Ash wettability conditions splash erosion in the postfire

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Introduction

Soil sustainability and recovery after fire depend on physical, chemical and biological processes and fire severity (Neary et al., 1999; Mataix-Solera and Guerrero, 2007). Fire effects on soils are divided in two types: direct effects, as a consequence of combustion and temperature reached and indirect effects (Neary et al., 1999) as consequence of changes in other ecosystem components, such as decrease in vegetal coverage or ash and partially burned litter contribution including changes in flora (Pausas and Verdú, 2005; Trabaud, 2000).

Low intensity fires, during which high temperatures are not reached, affect vegetal coverage but will not cause major impacts on soil. In contrast, prolonged, recurrent, or high-intensity fires may cause important impacts on the soil system functioning (De Celis et al., 2013; DeBano, 1991; Mataix-Solera et al., 2009; Zavala et al., 2014), aggregation (Mataix-Solera et al., 2011), organic matter content and quality (Sevink et al., 1989), water repellency (DeBano, 2000; Doerr et al., 2000), soil nutrients (Stark, 1977), soil erosion (Larsen et al., 2009) and others. In these cases, the restoration period of the initial conditions can be very long and changes may become permanent (DeBano, 1991).

During combustion, fuel (biomass, necromass and soil organic matter) is transformed in materials with new physical and chemical properties. After burn, the soil surface is covered by a layer of ash and charred organic residues. Ash has important ecological, hydrological and geomorphological effects, even after being rearranged or mobilized by runoff or wind (Bodí et al., 2014).

Ash properties will depend on the burned species, the amount of affected biomass, fuel flammability and structure, temperature and the residence time of thermal peaks (Pereira et al., 2009). Some studies have emphasized the role of ash on soil protection during the after fire period, in which the vegetable coverage could be drastically decreased (Cerdà and Doerr, 2008; Woods and Balfour, 2008; Zavala et al., 2009).

The presence of an ash layer may be ephemeral, as it often is quickly removed or redistributed by water and wind erosion, animals or traffic (Zavala et al., 2009a). Many authors have observed that the capacity of ash to protect soil depends on properties as the topography, the meteorological conditions and the thickness of ash coverage (Cerdà and Doerr, 2008; Pereira et al., 2013; Woods and Balfour, 2010; Zavala et al., 2009).

Taking this into account, in this study we hypothesized that the wettability / hydrophobicity of the ash layer may have a significant effect on the soil response to splash erosion. Therefore, the aim of this study is to evaluate the dispersion of sediments produced by the impact of raindrops in function of ash wettability after a prescribed fire at plot scale.

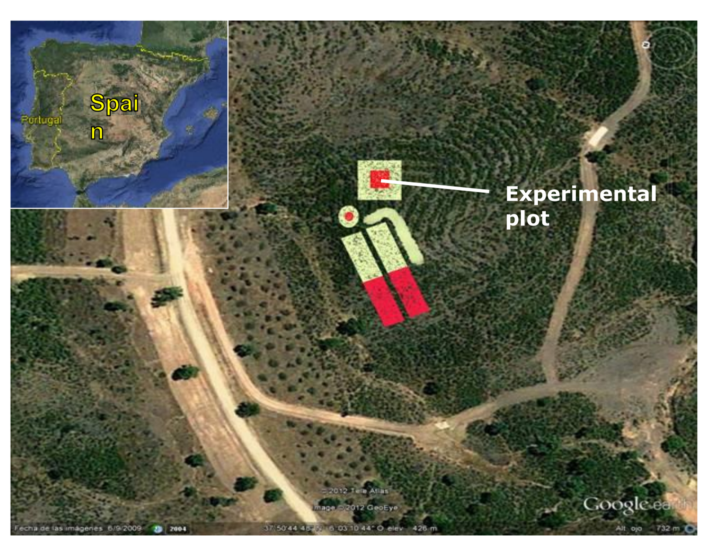

Figure 1. Study area.

Figure 2. View of the study plot inmediately before burn.

Figure 3. Installation of termocouple probes.

Figure 4. Prescribed burning.

Figure 5. Detail of the system for collection of sediments.

Figure 6. The sediment collector installed in the soil.

Material and methods

In 20 November 2012, a prescribed fire was carried out in an area located in the public mount "Las Navas", near Almaden de la Plata, Sevilla (approx. 37º 50' 44.44" N / 6º 3' 7.44"W and 428 masl; **Figure 1**). Soils are acidic and shallow, developed from acidic metamorphic rocks (schists, slates and pyrophyllites). Vegetation is dominated by shrub legumes (*Calicotome villosa* and several species of *Ulex* and *Genista*; **Figure 2**). The experimental area was framed and plowed to eliminate the risk of fire spreading during the experiment. Previously to burn, level staffs were installed for determination of flame height. The temperature reached in the soil was monitored during the fire by a set of six thermocouples which were buried in soil (2 cm depth) and connected to a data-logger for monitoring the topsoil temperature every 60 s (**Figure 3**). The environmental conditions were also monitored during the experiment by a mobile weather station. At the moment of the ignition, temperature was around 20 ºC and the wind speed was near 0.0 m/s. After ignition, the experimental area was allowed to burn during 2.5 h (**Figure 4**). During burning, flames reached 200 cm height, although thermal peaks recorded 2 cm depth were relatively low (not surpassing 80 ºC). After burning, the soil surface was covered by a pattern of white and black ash, indicating varying degrees of fire severity, and areas covered by water repellent or hydrophilic ash were selected using the ethanol percentage test (EPT).

Table 1. Classification of the ntensity of ash water repellency.

EPT class	Ethanol (%)	Intensity of water repellency
0	0	Very wettable
1	3	Wettable
2	5	Slight water repellency
3	8.5	Moderate water repellency
4	13	Strong water repellency
5	24	Very strong water repellency
6	36	Extreme water repellency

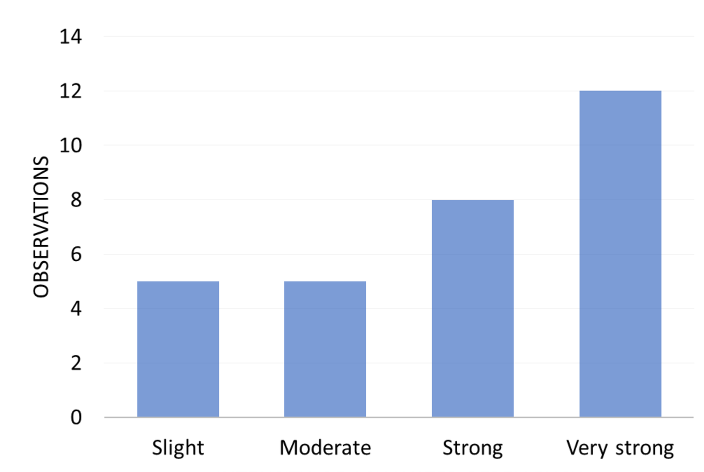

Figure 7. Intensity of ash water repellency in non-wettable areas.

The EPT provides an indirect measurement of the surface tension of the ground and, therefore, indicates the intensity of soil water repellency and is based on the different surface tension of a number of standardized solutions of ethanol in water. The procedure consists in applying drops (0.05 mL) of different ethanol solutions with different concentrations onto the surface of the ash layer observing if infiltration occurs in a period that not exceed 5 s (Jordán et al., 2010) . Every drop is allowed to fall from a distance not bigger than 15 mm to avoid the excess of kinetic energy that can affect infiltration. Applying drops with decreasing surface tension (that is, with concentrations of increasing ethanol) until a drop resists the infiltration allows the classification of the ground in a particular class of surface tension between two concentrations of ethanol: that in which infiltration occurs immediately (in less than 5 s) and the above solution of weaker concentration. Thus, it is assumed that solution whose drop is infiltrated within the first 5 s after application has a lower surface tension than soil surface (**Table 1** shows the classification of water repellency).

Fifteen representative points were selected at wettable or water-repellent ash zones. At each selected point, surrounded by white/wettable or dark/water-repellent ash to a minimum distance of 0.5 m, splash sediment collection device was installed. This system consist on a couple of funnels (100 mm in diameter; **Figure 5**) arranged one inside the other, with a paper filter beween both (**Figure 6**). Each device was inserted in soil until only 10 mm protruding the ground surface in order to avoid capturing runoff sediments. Sediments collected at each point of study were collected monthly and determined gravimetrically after oven drying between November 2012 and May 2013.

Table 2. Sediment collected (mean ± standard deviation) per dampling campaign and ANOVA p-value. Means followed by different letters are significantly different for each zone.

Zone	Sampling date	N	Sediment collected	ANOVA p-value
Water-repellent ash	1	15	3.9 + 0.44 a	0.0000
	2	15	5.28 + 0.69 b	
	3	15	10.61 + 1.34 c	
	4	15	14.2 + 1.75 d	
	5	15	16.97 + 1.66 e	
	6	15	19.91 + 2.16 f	
	7	15	21.74 + 3.27 g	
Wettable ash	1	15	1.29 + 0.12 a	0.0000
	2	15	1.48 + 0.17 a	
	3	15	3.06 + 0.39 b	
	4	15	4.32 + 0.47 c	
	5	15	4.96 + 0.52 d	
	6	15	6.1 + 0.58 e	
	7	15	6.14 + 0.69 e	

Figure 7. Filter papers with collected sediment, during oven-drying.

Results and discussion

Depending on the intensity of the water repellency, the ash layer fluctuated between wettable and very strongly water repellent. Ash has a high permeability and water storage. However, its hydrophilic character has been emphasized rarely (Cerdà and Doerr, 2008). Different authors have described hydrophobic behaviors depending on the burned vegetation such as oak (Gabet and Sternberg, 2008) or pine forest (Stark, 1977) in the United States, eucalyptus forest in Australia (Khanna et al., 1996) or Mediterranean tree and shrub species in Spain (Bodí et al., 2011). In the latter case, Bodí et al. (2011) observed that ash has different properties depending on the combustion conditions, organic carbon content and color. This variability of behavior agrees with the results obtained in the present work.

Significant differences between splash erosion from wettable and water-repellent ash zones were found ($p < 0.0001$). In the water-repellent ash zone, large differences were found among samples. The amount of sediment displaced by splash increased rapidly up to 264.10% (from 3.90 ± 0.44 to 14.20 ± 1.75 g) during the first four months after burn (November 2012 - February 2013). In contrast, during the last three months (March - May 2013), the amount of displaced sediments remained high, but with low growing rate (28.11%, from 16.97 ± 1.66 to 21.74 ± 3.27 g).

In the wettable ash zone, the amount of sediment displaced was much smaller, with mean values between 1.29 (November 2012) and 6.14 g (May 2013). During the first two sampling dates after burn, data did not differ significantly among sites (1.38 ± 0.18 g on average), but the amount of sediment collected grew slowly during the experimental period between 3.06 ± 0.39 and 6.14 ± 0.69 g (January - May 2013). Several authors have suggested that ash acts protecting soil from the direct impact of raindrops and thus reduce sediment dispersion by splash (Cerdà and Doerr, 2008, Larsen et al, 2009; Woods and Balfour, 2008, Zavala et al, 2009). However, there is very little information about the effect of hydrophobicity on splash erosion. In a rainfall simulation experiment under laboratory conditions, Bodí et al. (2012) observed that splash erosion was at least two times higher in samples of water repellent soil than in hydrophilic soil, but no differences in ash loss or thickness of ash layer were observed.

Conclusions

Our results highlight the role played by ash water repellency and the influence of burn severity on the development of a pattern of splash erosion intensities. Splash erosion was reduced in one order of magnitude on wettable ash zones. In contrast, the presence of a water-repellent ash layer increases the mobilization of sediments at plot scale. Further research should focus on the impacts of ash wettability on splash erosion at hillslope scale in the post fire.

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