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Stones resting on the top soil cause heterogeneous patterns of fire-induced water repellency

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Keywords

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Abstract

Depending on soil and fire characteristics, soil water repellency (SWR) may be induced, enhanced or destroyed by burning. The spatial pattern of SWR may be extremely heterogeneous as a consequence of the temperature peaks, the variation of fire temperature, the distribution of fuel, or the amount and type of ashes. In this research, we have studied the effect of stone cover and position on the intensity and spatial distribution of fire-induced SWR after low-, moderate- and high-severity fire. Generally, SWR increased with fire severity, but stones did induce some differences and increased the heterogeneity of the spatial distribution of fire-induced SWR. In low-stone-cover areas, SWR from soil surfaces below stones increased respect to non-covered soil surfaces. In areas under high stone cover, SWR increased from non-covered soil surfaces to soil surfaces below stones after low-severity fire. In moderate- and high-severity burnt soils under high stone cover, SWR was more severe than in non-covered soil surface, but no significant differences were observed.

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1 INTRODUCTION

Wildfires may induce or enhance soil water repellency (SWR) in burnt areas (DeBano, 2000; Doerr et al., 2000). Burning induces the condensation of hydrophobic organic substances on the surface of soil particles (DeBano 2000). The intensity of SWR depends mostly on temperature peaks, the amount and type of burnt litter, moisture content and other soil properties (Doerr et al., 2000). Spatial and temporal variations of SWR are due to variation of fire temperature, fuel distribution, or the amount and type of ashes produced during burning (Bodí et al., 2011; DeBano, 2000; Shakesby and Doerr, 2006). Stones may influence soil physical properties, run-off and infiltration rates (Poesen & Lavee, 1994; Poesen et al., 1997). Also, it has been demonstrated that stones resting on the soil surface contribute to increase soil thermal conductivity and heat storage capacity (Poesen & Lavee, 1994). But up to date, no studies have considered the effect of stones on the development and spatial distribution of SWR. The aim of this research is to study the effect of stones on the spatial distribution of SWR after a wildfire in a burnt area from southern Spain.

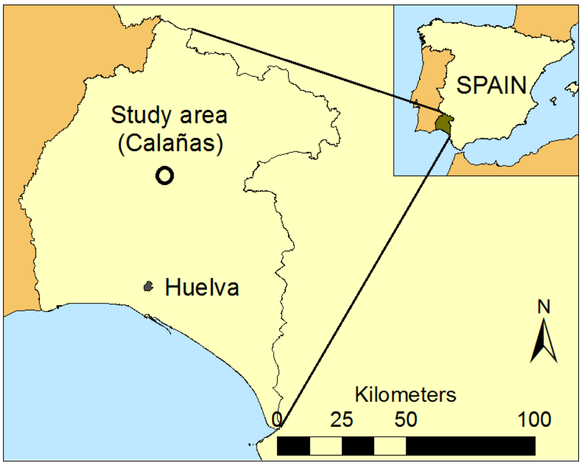

Figure 1. Study area.

2 METHODS

2.1 STUDY AREA AND EXPERIMENTAL DESIGN

During summer of 2011, an arson fire affected about 9000 m^2 in a forest area near Calañas (Huelva, SW Spain; Figure 1). Vegetation in this area is formed by Mediterranean shrubland and woodlands (mainly *Pinus pinea* and *Eucalyptus globulus*).

For this experiment, the burnt area was divided in different zones according to fire severity: unburnt (control adjacent areas not affected by fire), low (LFS), moderate (MFS) and high fire severity (HFS). Areas showing homogeneous fire severity were divided in subareas with low and high stone cover (<20% and >60%, respectively) with minimum size 10 m^2 and 4 m minimum distance between adjacent areas. SWR was assessed by the water drop penetration time (WDPT; Doerr, 1998) in the area included in the vertical projection of a stone (under stone, US) and in the middle point between two nearby stones (between stones, BS) during the first 7 days immediately following burning.

2.2 SOIL CHARACTERIZATION

For soil characterization, four soil plots were selected in points from unburnt areas adjacent to the fire-affected surface, 20 m North, South, East and West. At each soil plot, four soil profiles were described and sampled for laboratory analysis in points 5 m North, South, East and West from the selected plot. Soil samples were transported in plastic bags to the laboratory. Samples were kept at laboratory room temperature (25 ^{o}C) to a constant weight and sieved (2 mm) to eliminate coarse soil particles. Soil acidity (pH) was measured in aqueous soil extract in de-ionized water (1:2.5 soil:water). Soil organic carbon content was determined by the Walkley-Black method (Walkley & Black, 1934). Soil texture was determined by densimetry according to USDA (2004). Finally, soils were classified according to IUSS Working Group WRB (2006).

2.3 ASSESSMENT OF FIRE SEVERITY

Fire severity was assessed in agreement with Keeley (2009). The burnt area was divided in different zones according to fire severity: unburned (control areas not affected by fire), low, moderate and high fire severity. Description of fire severity classes is shown in Table 1. Areas showing homogeneous fire severity were divided in subareas with low rock fragment cover (<20%) and high rock fragment cover (>60%). The minimum size of the selected subareas was 10 m2 and the minimum distance between adjacent areas was 4 m. For SWR and infiltration rate measurements, experimental points were selected below rock fragments (area included in the vertical projection of a rock fragment) and between rock fragments (in the middle point between two rock fragments).

2.4 DATA ANALYSIS

Data analysis included correlations, regression and ANOVA. Assumptions of normality for WDPT data were tested using the Shapiro-Wilk test. The distribution of WDPT data did not satisfy assumption of normality, and alternative non-parametric tests were used: Kruskall-Wallis ANOVA and Mann-Whitney U test. When Kruskall-Wallis or ANOVA null hypotheses were rejected, post-hoc pair-wise comparisons were performed to investigate differences between pairs of means (Bonferroni test). All computations were performed using Statgraphics Centurion version 16 (StatPoint Technologies, 1982-2011).

3 RESULTS AND DISCUSSION

3.1 SOIL PROPERTIES

Soils were classified as Lithic Leptosols (IUSS Working Group WRB, 2006). Soil characteristics are shown in Table 2. On average, soil depth was 9.2 ± 0.8 cm, and maximum depth did not exceeded 10 cm. Mean soil pH was 5.7 ± 0.5 (with pH values ranging between strong to slightly acid).

Table 1. Criteria for assessment of fire severity in the study area.

Fire severity	Description
Unburned	Not affected
Low	Burnt herbs; shrubs partly charred but not consumed and most branches intact after fire; < 50% canopy burned; occasional deposition of black ash; most soil organic layer unaffected
Moderate	Herbs completely consumed; stems thinner than 10 mm were not completely consumed; 50-80% canopy consumed; black and white ashes covering soil; organic layer deeply charred; white ashes covering part of the soil
High	Shrubs consumed and scorched trees; stems thinner than 10 mm were completely consumed (many shrubs were consumed completely except the base); white ash covering most of the soil surface; organic layer showing severe damages and litter consumed; mineral soil colour shows evidence of alteration

Table 2. Mean WDPT (s) ± standard deviation (SD) for each fire severity. P-value from Kruskal-Wallis test is 0.0000. Different letters represent significant differences at p < 0.05.

Fire severity	WDPT ± SD
Unburned	2 ± 1 a
Low	9 ± 9 a
Moderate	44 ± 23 b
High	232 ± 134 c

Mean organic carbon content was 1.6 ± 0.6 %, but values ranged between 1.0 ± 0.0 and 2.2 ± 0.1%. Soil texture is loam, with mean sand content 50.2 ± 12.9% and clay content 17.3 ± 5.7%. Finally, mean soil water content was 2.10 ± 0.17%, with mean values from different control locations ranging between 1.98 ± 0.09 and 2.18 ± 0.19.

3.2 STONES AND SOIL WATER REPELLENCY

Soil water repellency increased with fire severity (Table 3). DeBano (2000) reported that SWR increases with burning severity (although it is expected that water repellency would disappear after extreme severity fires if combustion of organic matter is complete). After fire, litter and aerial plant parts are partly or completely consumed, and the mineral soil surface may be partly or completely covered by ash, charred litter, plant residues (Doerr et al., 2000) and surface stones (García-Moreno et al., 2013). The results of WDPT assessment for different fire severity and stone cover classes are shown in Figure 2. Stones resting on the soil surface are responsible of a heterogeneous distribution of SWR after burning. Even after LFS and low stone cover (<20%), SWR was enhanced at surface under the vertical projection of stones (Table 4). In areas under stones, WDPT values between high and low stone cover areas under different fire severities did not vary significantly (Table 3). Between stones, no significant differences were observed between low and high stone cover in unburnt soils after LFS; but WDPT increased from low to high stone cover areas after MFS and HFS areas. This response may be explained by the heat flow dynamics between fire, stones and soil surface. Recently, García-Moreno et al. (2013) observed that temperature peaks were reached some minutes later in stone-covered than in exposed soil surface. In this experiment, temperature in uncovered soil reached 300-350 °C, but temperature peaks were delayed and longer in time under stones, reaching 350-400 °C. Heat transferred to the topsoil stones is stored and released much more slowly than in uncovered areas. Even after burning, stones may continue transmitting heat to the soil surface. In their experiment, García-Moreno et al. (2013) observed that SWR was enhanced in the topsoil (10 mm) in areas under stone cover 0%, and decreased with stone cover. This is not in agreement with our results, which show increased SWR in areas between and under stones after MFS and HFS.

Mean WDPT values were much higher in US plots. It is suggested that prolonged heat transfer from stones to soil contributed to extend the period of residence for temperatures above the threshold for water repellency induction at the soil surface, hence increasing water repellency. In BS areas, weaker water repellency was reached. In these cases, temperatures at the soil surface may have been even higher, but peaks shorter in time were probably reached during LFS. After MFS and HFS, no significant differences were observed between WDPT from BS and US sites under high stone cover, probably as a consequence of proximity between stone-covered areas and high fire temperatures. Stones can induce a lateral heat flow (Poesen & Lavee, 1994), which reduced the intensity of temperature gradient between BS and US sites. Also, occasional amounts of ashes between nearby stones have been observed, as a result of prolonged combustion of litter and plant residues with low oxygen

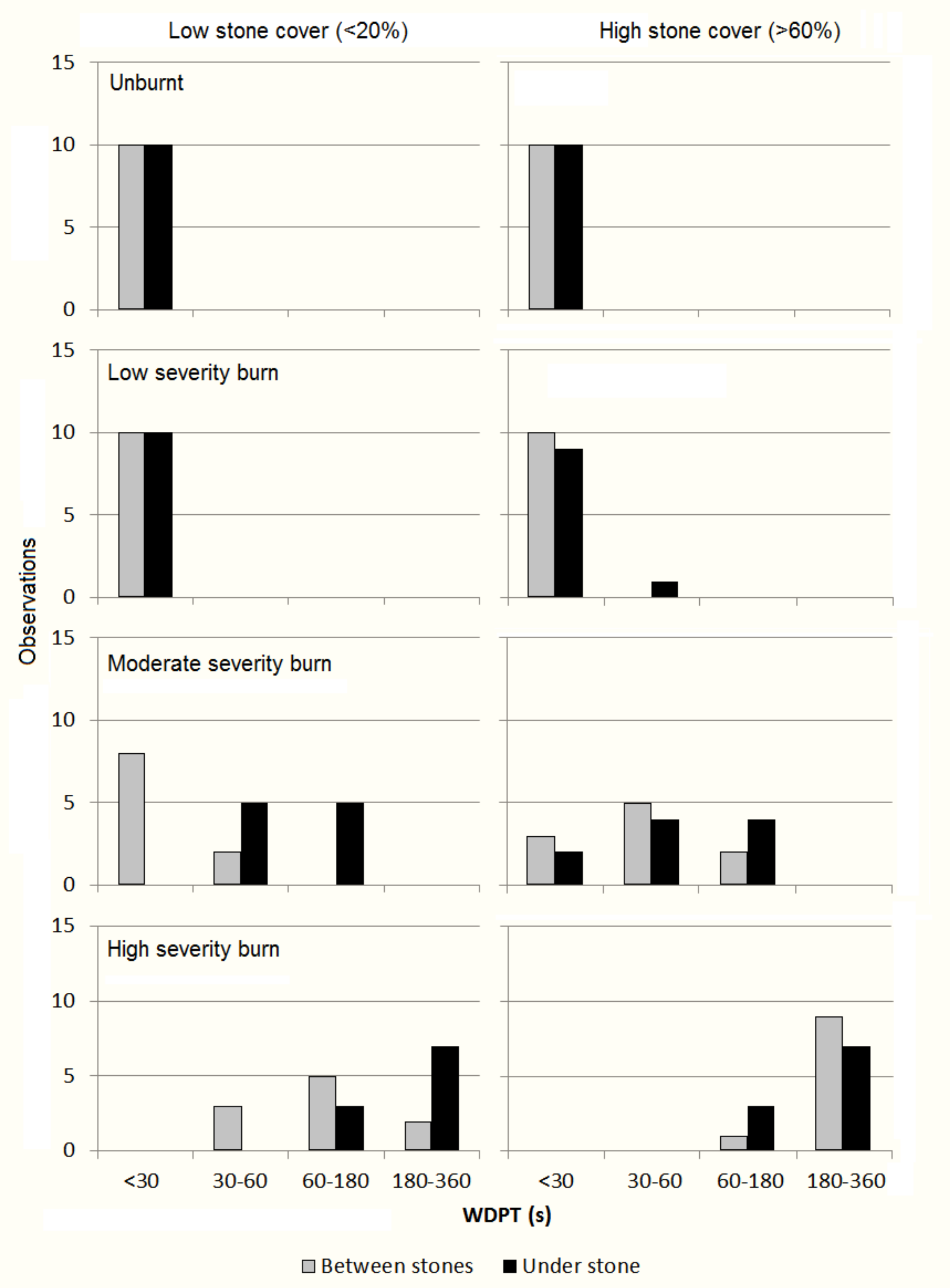

Figure 2. Number of WDPT data for different classes (<30, 30-60, 60-180 and 180-360 s), fire severity and stone cover class (low, <20%; high, >60%).

Table 3. Results of the Mann-Whitney U test (M-U) for WDPT values (mean ± standard deviation, s) from areas with different fire severity, stone cover class and type of determination (between stones and under stones).

Fire severity	Stone cover	Between stones	Under stones	M-U, p
Unburned	<20%	2±1	2±1	> 0.5
	>60%	2±1	2±1	> 0.5
	M-U, p	> 0.05	> 0.05	
Low	<20%	3±2	13±7	0.0010
	>60%	3±2	17±10	0.0003
	M-U, p	> 0.05	> 0.05	
Moderate	<20%	23±11	58±18	0.0007
	>60%	45±17	53±28	>0.05
	M-U, p	0.0100	> 0.05	
High	<20%	101±54	239±102	0.0010
	>60%	263±71	322±173	> 0.05
	M-U, p	0.0006	>0.05	

availability. Flameless smouldering may have contributed to enhanced water repellency in BS sites under high stone cover.

4 Conclusions

Stones resting on the soil surface caused a patchy distribution of SWR after burning. In areas under low stone cover (<20%), water repellency from soil surfaces covered by stones increased respect to soil surfaces non-covered by stones, with mean WDPT increased more than 3 times.

In areas under high stone cover (>60%), SWR increased significantly from BS soil surfaces to US soil surfaces after LFS. In MFS and HFS soils under high stone cover, mean WDPTs were higher than in soil surfaces non covered by stones, but no significant differences were observed. In this case, closeness between stones during severe burning may have contributed to reduce the intensity of temperature gradient between BS and US sites. Smouldering processes after the passage of fire is also suggested to be a factor implied in water repellency development.

Acknowledgements

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