobic compounds condense on cooler soil particles at or below the soil surface forming water repellent conditions (DeBano et al., 1976). Natural water repellent soil conditions also occur in unburned plant communities due to coating of soil particles with hydrophobic compounds leached from organic matter accumulations, by-products of microbial activity, and or fungal growth under thick layers of litter and duff material (Savage et al., 1972; DeBano, 2000; Doerr et al., 2000). Under unburned conditions litter and vegetation cover promote water storage and mitigate water repellency impacts on infiltration and erosion (Rauzi et al., 1968; Blackburn et al., 1986). Fire removes this protective covering, exposing the soil to raindrop impact and removing barriers to overland flow (Moffet et al., 2007; Pierson et al., 2008).

Recent studies have identified seasonal variability in the presence and strength of soil water repellency under burned and unburned conditions (Doerr and Thomas, 2000; Dekker et al., 2001; Huffman et al., 2001). Doerr and Thomas (2000) observed seasonal patterns in soil water repellency correlated to rainfall patterns, biological productivity, and spatial variations in water repellency during soil wetting. Dekker et al. (2001) demonstrated that soil water repellency is a function of soil water content, that critical soil water thresholds demarcate wettable and water repellent soil conditions, and that the relationship between moisture content and soil water repellency is affected by drying regime. In a multiple fire study, Huffman et al. (2001) found that time since burning was not a significant predictor of soil water repellency in pine forests of the Colorado Front Range and noted the water repellent soils became

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wettable when soil moisture levels exceeded 12 to 25%. These studies indicate that seasonal variability in site characteristics that influence soil water repellency can confound assessment of long-term soil water repellency persistence (Doerr et al., in press).

The temporal dynamics of soil water repellency and respective impacts on rangeland hydrology and erosion have received little attention in the literature. Pierson et al. (2001, 2002) used rainfall simulations to investigate infiltration, runoff, and erosion processes on burned and unburned steeply-sloped sagebrush sites with coarse-textured soils. Burned shrub coppice microsites (areas underneath shrub canopy) had significantly lower infiltration compared to unburned shrub coppices in both studies. The lowest infiltration rates were observed on unburned interspaces (areas between shrub canopies) that were densely covered in very dry litter and senescent grasses. Pierson et al. (2001) developed a Water Repellency Index (WRI) to quantify the relative impact of soil water repellency on infiltration. The index differs from a previous water repellency index presented by Tillman et al. (1989) that is a ratio of the intrinsic sorptivity of ethanol to that for water. The Pierson et al. (2001) index scales the difference in final and minimum infiltration rates by the final infiltration rate. Using this WRI, Pierson et al. (2001) found burned coppice microsites had an average reduction of 28% in infiltration immediately post-fire with relatively little variability between plots. Pierson et al. (2002) attributed results to naturally strong soil water repellency, but did not explicitly measure soil water repellency in their experiment.

The goal of this paper is to document the effects of fire on the spatial and temporal variability in soil water repellency and potential impacts on infiltration and runoff on sagebrush-dominated landscapes. The objective of this paper is to test if relationships exist between directly measured soil water repellency, and the spatial and temporal variation in infiltration capacity and runoff generation on burned and unburned microsites within coarse-textured sagebrush-dominated ecosystems. The results of Pierson et al. (2001, 2002) are extended by adding data, analysis, and interpretation. Data from an additional independent study is also included to broaden the inference space of conclusion.

2. Study areas

2.1. Eighth Street Wildfire (1996)

The Eighth Street Wildfire study area (43°40′00″ latitude 116°06′ 48″ longitude) is located 5 km north of Boise, Idaho, USA, in the Boise Foothills. The fire burned 6070 ha at low to high intensities in late summer 1996 and was the focus of the hydrologic experiments presented in Pierson et al. (2002). The research area mean elevation is 1400 m. Annual precipitation ranges from 350 mm at lower elevations to 750 mm near ridgelines, most of which falls between November and May. Mean annual air temperature ranges from 8 to 11 °C. Soils of the area are derived from granite and consist of gravelly coarse sandy loams (Ultic Haploxerolls), on slopes of 35–60% (USDA-NRCS, 1997). Typical vegetation consists of big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle & Young), and Idaho fescue (*Festuca idahoensis* Elmer). Some slopes are characterized by increases in three-awn (*Aristida* L. spp.), Sandberg bluegrass (*Poa secunda* Vasey), cheatgrass (*Bromus tectorum* L.) and rabbitbrush (*Chrysothamnus* Nutt. spp.) (Interagency Fire Rehabilitation Team, 1996).

2.2. Denio Wildfire (1999)

The Denio Wildfire study area is located approximately 24 km southwest of Denio, Nevada, USA, in the Pine Forest Range, 41°45′00″ latitude 118°41′09″ longitude. The fire severely burned 34,400 ha in 1999 and was the focus of hydrologic investigation by Pierson et al. (2001). The research area mean elevation is 2050 m. Average annual precipitation is 350–400 mm and mean annual air temperature ranges from 5 to 7 °C. The study area is located within Major Land Resource area 23 (Malheur High Plateau) (USDA-SCS, 1981). The soils are mapped as Ola bouldery sandy loam, which consists of moderately deep soils formed in residuum from granite on mountain sideslopes. The Ola soil classification is coarse-loamy, mixed, frigid Pachic Haploxerolls (USDA-NRCS, 2001). Slopes in the study area range from 35 to 40%. Vegetation is dominated by mountain big sagebrush [*A. tridentata* ssp. *vaseyana* (Rydb.) Beetle], Idaho fescue and bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Löve] (USDA-NRCS, 1990). Subdominant grasses consist of Sandberg bluegrass, bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey], California brome (*Bromus carinatus* Hook & Arn.), basin wildrye [*Leymus cinereus* (Scribn. & Merr.) A. Love] and Columbia needlegrass [*Achnatherum nelsonii* (Scribn) Barkworth]. Subdominant shrubs are green rabbitbrush [*Chrysothamnus viscidiflorus* (Hook.) Nutt.] and common snowberry [*Symphoricarpos albus* (L.) Blake]. Major forb species include lupine (*Lupinus* spp.), longleaf hawksbeard (*Crepis acuminata* Nutt.), Indian paintbrush (*Castilleja* spp.), rosy pussytoes (*Antennaria rosea* Greene) and low scorpionweed (*Phacelia humilis* Torr & Gray).

2.3. Breaks Prescribed Fire (2002)

The Breaks study area (43°6′30″ latitude 116°46′50″ longitude) is located on the Reynolds Creek Experimental Watershed in the Owyhee Mountains, southwestern Idaho, USA. The prescribed fire was ignited in late September and a head fire burned over the study site. The burn severity across the study site was moderate to severe due to high fuel loads and the late afternoon time of day when the fire reached the site. Mean elevation of the research site is 1750 m. Mean annual precipitation is approximately 600 mm and mean annual air temperature is approximately 8 °C. The soils are mapped as Kanlee–Ola–Quicksilver association (Harkness, 1998). The plots in this study are on the deeper Kanlee (fine-loamy, mixed, superactive, frigid Typic Argixerolls) and Ola (coarse-loamy, mixed, superactive, frigid Pachic Haploxerolls) series. The hillslopes of the study area are east facing with 35 to 50% slope angles above granite bedrock. Soil textures are coarse sandy loam at and near the surface (0–30 cm depth) and loam or coarse sandy loam in the subsoil that extends beyond 100 cm depth. Rock fragment (>2 mm diameter) content near the soil surface is about 5 to 15% and ranges between 5 and 50% in the subsoil. Vegetation includes mountain big sagebrush with sub-dominant shrubs of rabbitbrush (*Chrysothamnus viscidiflorus*), antelope bitterbrush [*Purshia tridentata* (Pursh) D.C.], and widely scattered juniper (*Juniperus occidentalis*). Dominant grasses are bluebunch wheatgrass, and Idaho fescue. Additional site description details can be found in Moffet et al. (2007).

3. Methods

3.1. Experimental design

The Eighth Street site was sampled with 10 rainfall simulation runoff plots (0.5 m^2) for each treatment 1 year after the fire (Pierson et al., 2002). Treatments included slope, aspect (north and south) and fire severity (unburned, moderate, and high). Additional plots were sampled 2 years after the fire only on the high fire severity treatments. The plots were arranged with half the plots randomly placed on coppice microsites and half on interspace microsites. Burned sites were closely matched to the soil type, slope, aspect and pre-existing vegetation found on unburned controls. All study sites were located on steep hillsides (approximately 40% slopes) at an approximate elevation of 1220 m. The severely and moderately burned and unburned north aspect sites were the only sites comparable to the Breaks and Denio sites. Therefore, data from the south aspects were not included in this analysis. The sample sizes in this analysis were 10