

Pre- and Postfire Distribution of Soil Water Repellency in a Steep Chaparral Watershed¹

Ken R. Hubbert,² Peter M. Wohlgemuth,³ and Haiganoush K. Preisler⁴

Abstract

The development and nature of water repellent soils and their spatial distribution on the landscape are not well understood relative to evaluating hillslope response to fire. Soil water repellency is particularly common in chaparral communities, due in part to the coarse-textured soils, and the high resin content of the organic litter. Objectives of this study were 1) to investigate pre- and post-fire distribution of soil water repellency on the landscape, and 2) to determine if species composition affected changes in soil water repellency. A prescribed burn was conducted on a 1.28 ha mixed chaparral study site located in the San Dimas Experimental Forest. We sampled pre- and post-fire soil water repellency using the water drop penetration time method at 105 sites. At each site, measurements were taken at the surface, 2 cm, and 4 cm depths within a 15 x 15 cm square plot. Thirty-eight percent of the pre-fire soil surface exhibited moderate to high repellency. At 7 days post-fire, moderate to high repellency in the surface soil increased to 66 percent. After 76 days, post-burn surface soil water repellency returned to near pre-fire values. Variability in water drop penetration time among replicates within a given 15 x 15 cm plot was as large as the variability seen among sites over the whole watershed. At the 2 cm depth, 7 day post-fire moderate and high repellency increased 14 percent. Beneath chamise, soils exhibiting high repellency increased by 17 percent after the burn, and by 38 percent under ceanothus, whereas high repellency beneath sugar bush decreased by 23 percent. Greater understanding of the pre- and post-fire spatial distribution of water repellency is necessary for land management decisions in steep chaparral watersheds.

Introduction

Wildfire can increase soil water repellency across a landscape. The spatial distribution of repellency can be highly variable for several reasons: non-uniform fire temperature and duration, depth and moisture content of the litter layer, litter type and composition, varying plant species, live and dead fuel densities and moisture contents, and differences in soil moisture and soil texture (DeBano 1981, Robichaud 1996). Therefore, most fires create a mosaic of low-, moderate-, and high-severity burn areas (Robichaud and Miller 1999). For example, dry south-facing slopes may burn at high severity, but moist north-facing slopes and drainage areas may burn at lower severities (DeBano and others 1998).

In a water repellent soil, water will not readily penetrate and infiltrate into the soil, but will “ball up” and remain on the surface (Adam 1963, DeBano and others 1967). Soil water repellency is particularly common in chaparral communities, due in part to the coarse-textured soils, and the high resin content of the organic litter (DeBano 1981). Coarse-textured soils generally exhibit more intensive soil water

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²Soil scientist, Hubbert and Associates, Apple Valley, CA. e-mail: huboutwest@aol.com.

³Hydrologist, USDA Forest Service, Pacific Southwest Research Station, Riverside Fire Laboratory, 4955 Canyon Crest Dr., Riverside, CA. 92507.

⁴Statistician, USDA Forest Service, Pacific Southwest Research Station, P.O. Box Berkeley, CA. 94701.

repellency because there is less particle surface area to be coated by hydrophobic substances than would be in a finer textured soil (DeBano 1981). Fire volatilizes the existing organic water-repellent materials, which then can move vertically down the soil profile and recondense on mineral soil particles producing a more continuous water-repellent layer (DeBano and others 1967). Nevertheless, live roots, old root channels, and soil cracks can serve as penetrating points for preferential flow of water through the water repellent layers thus providing water to the deeper rooted chaparral species (Meyer 1993).

Because prescribed fires do not burn uniformly across a broad landscape, or even at smaller scales in steep watersheds, the spatial patterns of soil water repellency should not be expected to be uniform (Robichaud and Miller 1999). This work addresses prescribed pre- and post-fire distribution of soil water repellency in a steep chaparral watershed. Specific objectives were to 1) determine pre- and post-fire spatial and temporal variability of water repellency in steep chaparral soils, and 2) investigate how different plant species affect the distribution of soil water repellency on the landscape.

Fire can exacerbate the amount of soil water repellency across the land surface, reducing infiltration, and, in turn, increase overland flow (Shakesby and others 2000). But a mosaic distribution of water repellency accompanied by preferential flow pathways may lower the intensity of the hydrologic response and resulting erosion (Meyer 1993, Ritsema and Dekker 1994). Thus, it is critical that land managers understand pre- and post-fire spatial distribution of water repellency in steep chaparral watersheds.

Materials and Methods

The 1.28 ha study watershed (34° 12'45" N, 117° 45' 30" W) is located in the San Dimas Experimental Forest (SDEF) in the foothills of the San Gabriel Mountains of southern California, approximately 45 km northeast of Los Angeles, California. The climate is Mediterranean, with hot, dry summers, and cool, wet winters. Mean annual precipitation is 678 mm (Dunn and others 1988). Topography is rough with precipitous canyons and steep slopes (Ryan 1991). Bedrock in the area has been subjected to intense heat and pressure resulting in a high degree of alteration, faulting, folding, and fracturing, resulting in rocks that are poorly consolidated and very unstable (Sinclair 1953). Soils are coarse-loamy, mixed, thermic Typic Xerorthents (Hubbert and others 2006) and are low in organic matter content (Ryan 1991). Common chaparral species were chamise (*Adenostoma fasciculatum* Hook & Arn.), hoaryleaf ceanothus (*Ceanothus crassifolius* Torr.), sugar bush (*Rhus ovata* S. Watson), bigberry manzanita (*Arctostaphylos glauca* Lindl.), scrub oak (*Quercus berberidifolia* Liebm.), black sage (*Salvia mellifera* E. Greene), and wild buckwheat (*Eriogonum fasciculatum* Benth.). Chaparral stand age was 41 yr, with the watershed last burning during a 1960 wildfire that consumed 88 percent of the 7,727 ha SDEF.

The study watershed was burned on May 15, 2001, ignited by flaming gel applied by a helicopter. Residence time of the prescribed burn ranged from 1 to 3 hr, consuming approximately 90 percent of the 1.28 ha study watershed. Burn severity was estimated by measuring the minimum diameter of chamise branches remaining post-fire. Burn intensity (heating) was estimated qualitatively from the color of ash and degree of litter consumption (Miller 2001).

There were 105 sampling plots within the 1.28 ha watershed. Fifty-four of these sampling plots were randomly spaced along eight transects that crossed the watershed in an east-west direction. The remaining 51 plots were selected randomly between transects. Pre-fire cover by species, litter composition and litter depth were identified at each sampling site. Pre- and post-fire soil water repellency was determined by noting the water drop penetration time (WDPT) (Krammes and DeBano 1965) in dry surface soil at each sampling point. Pre-fire litter and post-fire ash were carefully removed to expose the soil mineral surface. Twenty drops from an eyedropper were applied at the mineral soil surface within a 15 x 15 cm area. Another 20 measurements were taken at the 2 cm depth and 10 measurements at the 4 cm depth. The time of water drop penetration was determined when the droplet changed from convex to flat, and infiltrated. We have modified existing soil water repellency indexes (DeBano 1981, Dekker and Ritsema 2000) to give us the following classification scheme: 0 to 1 s—not repellent, 1 to 5 s—very low repellency, 5 to 30 s—low repellency, 30 to 180 s—moderate repellency, and >180 s—high repellency. This classification scheme is in agreement with Robichaud (1996), except that the time for “no repellency” is 0 to 1 s instead of 0 to 5 s.

The smooth surfaces in *figures 1, 2, and 3* were produced by the nonparametric smoothing routine (loess) located within the S-plus statistical package (Cleveland and others 1992, S-PLUS 2001). The technique is based on locally weighted regression methods. It fits a polynomial surface by weighted least squares with the weights picked such that nearby data points have the most influence.

Results and Discussion

Burn severity (effects of the fire) was low to moderate throughout the watershed, with litter depth and moisture content contributing to the landscape distribution of soil heating. Thirty-eight percent of the pre-fire soil surface exhibited moderate to extreme repellency (>30 s), 22 percent low repellency (5 to 30 s), and 40 percent very low to no repellency (<5 s) (*fig. 1b*). In the surface spatial plot (*fig. 1a*), the variability of surface water repellency extended from the lower to upper watershed. Krammes and DeBano (1965) suggested that at least 60 percent of pre-fire soils on SDEF could be classified as water repellent. In the pre-fire soil landscape, continuous layers of water repellent soil are generally not formed because rodent, worm, insect, and root activity create macropores for water infiltration (DeBano 1981, Spittler 1996). We observed almost no pre-fire water repellency at 4 cm depth (*fig. 3b*). We believe this was partly due to higher pre-fire soil moisture contents (median >0.12 cm³ cm⁻³) at 4 cm depth and the effect of time since the 1960 wildfire.

At 7-d post-fire, moderate to high repellency in the surface soil had increased to 66 percent, with very low and no repellency soils dropping 18 percent (*fig. 1a*). The increase in surface water repellency was clearly seen in the post-fire 7-d spatial plot (*fig. 1a*), but variability still remained high throughout the watershed (*fig. 1d*). The amount and distribution of chaparral fuel that collapses during fire and smolders on the ground can cause pronounced spatial variation in total surface heating (Odion and Davis 2000). Post-fire 7-d increases in surface water repellency observed in our experiments resulted from release of hydrophobic substances contained in litter and plant material during combustion (DeBano and others 1970).

At 76-d post-burn, repellency patterns appeared to be returning to pre-fire spatial patterns (*fig. 1e*) and the histogram showed surface soil water repellency returning to

near pre-fire values (*fig. 1f*). In most cases, soil moisture plays an important role in the decrease of water repellency (Robichaud 1996, Doerr and Thomas 2000). However, no precipitation occurred during the post-fire 76-d time period and median soil moisture contents remained below 0.5 cm³ cm⁻³. It is unknown if fog drip resulted in any decrease in surface repellency during this time period. We believe the breakdown of water repellency (*fig. 1*) was due to movement of the unstable surface soils on the very steep slopes (>55 percent), wind erosion, and perturbation of the soil by plants and fauna. It was unlikely that decomposition and displacement of water repellent substances by microorganisms (Crockford and others 1991) or by fine roots occurred, possibly because of low soil moisture conditions. At the 2 cm depth, moderate and high repellency increased from 33 percent pre-fire to 47 percent 7 day post-fire (*fig. 1b*).

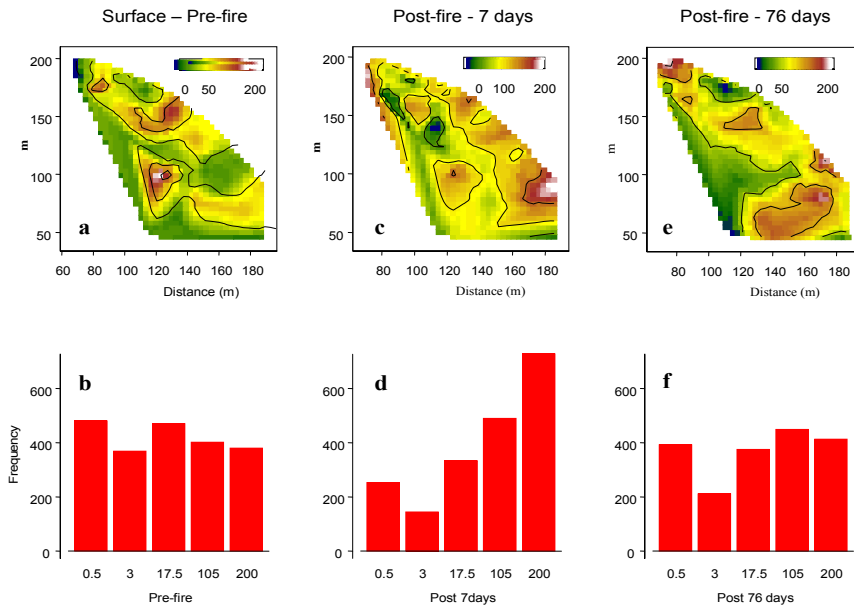


Figure 1—Spatial plots and corresponding histograms describing pre-fire and post-fire surface soil water repellency. Water repellency times were grouped into 5 cells. The x-axis groups (0.5 s, 3 s, 17.5 s, 105 s, and 200 s) represent the repellency index: 0 to 1 s—not repellent, 1 to 5 s—very low repellency, 5 to 30 s—low repellency, 30 to 180 s—moderate repellency, and >180 s—high repellency. The heights of the bars are the total number of cases (at all locations) that fell in the corresponding group.

DeBano and others (1970) noted that increases in repellency were due to volatilization and recondensation of organics moving downward along a temperature gradient, with repellency intensified at temperatures of 175 to 200°C. However, temperatures in the surface soil may not have been high enough to volatilize the organics. At 7 day post-fire, “moderate to high” soil repellency at the 4 cm depth increased to 26 percent (*fig. 3d*). Although the fire was of low to moderate intensity, it appears that the increase in water repellency at depth was due in part to volatilized organics translocated downward and soil drying. After 76 day, both the 2 and 4 cm depths had not returned to pre-fire values as seen at the soil surface and moderate to high repellency continued to increase beyond post 7 d (*fig. 2f, 3f*). We believe this was a function of drying soils and the absence of surface soil erosion factors of wind and gravity. The continued increase in repellency may have been due to further soil

drying by evapotranspiration, and seasonal soil temperature change at the 4 cm depth that re-intensified latent soil water repellency. As reported by Dekker and others (1998), even slight drying at 25°C can contribute to an increase in soil water repellency at the 2.5 to 5 cm depth.

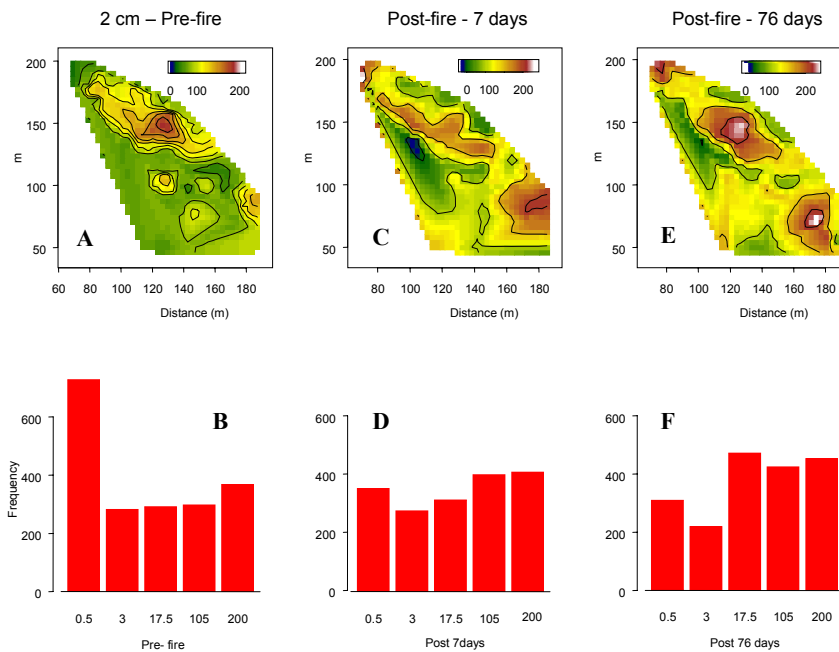


Figure 2—Spatial plots and corresponding histograms describing pre- and post-fire soil water repellency at 2 cm depth.

Variability in WDPT among replicates within a 15 x 15 cm plot was as large as the variability among sites over the study watershed (*table 1*). At the soil surface, approximately 50 percent of the overall variability in times of water drop penetration was due to within site variation. The percent of total variation due to within site variability seemed to decrease at lower depths (approximately 40 percent at 2 cm and 30 percent at 4 cm). Variability was greatest at the surface and decreased with depth (*table 1*). At the 4 cm depth, lower within site variability values were partially due to higher soil moisture contents as compared to dryer moisture contents at the surface and 2 cm depth. Type and species composition of litter played a role in the post-fire variability of soil water repellency (*fig. 4*), as reported by Doerr and others (1998).

Beneath chamise, soils exhibiting high repellency increased by 17 percent 7 days after the burn, and under ceanothus by 38 percent, whereas high repellency beneath sugar bush decreased by 23 percent (*fig. 4*). In the study watershed, the depth of chamise litter averaged only 19 mm (Hubbert and others 2006), but still exhibited >35 percent water repellency 7-d post-fire (*fig. 4*). DeBano and others (1970) have noted that leaf materials of chamise contain large amounts of hydrophobic substances. It appeared that ceanothus litter (average depth=55 mm) also contained large amounts of hydrophobic substances that were released during fire, but were not released during intervening periods absent of fire. The low (<4 percent) water repellency beneath ceanothus indicated that very little hydrophobic substances were leached out of the leaves. The decrease in high repellency beneath sugar bush (average litter depth=62 mm) may have been due to higher fire-induced surface soil temperatures or lower leaf contents of hydrophobic substances. We observed an overall increase in repellency under all species categories post fire. Since the majority

of chaparral species are resprouters, the enhanced post-fire water repellency may discourage seed emergence and development, thus preventing competition for water.

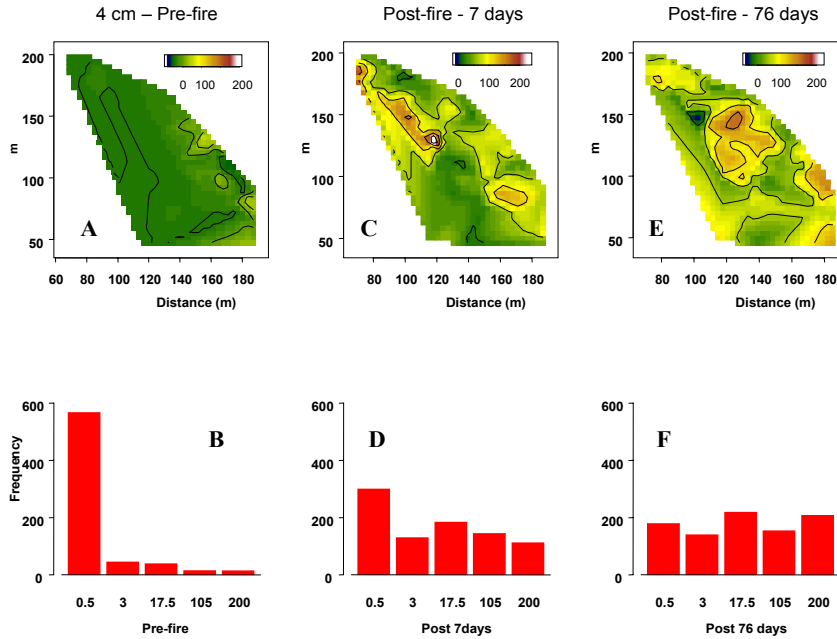


Figure 3—Spatial plots and corresponding histograms describing pre- and post-fire soil water repellency at 4 cm depth.

Table 1—Percent variability of water drop penetration time measured between replicates and between sites.

	Pct between sites	Pct within 15 x 15 cm site
Surface pre-fire	58.2	41.8
Surface 7-d post-fire	47.5	52.5
Surface 76-d post-fire	51.0	49.1
2 cm pre-fire	66.6	33.4
2 cm 7-d post-fire	54.6	45.4
2 cm 76-d post-fire	57.9	42.1
4 cm pre-fire	74.8	25.2
4 cm 7-d post-fire	65.1	34.9
4 cm 76-d post-fire	60.9	39.1

Water repellent layers may be beneficial to some chaparral species. Burrow holes, tension cracks, old root channels, and live roots can serve as penetrating points for preferential flow of water when ponding occurs due to repellency and may help contribute to the high within and between site variability of soil water repellency exhibited at the soil surface. These macropores provide conduits for infiltration to lower soil horizons, thus bypassing water-repellent layers near the surface (Imerson and others 1992). High rates of hillslope runoff are prevented from occurring, and water storage at greater depths in the soil is enhanced, permitting its later use in transpiration (Scott and Lesch 1997, McDonald 1981). Deep water allows fast post-fire recovery of deeply rooted chaparral resprouters, which are not affected directly by the water repellent layer, because their root systems remain intact, both above and below it (Meyer 1993).

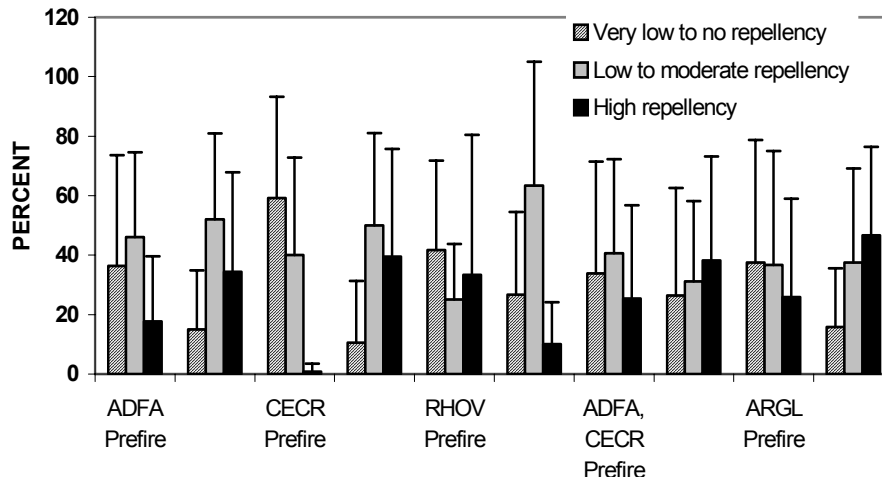


Figure 4—Percent of surface soil water repellency in relation to species litter composition pre-fire and 7 day post-fire. ADFA=chamise, CECR=ceanothus, RHOV=sugar bush, ARGL=manzanita. Error bars represent one standard deviation from the mean. Very low to no repellency <5 s, low to moderate repellency 5 to 180 s, and high repellency >180 s.

Conclusions

At 7 days post-fire, moderate to high repellency in the surface soil had increased by 38 percent from 28 (pre-fire) to 66 percent. After 76-d post-burn, surface soil water repellency returned to near pre-fire values, but increases in repellency at the 2 and 4 cm depths remained. The variability of surface and 2 cm depth water repellency across the watershed was high pre-fire, 7-d post-fire, and 76-d post-fire. Variability in WDPT among replicates within a given 30 cm² plot was as large as the variability seen among plots over the study watershed. At 2 cm depth, 7-d post-fire moderate and high repellency increased 14 percent, suggesting volatilization and recondensation of organics moving downward on a temperature gradient. The 38 percent increase of high soil repellency beneath ceanothus suggested that large amounts of hydrophobic substances from leaf materials are released during fire.

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