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# Short-term changes in soil Munsell colour value, organic matter content and soil water repellency after a spring grassland fire in Lithuania

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**Abstract.** Fire is a natural phenomenon with important implications on soil properties. The degree of this impact depends upon fire severity, the ecosystem affected, topography of the burned area and post-fire meteorological conditions. The study of fire effects on soil properties is fundamental to understand the impacts of this disturbance on ecosystems. The aim of this work was to study the short-term effects immediately after the fire (IAF), 2, 5, 7 and 9 months after a low-severity spring boreal grassland fire on soil colour value (assessed with the Munsell colour chart), soil organic matter content (SOM) and soil water repellency (SWR) in Lithuania. Four days after the fire a 400 $m^2$ plot was delineated in an unburned and burned area with the same topographical characteristics. Soil samples were collected at 0–5 cm depth in a 20 m × 20 m grid, with 5 m space between sampling points. In each plot 25 samples were collected (50 each sampling date) for a total of 250 samples for the whole study. SWR was assessed in fine earth (< 2 mm) and sieve fractions of 2–1, 1–0.5, 0.5–0.25 and < 0.25 mm from the 250 soil samples using the water drop penetration time (WDPT) method. The results showed that significant differences were only identified in the burned area. Fire darkened the soil significantly during the entire study period due to the incorporation of ash/charcoal into the topsoil (significant differences were found among plots for all sampling dates). SOM was only significantly different among samples from the unburned area. The comparison between plots revealed that SOM was significantly higher in the first 2 months after the fire in the burned plot, compared to the unburned plot. SWR of the fine earth was significantly different in the burned and unburned plot among all sampling dates. SWR was significantly more severe only IAF and 2 months after the fire. In the unburned area SWR was significantly higher IAF, 2, 5 and 7 months later after than 9 months later. The comparison between plots showed that SWR was more severe in the burned plot during the first 2 months after the fire in relation to the unburned plot. Considering the different sieve fractions studied, in the burned plot SWR was significantly more severe in the first 7 months after the fire in the coarser fractions (2–1 and 1–0.5 mm) and 9 months after in the finer fractions (0.5–0.25 and < 0.25 mm). In relation to the unburned plot, SWR was significantly more severe in the size fractions 2–1 and < 0.25 mm, IAF, 5 and 7 months after the fire than 2 and 9 months later. In the 1–0.5- and 0.5–0.25 mm-size fractions, SWR was significantly higher IAF, 2, 5 and 7 months after the fire than in the last sampling date. Significant differences in SWR were observed among the different sieve fractions in each plot, with exception of 2 and 9 months after the fire in the unburned plot. In most cases the finer fraction (< 0.25 mm) was more water repellent than the others. The comparison between plots for each sieve fraction showed significant differences in all cases IAF, 2 and 5 months after the fire. Seven months after the fire significant differences were only observed in the finer fractions (0.5–0.25 and < 0.25 mm) and after 9 months no significant differences were identified. The correlations between soil Munsell colour value and SOM were negatively significant in the burned and unburned areas. The correlations between Munsell colour value and SWR were only significant in the burned plot IAF, 2 and 7 months after the fire. In the case of the correlations between SOM and SWR, significant differences were only identified IAF and 2 months after the fire. The partial correlations (controlling for the effect of SOM) revealed that SOM had an important influence on the correlation between soil Munsell colour value and SWR in the burned plot IAF, 2 and 7 months after the fire.

## 1 Introduction

Fire is a natural phenomenon important to many ecosystems worldwide. It is accepted that fire plays an important role in plant adaptations and ecosystem development and distribution (Pausas and Kelley, 2009). It is well known that fire is a common occurrence and important disturbance in boreal ecosystems and a factor in the forest ecology of the region (Vanha-Majamaa et al., 2007). These ecosystems are strongly adapted to fire disturbance (Granstrom, 2001; Hylander, 2011; Pereira et al., 2013a, b). However, climate change, recent land-use change and fire suppression policies, may have important implications on the fire regime, fire severity and the role of fire in boreal environments (De Groot et al., 2013; Kouki et al., 2012; Van Bellen et al., 2010).

Fire has been recognized to be a soil-forming factor (Certini, 2014). Despite this, little research has been carried out on soil properties from boreal grassland ecosystems (Pereira et al., 2013a, c). The majority of studies on fire impacts on grassland soils have been carried out in tropical (Coetsee et al., 2010; Michelsen et al., 2004), subhumid (Knapp et al., 1998), desert (Ravi et al., 2009a; Whitford and Steinberger, 2012), arid (Vargas et al., 2012), semiarid (Dangi et al., 2010; Ravi et al., 2009b; Xu and Wan, 2008), temperate (Harris et al., 2007) and Mediterranean environments (Marti-Roura et al., 2013; Novara et al., 2013; Úbeda et al., 2005).

After a fire, the degree of direct and indirect impacts on soils (e.g. ash and soil erosion, water balance, organic matter, hydrophobicity, ash nutrient input, and microbiological changes) has consequences for the complex spatio-temporal distribution and availability of nutrients (Kinner and Moody, 2010; Malkinson and Wittenberg, 2011; Moody et al., 2013; Pereira et al., 2011; Sankey et al., 2012; Shakesby, 2011). The spatio-temporal extent of fire impacts depends on the fire severity, topography of the burned area and the post-fire meteorological conditions.

Fire can change soil colour. In fires of high severity the temperatures increase soil redness, especially at temperatures of 300–500 °C (Terefe et al., 2008) or > 600 °C (Ketterings and Bigham, 2000; Ulery and Graham, 1993), which is attributed to the destruction of the organic matter and increase in iron oxides such as hematite (Terefe et al., 2005). In contrast, low-severity fires darken the soil as a result of the incorporation of ash/charcoal into the soil surface and matrix (Eckmeier et al., 2007). These authors observed that soil lightness of colour had a significant negative correlation with charcoal carbon. Despite this knowledge, little is known about the soil lightness changes in the immediate period after the fire, when the major changes in soil properties and ash transport happen (Pereira et al., 2013a; Scharenbroch et al., 2012).

Few studies have been carried out about fire effects on soil colour lightness in comparison to unburned soils. Eckmeier et al. (2007) studied the effects of a slash-and-burn fire on soil lightness compared to soil in an unburned plot. However, the study was carried out immediately after the fire and 1 year after the fire. Major changes were not observed in detail in the year after the fire. The changes in soil lightness after fire can have implications for temperature (albedo increase or decrease) and microbiological activity (Certini, 2005; Gomez-Heras et al., 2006). Thus it is important to have high-resolution studies of fire effects on soil lightness.

Fire affects also the soil organic matter (SOM) chemical composition and quantity. Fire can increase or decrease SOM depending on the type of fire and severity, a parameter which considers the effects of biophysical variables such as topography, soil type, vegetation species and ecosystem affected (Certini et al., 2011; González-Peréz et al., 2004; Knicker, 2007). Low-severity fires can increase SOM in the immediate period after, due to the incorporation of charred material (De Marco et al., 2005), and high-severity fires tend to consume the major part of SOM due to the high temperatures (Neff et al., 2005). Depending on the rainfall and topography, important amounts of SOM can be also lost by erosion some months after a fire (Novara et al., 2011).

The soil Munsell colour value, chroma and hue are useful methods to estimate SOM content (Spielvogel et al., 2004; Viscarra Rossell et al., 2006). The Munsell colour value is used to describe the lightness of the soil, chroma measures the colour intensity and hue the shade of the soil (Thwaites, 2002). Usually, SOM content is negatively correlated with soil hue, value and chroma (Ibañez-Ascencio et al., 2013; Viscarra Rossell et al., 2006). However, this relationship depends on the SOM composition. In soils with high organic carbon, soil darkening is attributed to the composition and quantity of black humic substances (Schulze et al., 1993). Soil colour estimation has been carried out using visual observation in the field (Post et al., 1983), in a laboratory environment (Torrent et al., 1980; Scharenbroch et al., 2012), using diffuse reflectance spectrophotometers (Spielvogel et al., 2004; Torrent and Barron, 1983) and more recently, smartphone applications (Gomez-Robledo et al., 2013).

It is widely known that fire can induce soil water repellency (SWR), with implications for soil infiltration, water and nutrient availability and an increase of runoff and erosion (DeBano et al., 2000; Mataix-Solera et al., 2013; Varela et al., 2005). The fire impacts on SWR depend on type of soil affected, temperature reached, fire severity, fire recurrence, time of residence, type and amount of vegetation combusted, ash produced and pre- and post-fire soil moisture content (Bodí et al., 2011; Doerr et al., 2000; Jordán et al., 2011; MacDonald and Huffman, 2004; Mataix-Solera and Doerr, 2004; Tessler at al., 2012; Vogelmann et al., 2012). Previous studies observed that after a fire, SWR is especially changed in soils that were wettable before the fire compared to those that are hydrophobic (Gimeno-Garcia et al., 2011). In wettable soils, fire usually increases SWR (Granged et al., 2011; Mataix-Solera and Doerr, 2004), meanwhile in hydrophobic soils, fire can slightly reduce or have no impact on SWR (Doerr et al., 1998; Jordán et al., 2011; Neris et al., 2013). However, this effect depends on fire severity. Rodriguez-Alleres et al. (2012) reported that moderate-to-high severity fires can increase SWR in naturally repellent soils. Soil heating increases SWR due the volatilization of organic compounds in the litter and topsoil. The heating of the soil surface layer develops a pressure gradient in the heated layer, causing the upward movement into the atmosphere of these compounds, while others move downwards. The decrease of soil temperature with depth forces SOM compounds to condense onto soil particles at or below the soil surface. Soil heating can redistribute and concentrate the natural substances in soil and litter, facilitate the bonding of these substances to soil particles, and increase their hydrophobicity as a result of conformational changes in their structural arrangement (Doerr et al., 2009). Heat changes the SOM composition through thermal alteration and chemical transformation. Heating also induces an increase in the content of aromatic compounds, the formation of complex high-molecular-weight compounds and low-molecular-weight oxo- and hydroxyacids (Atanassova and Doerr, 2011). Soil moisture controls SWR. Doerr and Thomas (2000) observed in coarse-textured burned and unburned soils that SWR disappeared when soil moisture exceeded 28 %. MacDonald and Huffman (2004) noted soil moisture thresholds where soils became hydrophilic were 10 % for unburned sites, 13 % for areas burned with low severity and 26 % for sites burned at moderate and high severity. Post-fire changes in SWR are not well understood. Doerr et al. (2009) stated that more detailed studies are needed to determine (i) the duration of fire-induced SWR in different vegetation types and (ii) the relative roles of physical, chemical, and biological factors in breaking down post-fire SWR.

Spring grassland fires are frequent in Lithuania. After the winter, farmers burn the dead grass in order to improve fields for spring and summer crops (Pereira et al., 2012a). Thus, it is important to know the effects of these fires on soil properties in order to understand the impacts of this practice and their persistence in time, especially in this environment where few studies have been carried out. This study contributes to a better understanding of fire effects and short-term changes in soil properties in boreal grasslands. At this time, the use of fire for landscape management is forbidden in Lithuania but, frequently, farmers set fires and leave the area until the fires are extinguished, leading on many occasions to loss of infrastructure and impacts on natural resources (Mierauskas, 2012; Pereira et al., 2012a).

The aim of this work was to study the short-term temporal effects of a low-severity spring grassland fire on some surface soil properties (0–5 cm) such as soil colour value (assessed with the Munsell colour chart), SOM content and SWR, in order to observe if this grassland fire induced relevant short-term impacts on these soil properties. The study focused on the upper soil layer because previous studies have shown that fire effects on soil are especially limited to the first 5 cm (Marion et al., 1991; Blank et al., 2003), and especially in low-severity fires, where soil temperatures rarely exceed 100 °C at the surface and 50 °C at 5 cm (Agee, 1973).

## 2 Materials and methods

### 2.1 Study site and design

On 15 April 2011 an area of 20–25 ha near Vilnius (Lithuania) was affected by a wildfire. The burned area is located at coordinates 54°42′ N, 25°08′ E with an elevation of 158 m a.s.l. (above sea level). According to the local farmers, the fire was attributed to human causes resulting from the burning of grass and wood residues (Pereira et al., 2012a). The characteristics of the study area are described in Table 1. Fire severity was considered low based on the predominance of black ash and unburned patches (Pereira et al., 2013a). Four days after the fire, a plot of 400 $m^2$ was delineated (20 m $\times$ 20 m, with a grid with 5 m spacing between sampling points) in an unburned and burned area with the same topographical characteristics (flat area). In total, 25 samples (topsoil, 0–5 cm) were collected in each plot, immediately after burning (IAF) and 2, 5, 7 and 9 months later. Samples were stored in plastic bags, taken to the laboratory and air-dried for 24 h to constant weight. Subsequently, the samples were carefully sieved through a 2 mm mesh.

### 2.2 Laboratory analysis

The soil colour value was assessed using the Munsell colour chart (Viscarra Rossel et al., 2006) in the 2 mm sieved fraction. The Munsell value gives information about soil darkness/lightness. Low values correspond to dark soils and high values to light soils (Eckmeier et al., 2007). All the soil value analyses were carried out by the same person under the same light conditions. SOM content was

**Table 1.** Main characteristics of the study area.

| Geological substrate (Kadunas et al., 1999) | Glacio-lacustrine deposits |
|---|---|
| Soil type (WRB, 2006) | Albeluvisols |
| [a, b]Texture (% sand, silt and clay) (USDA, 2004) | 9.4 (±3.07), 63.5 (±8.14), 27.1 (±5.21) (Silt loam) |
| [a]pH | 7.2 (±0.15) |
| [a]Organic matter content (%) | 6.5 (±1.16) |
| Mean annual rainfall (mm) (Bukantis, 1994) | 735 |
| Mean annual temperature (°C) (Bukantis, 1994) | 8.8 |
| Dominant vegetation | Fall dandelion (*Leontodon autumnalis* L.) and sweet vernal grass (*Anthoxanthum odaratum* L.) |

[a] Values based on unburned soil samples ($N = 25$).
[b] Sand: 2–0.05 mm, silt: 0.05–0.002 mm, clay: < 0.002 mm.

estimated by the loss-on-ignition (LOI) method using approximately 1 g of soil heated to 900 °C for 4 h (Avery and Bascomb, 1974) after drying at 105 °C for 24 h to remove the moisture. LOI was calculated according to the formula $LOI = (Weight_{105} - Weight_{900}) / Weight_{105}) \times 100$.

Soil texture of unburned samples was analysed using the Bouyoucos method (Bouyoucos, 1936) and pH with 1 : 2.5 deionized water (Table 1). Soil water repellency was assessed in the samples sieved through the 2 mm mesh (fine earth) and in the subsamples of all of the 250 samples divided into different soil sieve fractions of 2–1, 1–0.5, 0.5–0.25 and < 0.25 mm, as used in previous studies (Jordán et al., 2011; Mataix-Solera and Doerr, 2004). Soil sieving was done on the dried samples and the separation of fractions was carried out carefully, in order to not destroy the aggregates (Mataix-Solera and Doerr, 2004). In total 1250 SWR subsamples were analysed. Between 5 and 7 g of soil of each sample and subsample were placed in 60 mm diameter plastic dishes and exposed to a controlled laboratory environment (temperature of 20 °C and 50 % of air relative humidity) for 1 week in order to avoid potential effects of atmospheric conditions on SWR (Doerr, 1998; Doerr et al., 2005). The persistence of SWR was measured with the water drop penetration time (WDPT) method that involves placing three drops of distilled water onto the soil surface and registering the time required for the complete penetration of the drops (Wessel, 1988). The average time of the three drops was used to assess the WDPT of each sample and subsample. WDPT classes were assessed according to Doerr (1998) (Table 2).

**Table 2.** WDPT classes used in this work. Water drop penetration time measured in seconds (s) (according to Doerr, 1998).

| WDPT classes | Wettable | Low | Strong | Severe |
|---|---|---|---|---|
| WDPT interval (s) | < 5 | 6–60 | 61–600 | 601–3600 |

### 2.3 Statistical analysis

Data normality and homogeneity of the variances were tested with the Shapiro–Wilk test (Shapiro and Wilk, 1965) and Levene test, respectively. Data were considered normal and homogeneous at a $p > 0.05$. In this study, data did not follow the normal distribution and displayed heteroscedasticity. Thus the alternative non-parametric Kruskal–Wallis ANOVA (analysis of variance) test (K–W) was used to analyse differences among sampling dates and SWR according to the aggregate sieve fractions in each plot. The comparison between plots was carried out with the Mann–Whitney $U$ test (MU). If significant differences at a $p < 0.05$ were observed after the K–W test, a Tukey HSD (honestly significant difference) post-hoc test was applied.

Correlations between the variables were carried out with the Pearson coefficient of correlation after variables SQR transformation, in order for the data to meet normality requirements. In the case of SWR, the coefficient of correlation just considered the fine-earth samples. A partial correlation was carried out between Munsell colour value and SWR, using SOM content as a control variable in order to observe if SOM influenced the correlation between Munsell colour value and SWR. Significant correlations were considered at a $p < 0.05$. Statistical analyses were carried out with STATISTICA 6.0 (Statsoft Inc., 2006).

## 3 Results

### 3.1 Soil Munsell colour value

The soil colour in the burned and unburned plots was in the soil Munsell 10YR hue for all the samples. The Munsell colour value was significantly different among sampling dates in the burned plot (K–W = 35.37, $p < 0.001$), but not in the unburned area (K–W = 9.20, $p > 0.05$) (Fig. 1). Soil was significantly darker in the burned than in the unburned plot for all sampling dates, IAF (MU = 1, $p < 0.001$), 2 months (MU = 69, $p < 0.001$), 5 months (MU = 46, $p < 0.001$), 7 months (MU = 56, $p < 0.001$) and 9 months later (MU = 84, $p < 0.001$).

### 3.2 Soil organic matter

SOM content was not significantly different among sampling dates in the burned plot (K–W = 6.60, $p > 0.05$), but it was in the unburned area (K–W = 20.96 $p < 0.001$) (Fig. 2). SOM

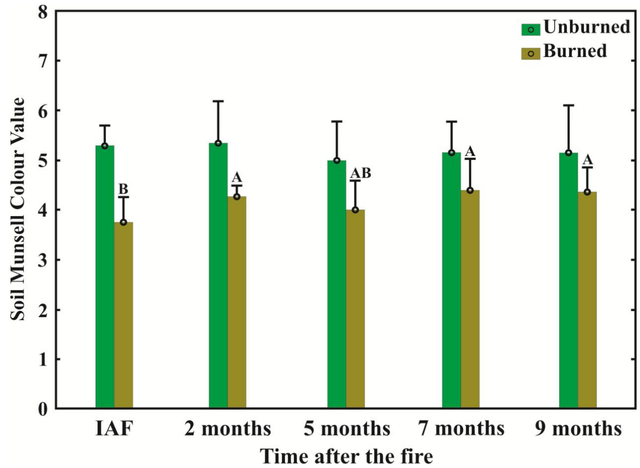


**Fig. 1.** Evolution of soil Munsell value in the unburned and burned plots in the post-fire sampling dates (bars represent ± standard deviation). Different letters indicate significant differences ($p < 0.05$) among times. IAF (Immediately After the Fire).

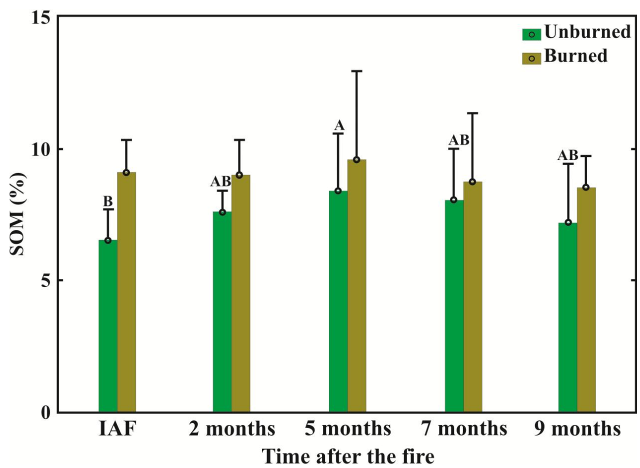


**Fig. 2.** Evolution of SOM content in the unburned and burned plots in the post-fire sampling dates (bars represent ± standard deviation). Different letters indicate significant differences ($p < 0.05$) among times.

content was significantly higher in the burned plot than in the unburned plot IAF (MU = 31, $p < 0.001$) and 2 months after the fire (MU = 116, $p < 0.001$). Five (MU = 266, $p > 0.05$), 7 (MU = 299, $p > 0.05$) and 9 months (MU = 254, $p > 0.05$) after the fire no significant differences were observed between plots.

### 3.3 Soil water repellency

The SWR of the fine earth was significantly different among sampling dates in the burned (K–W = 94.18, $p < 0.001$) and unburned plots (K–W = 45.65, $p < 0.001$) (Fig. 3). With time a decrease of SWR was observed in the burned area. In the unburned area SWR was significantly more severe IAF, 2,

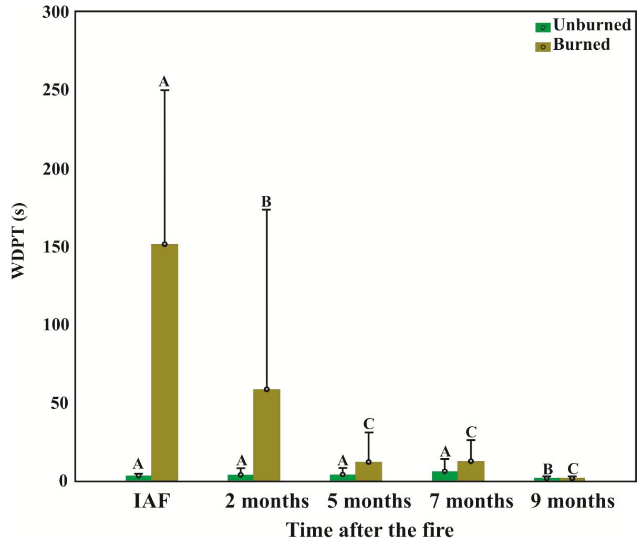


**Fig. 3.** Evolution of SWR (composite sample) in the unburned and burned plots in the post-fire sampling dates (bars represent ± standard deviation). Different letters indicate significant differences ($p < 0.05$) among times.

5 and 7 months after the fire than 9 months later. SWR was significantly high in the burned soil in the first two sampling dates, IAF (MU = 0, $p < 0.001$) and 2 months after the fire (MU = 26, $p < 0.001$). No significant differences were observed between plots 5 (MU = 249, $p > 0.05$), 7 (MU = 238, $p > 0.05$) and 9 months (MU = 267, $p > 0.05$) after the fire.

In relation to the analysed sieved soil fractions, significant differences were observed in SWR among all sieve fractions in the burned and unburned areas (Table 3a). In the burned area significant differences were observed in the coarser sieve fractions (2–1 and 1–0.5 mm) in the first 7 months after the fire, whereas in the finer fractions (0.5–0.25 and < 0.25 mm), significant differences among fractions were not identified until 9 months later (Table 4). In the unburned area's aggregate-size fractions of 2–1 and < 0.25 mm SWR was more severe IAF, 5 and 7 months after the fire than 2 and 9 months after the fire. In the size fractions 1–0.5 and 0.5–0.25 mm, SWR was significantly more persistent IAF, 2, 5 and 7 months after the fire than 9 months after the fire (Table 4).

The SWR was higher in the finer fractions (0.5–0.25 and < 0.25 mm) than in the coarser fractions (2–1 and 1–0.5 mm) (Table 4). Significant differences were observed in the studied sieve fractions in SWR in each plot during the experimental period, with the exception of 2 and 9 months after the fire in the unburned plot (Table 3b). In the unburned and burned plots for all sampling dates, the SWR in the finer fraction (< 0.25 mm) was significantly more severe than in the other sieve fractions, except for IAF and 5 months after the fire in the unburned plot, where no significant differences were observed between 0.5–0.25 mm and < 0.25 mm sieve fractions

**Table 3.** Results of Kruskal–Wallis ANOVA and Mann–Whitney tests for SWR according to the analysed sieved fractions, (a) time, (b) soil sieved fractions in the same plot and (c) between plots in each soil sieved fraction.

| (a) | Sieved fraction mm | Plots | K–W | *p* |
|---|---|---|---|---|
| | 2–1 | Unburned | 43.07 | *** |
| | | Burned | 75.25 | *** |
| | 1–0.5 | Unburned | 35.39 | *** |
| | | Burned | 78.17 | *** |
| | 0.5–0.25 | Unburned | 41.17 | *** |
| | | Burned | 87.28 | *** |
| | < 0.25 | Unburned | 62.89 | *** |
| | | Burned | 89.44 | *** |
| **(b)** | **Sampling date** | **Plot** | **K–W** | ***p*** |
| | IAF | Unburned | 25.14 | *** |
| | | Burned | 33.29 | *** |
| | 2 months | Unburned | 4.06 | n.s. |
| | | Burned | 24.35 | *** |
| | 5 months | Unburned | 41.30 | *** |
| | | Burned | 9.07 | * |
| | 7 months | Unburned | 36.21 | *** |
| | | Burned | 27.07 | *** |
| | 9 months | Unburned | 4.25 | n.s. |
| | | Burned | 8.60 | * |
| **(c)** | **Sampling date** | **Sieve fractions mm** | **MU** | ***p*** |
| | IAF | 2–1 | 30 | *** |
| | | 1–0.5 | 30 | *** |
| | | 0.5–0.25 | 13.50 | *** |
| | | < 0.25 | 15 | *** |
| | 2 months | 2–1 | 39 | *** |
| | | 1–0.5 | 10.50 | *** |
| | | 0.5–0.25 | 22.50 | *** |
| | | < 0.25 | 13.00 | *** |
| | 5 months | 2–1 | 30.50 | *** |
| | | 1–0.5 | 29.50 | *** |
| | | 0.5–0.25 | 67 | *** |
| | | < 0.25 | 164 | * |
| | 7 months | 2–1 | 255 | n.s. |
| | | 1–0.5 | 265 | n.s. |
| | | 0.5–0.25 | 193 | * |
| | | < 0.25 | 196 | * |
| | 9 months | 2–1 | 298.5 | n.s. |
| | | 1–0.5 | 297.5 | n.s. |
| | | 0.5–0.25 | 299 | n.s. |
| | | < 0.25 | 225 | n.s. |

n.s.: non-significant at a $p < 0.05$. $< 0.05$*, and $< 0.001$***.
IAF (immediately after the fire).

(Table 4). Significant differences were also found in SWR between both plots IAF, 2 and 5 months after the fire. Seven months after the fire significant differences were only observed in the finer fractions (0.5–0.25 and < 0.25 mm) and 9 months later no significant differences were identified between plots in any of the sieve fractions (Table 3c).

In the unburned plot, for all the sampling dates and aggregate sieve fractions analysed, samples were predominantly wettable (Fig. 4a, c, e, i), with the exception of 7 months after the fire where the finer fraction (< 0.25 mm) samples were classified as "low". In the burned plot the SWR was classified mainly as "low" (Fig. 4b, d, f, h, j). However, SWR was classified as strong and severe IAF in the finer fraction (< 0.25 mm). With time SWR persistence was reduced in all the fractions and 9 months after the fire the samples were all wettable, with SWR < 5 s (Fig. 4i, j).

### 3.4 Correlation between variables

In the unburned area the correlations between soil Munsell colour value and SOM were always negatively significant ($p < 0.05$). The correlations between soil Munsell colour value and SWR and between SOM and SWR were not significant in any case (Table 5). The correlations between Munsell colour value and SOM in the burned area were negatively significant for all sampling dates. However, the correlations between Munsell colour value and SWR and between SOM and SWR were only significant IAF, 2, and 7 months after the fire (7 months later only in the correlation between Munsell colour value and SWR). The coefficients of correlation decrease with time in all cases (Table 5). The partial correlation results showed that SOM controls the correlation between Munsell colour value and SWR, in the burned plot IAF, 2, and 7 months after the fire. IAF the original correlation was highly significant ($r = -0.81$, $p < 0.001$), being considerably reduced in the partial correlation ($r = 0.41$, $p < 0.01$), 2 months after the fire the original correlation was significant ($r = 0.39$, $p < 0.01$), disappearing in the partial correlation ($r = 0.26$, $p > 0.05$), and 7 months later the original correlation was significant ($r = 0.32$, $p < 0.05$), decreasing in the partial correlation ($r = 0.14$, $p > 0.05$) (Table 5).

## 4 Discussion

### 4.1 Soil Munsell colour value

Fire darkened the soil in the immediate period after the fire. Incomplete fuel combustion produces black ash (Úbeda et al., 2009), especially in low-severity fires, as in the present one, where the temperatures do not reach high values (Keeterings and Bigham, 2000). Normally, black ash is incorporated into the soil or can be eroded in the weeks following the fire (Pereira et al., 2013b), contributing to the darkening of the soil following the fire and the reduction of Munsell value as observed in this study and in previous reports (Ulery and

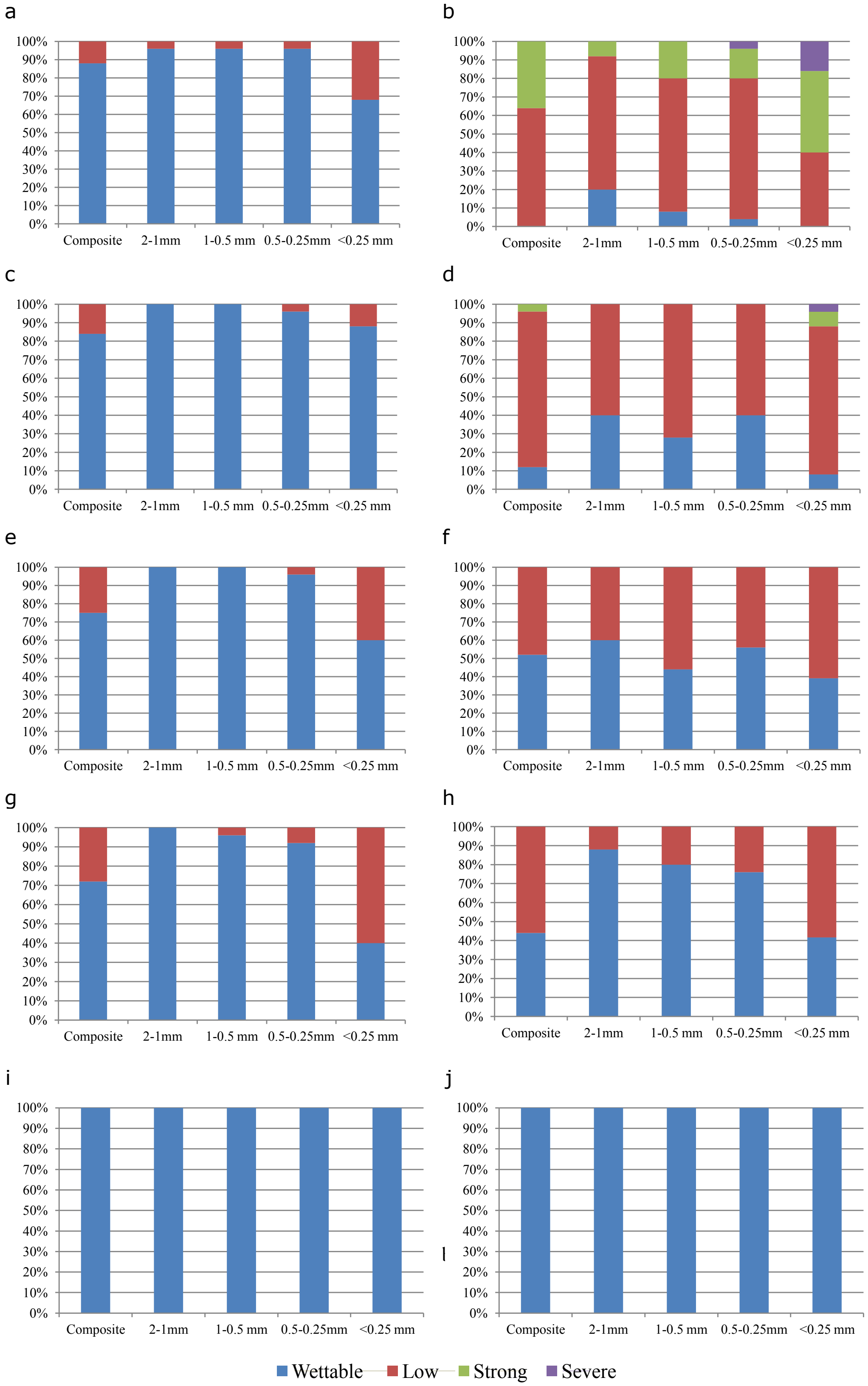


**Fig. 4.** Relative frequency of SWR for composite and sieved soil fractions, **(a)** unburned, after the fire; **(b)** burned, after the fire; **(c)** unburned, 2 months after the fire; **(d)** burned, 2 months after the fire; **(e)** unburned, 5 months after the fire; **(f)** burned, 5 months after the fire; **(g)** unburned, 7 months after the fire; **(h)** burned, 7 months after the fire; **(i)** unburned, 9 months after the fire; and **(j)** burned, 9 months after the fire.

**Table 4.** Water drop penetration time (s) in terms of the different size fractions for unburned and burned plots for different sampling dates. Statistical comparisons were carried out between times (upper case) and in each plot (different fractions in the same plot) during the studied sampling dates (lower case). Different letters represent significant differences at $p < 0.05$.

| Sampling date | Plots | 2–1 mm | 1–0.5 mm | 0.5–0.25 mm | < 0.25 mm |
|---|---|---|---|---|---|
| IAF | Unburned | 1.73(0.78)Ab | 2.02(1.91)Ab | 3.12(7.29)Aab | 15.44(37.42)Aa |
| | Burned | 65.74(133.01)Ab | 101.13(165.66)Ab | 159.65(301.90)Ab | 500.44(657.81)Aa |
| 2 months | Unburned | 1.57(0.58)B | 1.62(0.74)A | 1.78(1.36)A | 3.21(4.86)B |
| | Burned | 6.60(4.05)Bb | 12.24(15.14)Bb | 17.88(26.53)Bb | 119.13(237.27)Ba |
| 5 months | Unburned | 1.72(0.62)Ab | 1.73(0.61)Ab | 2.69(3.69)Aa | 11.66(16.02)Aa |
| | Burned | 6.70(5.02)Bb | 8.08(7.32)Bb | 9.13(9.86)Cb | 39.33(46.50)Ca |
| 7 months | Unburned | 2.12(0.79)Ab | 2.25(1.92)Ab | 2.70(2.42)Ab | 11.93(15.56)Aa |
| | Burned | 3.24(1.89)Cb | 3.61(2.67)Cb | 4.60(4.29)Db | 19.04(25.45)Da |
| 9 months | Unburned | 1.05(0.15)B | 1.08(0.22)B | 1.02(0.09)B | 1.33(0.25)B |
| | Burned | 1.10(0.30)Cb | 1.36(1.20)Cb | 1.09(0.34)Eb | 1.57 (0.85)Ea |

**Table 5.** Coefficients of correlation between the studied variables in the burned area.

| Sampling date | | Munsell colour value vs. SOM | Munsell colour value vs. SWR | SOM vs. SWR | Partial correlation (SOM) |
|---|---|---|---|---|---|
| IAF | Unburned | $-0.63^{c}$ | $-0.01^{n.s.}$ | $0.01^{n.s.}$ | n.c. |
| | Burned | $-0.74^{c}$ | $-0.81^{c}$ | $0.75^{c}$ | $-0.41^{b}$ |
| 2 months | Unburned | $-0.62^{c}$ | $-0.01^{n.s.}$ | $0.02^{n.s.}$ | − n.c. |
| | Burned | $-0.56^{b}$ | $-0.39^{b}$ | $0.34^{a}$ | $-0.26^{n.s.}$ |
| 5 months | Unburned | $-0.47^{b}$ | $-0.08^{n.s.}$ | $0.17^{n.s.}$ | n.c. |
| | Burned | $-0.45^{b}$ | $-0.23^{n.s.}$ | $0.22^{n.s.}$ | n.c. |
| 7 months | Unburned | $-0.50^{b}$ | $-0.10^{n.s.}$ | $0.18^{n.s.}$ | n.c.$^{n.s.}$ |
| | Burned | $-0.45^{b}$ | $-0.32^{a}$ | $0.17^{n.s.}$ | $-0.14^{n.s.}$ |
| 9 months | Unburned | $-0.41^{b}$ | $-0.01^{n.s.}$ | $0.01^{n.s.}$ | n.c. |
| | Burned | $-0.42^{b}$ | $-0.22^{n.s.}$ | $-0.07^{n.s.}$ | n.c. |

Significant at $< 0.05^{a}$, $< 0.01^{b}$ and $< 0.001^{c}$.
n.s.: non-significant at a $p < 0.05$.
n.c.: partial correlation not calculated due to the lack of correlation between Munsell colour value and SWR.

Graham, 1991). With time, despite the significant differences of soil Munsell colour value between plots, the soil became lighter in the burned plot. This may be attributed to the incorporation of burned residues into the first top centimetres of the soil, reducing soil surface darkness (Eckmeier et al. 2007; Pereira et al., 2012b, c; Woods and Balfour, 2011). The black ash cover has implications in the soil environment in the immediate period after the fire (e.g. temperature and water content). The soil blackening decreases the albedo. This leads to an increase of the soil temperature during the day and a more rapid cooling and heat loss at night (Bowman et al., 2009; Hart et al., 2005; Mataix-Solera et al., 2009; Moody et al., 2013; Scharenbroch et al., 2012). These changes in the soil environment may have effects on the soil temperature and consequently on the microbiological activity, since most biological reactions are related to the temperature. Warmer soils after the fire increase the rates of microbiological processes, such as organic matter decomposition and nutrient release, important to plant recovery (Badia and Marti, 2003; Dooley and Treseder, 2012; Hart et al., 2005; Raison and McGarity, 1980). The change in environmental conditions, together with the nutrient availability, rainfall amount after the fire, and warmer temperatures during the spring season, can explain the fact that 2 months after the fire vegetation recovered completely in this burned area. During this period a total of 88 mm of rainfall was registered (Pereira et al., 2012a; 2013a). As a result of this, 2 months after the fire the effects of soil colour on soil temperature may have been reduced. As in other grassland ecosystems, the fast vegetation recovery is an indicator that the ecosystem is resilient to the impacts of this type of fire (Bond and Parr, 2010; Lewis et al., 2009; Morgan, 1999; Wu et al., 2014).

### 4.2 Soil organic matter

SOM was higher in the burned plot, especially in the first 2 months after the fire. Among sampling dates, a significant difference was only observed in the unburned plot. Previous studies observed that SOM increases in the immediate period after the fire. Vergnoux et al. (2012) identified that in recent fire-affected areas the total organic carbon was significantly higher. In low-severity fires, as in this study, SOM increases temporarily due to the incorporation of ash and charred material into the soil profile (González-Peréz et al., 2004). Short-term increases of SOM in the immediate period after low and medium severity fires were also reported in other studies (De Marco et al., 2005; Gimeno-Garcia et al., 2000; Mataix-Solera et al., 2002; Vogelmann et al., 2012). In this work, during the experimental period significant differences among sampling periods were not observed in the burned plot and this may be related to the fact that the studied plot is located in a flat area and the fast vegetation recovery may have prevented or reduced wind erosion. Soil erosion and SOM transport are accelerated in fire-affected areas due to vegetation removal (Shakesby et al., 2011). Previous studies have shown that losses are high in sloped areas due to water erosion. Gimeno-Garcia et al. (2000) observed that 1 month after an experimental fire carried out in a sloped area, the majority of SOM was washed out due to an extreme rainfall event of more than 30 mm $h^{-1}$. Also, Novara et al. (2011) identified a redistribution and a major accumulation of SOM on the bottom of the slope after a fire in the Valencia region (Spain). The authors attributed this to transport of burned material by surface wash. In the unburned area significant differences among sampling periods were observed, showing that fire might have changed in the short-term the SOM seasonal variation. The lowest value of SOM was observed IAF (April 2011), increasing in the following months. This reduced SOM content in the beginning of the spring season may be attributed to the lack of fresh litter input and reduced biological activity during the winter due to the low temperatures. In summary, this spring fire of low severity increased SOM which may have contributed to the rapid recovery of the vegetation (Pereira et al., 2013a).

The correlation between soil Munsell colour value and SOM was always significantly negative, but especially high in the immediate sampling dates after the fire in both plots. Darker soils correspond to low Munsell values (Viscarra Rosell et al., 2006; Shields et al., 1968; Conant et al., 2011), independently of the area being affected by fire or not. In burned areas, soil became darker with the increasing content of aromatic carbon, present in high amounts in the charred material produced by fires (Dümig et al., 2009). In soils affected by low-severity fires, the colour is darker due to the incomplete combustion of organic matter (Terefe et al., 2008).

### 4.3 Soil water repellency

SWR in the fine earth was significantly different among sampling dates in the burned plot until 2 months after the fire, whereas in the unburned plot 9 months after the fire SWR was significantly lower than the previous sampling dates. Fire-induced SWR was reported in previous works in areas affected by low-severity fires (Gleen and Finley, 2010; Granjed et al., 2011; Stoof et al., 2011). Fire changes SWR in previously wettable soils depending on the fuel amount and litter consumed, soil temperature and pre-fire moisture level (Doerr et al., 2000). In this burned plot it is very likely that the direct impacts of fire (e.g. temperature) were minimal since IAF no significant differences were observed in soil moisture between the burned (14.17 % ± 2.83) and unburned (13.59 % ± 2.82) plots (Pereira et al., 2012b). In this case, since the temperature impact on the topsoil was probably minimal, the observed increase of SWR in the burned plot can be attributed to the indirect effect of ash deposition on the topsoil. Miranda et al. (1993) observed that during a prescribed fire in an open grassland, at 2 cm below the soil surface, the temperature ranged from 29 to 38 °C. According to these authors and Heringuer et al. (2002), in grassland fires the soil temperature does not increase importantly and the majority of the heat is lost by convection. Thus, as observed by Vogelman et al. (2012), the increase of soil temperature may not be the responsible for the increase of SWR. The ash produced at low temperature can be hydrophobic (Bodí et al., 2011) and once deposited onto the soil surface can contribute strongly to SWR increases. As in previous works, the ash collected in this burned area (all samples had black colour) was hydrophobic (Pereira et al., 2012a). Ash water repellency is strongly linked to ash chemistry, especially the organic matter content. Dlapa et al. (2013) observed that the wettability of ash decreases with organic matter content. Hydrophobic surfaces are mainly present in organic material, while inorganic material produced at high temperatures is hydrophilic. According to the authors, this explains the different hydrological properties of different types of ash. These results suggested that the incorporation of organic hydrophobic material produced by the fire may have increased temporarily the SWR. In the unburned plot, changes in SWR may be linked with the seasonal variability in this parameter. SWR is a short-term or seasonal phenomenon and depends, among other factors, on climate, the critical soil moisture content above which SWR disappears, texture and organic matter (Doerr et al., 2000; Vogelman et al., 2013). Nine months after the fire (January 2012), the soil was covered by a thick layer of snow and ice. SWR is more severe after dry periods than during wet conditions (Doerr et al., 2000). Buczko et al. (2005) observed in sandy luvisols that SWR was more severe in summer than in autumn/winter. The authors attributed this seasonal variability to the organization of organic amphiphilic compounds that changes during wetting and drying cycles according to the seasonal variations of the soil moisture regime. However, the seasonal variability of organic compounds dissolved into the soil solution may also be relevant. Studies carried out by Arye et al. (2007) observed that SWR decreases with the increase of dissolved organic matter leached out by water. In grassland soils, Farrel et al. (2011) observed that soil-dissolved organic carbon was higher in spring than in autumn and winter due to the reduced microbiological activity and the vegetation's seasonal carbon cycles, which have implications for SOM decomposition. Also, according to Kaiser et al. (2001), the soil samples collected in the summertime are richer in hydrophobic compounds than those collected in winter. Further research is needed in order to understand the dynamics of seasonal variation of SWR in boreal grasslands, especially during the wintertime in snow covered soils.

Two months after the fire, SWR decreased substantially in the burned plot, while SOM maintained the same levels during the whole study period. Vogelmann et al. (2012) also observed after a grassland fire an increase of SWR 2 months after the fire, decreasing thereafter. The preservation of SOM levels may be attributed to the rapid vegetation recuperation in the studied area, which maintained the SOM content levels, but vegetation recovery, rainfall, microbiological and invertebrate activity, may contribute to a decrease in the amount of hydrophobic compounds produced by the fire. The biological activity associated with vegetation recovery has implications on the reduction of SWR (Doerr et al., 2009). Knicker et al. (2013) observed that in fire-affected soils where there is no vegetation cover re-establishment and litter input, the different chemical composition of SOM and pyrogenic organic matter increase the SOM aromaticity with reduced solubility. The inputs of fresh litter from vegetation re-establishment replenish SOM and changes soil chemical composition towards that of an area unaffected by fire (Knicker et al., 2013).

In burned areas, previous reports have shown that after a fire, dissolved organic compounds increased in relation to the unburned plot. Michalzik and Martin (2013) observed that after a low-severity prescribed fire in a pine forest, the amount of dissolved organic carbon was significantly higher in the burned plot than in the unburned area. The authors concluded that the leaching of dissolved organic carbon increased measurably after low-severity fires. Similar findings were registered by Zhao et al. (2012) after a prescribed fire in a wetland located in north-eastern China. The authors identified that the dissolved organic carbon was higher in the burned plot than in the unburned plot, until the second growing season after the fire. The solubility of the dissolved organic fractions depends on pH (Andersson et al., 2000; Impellitteri et al., 2002). Impelliteri et al. (2002) observed that the solubility of humic and fulvic acids in soils increased with increasing pH, while hydrophilic acids remain constant at a pH range between 3 and 9. The authors found that at a pH between 3 and 6 the hydrophilic acids dominate the dissolved organic fraction, while at a pH between 7 and 9, humic acids were the dominant fraction. Humic and fulvic acids are recognized to be potential sources of SWR (Atanassova and Doerr, 2011; Badía-Villas et al., 2013; DeBano, 2000). Humic acids increase in percentage in the humin fraction after laboratory heating and real fires (González-Peréz et al., 2004). The potentially leached material in the burned area may be primarily composed of humic and fulvic acids, very likely leached in the first 2 months after the fire. The soil pH of the burned plot was in the range of 6.73–7.42 IAF and 7.13–7.66 2 months after the fire (not shown), hence favourable to the leaching of fulvic and especially humic acids. In contrast, pH levels were not the most advantageous to hydrophilic acid leaching. Overall, this may have facilitated the reduction of SWR. Fire induces important changes in pH and increases nutrient availability due to ash deposition, determining the composition of the microbial community. In the short term, the heat impacts on soil induce microbial mortality. Over the long term, there may be changes in soil microbial communities due to the modification of the plant community and soil environment (Hart et al., 2005). In addition to the direct impact of fire, bacterial activity can be increased in the immediate period after the fire due to increases in soil pH and dissolved organic compounds (Bárcenas-Moreno et al., 2011). This increase of soluble carbon in fire-affected soils stimulates the recolonization of some microbes such as heterotrophic bacteria and enhances the basal respiration rates (Mataix-Solera et al., 2009). After the fire, the increase of microbiological activity reduces the SWR, due to the decomposition of waxes and hydrophobic material (Franco et al., 2000; Noordman and Jansen, 2002). This activity contributes to the release of organic nutrients immobilized in aromatic compounds present in charred material and fundamental to plant recovery (Knicker et al., 2013). Microbiological activity stimulates root development, plant growth and vice versa (Cheng and Coleman, 1990; Fu and Cheng, 2002; Vessey, 2003). The plant regrowth protects the soil from raindrop impact (Cerdà and Robichaud, 2009) and root development creates new pathways and preferential water flow, increasing the water infiltration (Lange et al., 2009). The invertebrates' activity may also have contributed to the reduction of soil hydrophobic compounds and changed the hydraulic conductivity in the burned plot studied (Fig. 5). To our knowledge there are no studies about the impact of earthworm activity on SWR in burned soils, however, in contaminated areas, it was reported that earthworms have the capacity to take up hydrophobic compounds (Belfroid and Sijm, 1998; Belfroid et al., 1995). A bibliographic review carried out by Blouin et al. (2013) described that earthworm biomass is positively correlated with water infiltration. Earthworm burrows facilitate root penetration and increase hydraulic conductivity. Soil invertebrates can survive easily after grassland fires, since the severity needed to affect them is normally

**Fig. 5.** Evidence of earthworm activity (indicated with a red circle) in the burned plot 17 days after the fire.

not achieved (Neary et al., 1999). Previous studies observed that, in the period between 3 and 16 days after a fire in a grassland area, ants constructed their mounds (Pereira et al., 2013b). In other words, the increase of microbiological activity after the fire may have had impacts on the decomposition of hydrophobic material present in the soil particles and aggregates. In the burned area, the decomposition of this material together with the root development and invertebrate activities may have reduced SWR and increased water infiltration, facilitating the transport of the soluble hydrophobic material. These aspects may have had important effects on the SWR decrease 2 months after the fire in the burned area. Also, post-fire wetting and drying cycles (Doerr et al., 2009) and the exceedance of a "critical soil moisture threshold" (Doerr and Thomas, 2000; Huffman and MacDonald, 2004) are related to the SWR decrease. However, Doerr and Thomas (2000) showed that after wetting, SWR is not necessarily re-established when soil becomes dry again. Other factors involved in SWR reduction may be the spatial organization of amphiphilic molecules (Horne and McIntosh, 2000). Differences of SWR among sample times in each sieve fraction of each plot were identified in the burned and unburned plots. In the burned area the coarser-size fractions (2–1 and 1–0.5 mm) demonstrated significant differences in SWR in the first 7 months after the fire, while in the finer-size fractions (0.5–0.25 and < 0.25 mm) significant differences in SWR were observed until 9 months later. This shows that the hydrophobic substances attached to soil fractions disappear faster in the coarser sieve fractions than from the finer ones. This dynamic can be attributed to microbiological activity. Microbes may decompose the organic material at different rates. To our knowledge, no previous works have been conducted on microbial decomposition rates in different size fractions in burned areas. However, Fazle Rabbi et al. (2014) observed in Acrisols collected in a native pasture that the soil organic carbon mineralization was higher in macro- (250–2000 µm) and microaggregates (53–250 µm) than in the < 53 µm fraction. Fernández et al. (2010) found in non-tilled Entic Haplustoll soils that carbon losses through mineralization were especially observed in intermediate-size fractions (1–4 mm). Wu et al. (2012) identified in grassland soils that microbial biomass and dissolved organic carbon were significantly higher in the > 2000 µm-size fraction, than in the 0–63 µm-size fraction. Also, Jha et al. (2012) observed that water soluble carbon was significantly higher in macroaggregates than in microaggregates. These results may support the hypothesis that the mineralization rates and leaching of hydrophobic organic materials were higher in coarser sieve fractions than in the smaller ones. In relation to the differences observed in the unburned plot, in the coarser (2–1 mm) and the finer fractions (< 0.25 mm) SWR was more persistent IAF, 5 and 7 months after the fire in relation to the other sampling dates, while in the intermediate-size fractions (1–0.5 and 0.5–0.25 mm) SWR was significantly lower 9 months after the fire in comparison to the other sampling dates. The intermediate-size fractions followed the same pattern observed for the fine earth. The main differences were identified 2 months after the fire. It is not clear why this difference occurred in the second sampling date after the fire. In the international literature no previous works were found about the seasonal impacts on SWR according to soil aggregate sizes. Further research is needed to identify the factors responsible for these changes.

In the unburned and burned plots, the SWR was high in the finer fraction (< 0.25 mm). The results obtained in this study are in accordance with previous works in unburned (Arcenegui et al., 2008; Urbanek et al., 2007) and burned soils (Mataix-Solera and Doerr, 2004; Gimeno Garcia et al., 2011; Jordán et al., 2011), which identified that the finer soil fraction was more repellent than the coarser fractions. SWR is mainly attributed to soils with coarser textures that are more susceptible to developing repellent surfaces, due to the smaller specific surface area in relation to fine textured soils (Blas et al., 2010; Doerr et al., 2000). However, it has been observed that when a soil is hydrophobic, the finer fraction is usually more water repellent than the coarser ones (Jordán et al., 2011; Mataix-Solera and Doerr, 2004). In the present study SWR was especially severe in the finer fraction in the immediate sampling dates after the fire in the burned area. This can be attributed to the existence of hydrophobic ash smaller than 0.25 mm and/or the presence of hydrophobic interstitial organic matter that influenced the SWR (Mataix-Solera and Doerr, 2004). In the fine earth significant differences between plots were only identified in the 2 months after the fire. Nevertheless, between each fraction in the different plots, significant differences were observed in the coarser fractions (2–1 and 1–0.5 mm) until 7 months after the fire and in the fine fractions (0.5–0.25 and < 0.25 mm) until 9 months after the fire. The time for the burned plot to return to previous conditions depends also on the soil-size fraction because the rates of mineralization and/or leaching of organic hydrophobic substances may be not equal.

In the burned area the correlations between the Munsell colour value and SOM with SWR were significant only in the first 2 months after the fire (7 months later in the case of Munsell colour value and SWR). In unburned and burned areas SWR can be correlated (Lozano et al., 2013; Martínez-Zavala and Jordán-López, 2009; Mataix-Solera et al., 2002; Mataix-Solera and Doerr, 2004) or not (Blas et al., 2010) with the amount of SOM. The presence of hydrophobic compounds may be related to a certain type of organic material and not to the total SOM content (Doerr et al., 2000). Badía-Villas et al. (2013) observed a significant positive correlation between SWR and pyrolysed carbon, suggesting that SWR is strongly linked with organic materials produced by fire. Also, SWR may be affected by the ionic strength of the soil solution that induces an approximation of charged functional groups in SOM (Hurraß and Shaumann, 2006). These results suggest that the soil became water repellent from the hydrophobic substances produced during the fire, as organic coatings that covered the soil particles and aggregates that with time were decomposed and leached, especially from the coarser fractions. The significant correlations obtained in the first sampling dates after the fire in the burned plot may be the result of the presence of hydrophobic compounds with dark colour. Nevertheless, the partial correlation results showed that SOM controls the correlation of the Munsell colour value and SWR, IAF, 2 and 7 months after the fire, revealing that the original correlations were spurious. This suggests that SOM characteristics may have influenced the SWR. Other studies observed also that SOM has an important influence on SWR correlation with other variables, such as pH and the fungi parameters ergosterol- and glomalin-related soil proteins (Lozano et al., 2013). In fact, SWR must be more controlled by the chemical composition of SOM, than by its amount (DeBano et al., 1970). Horne and McIntosh (2000) observed that SWR was especially determined by amphipathic compounds rather than the organic matter's bulk characteristics. Spielvogel et al. (2004) found that SOM aromatic compounds contribute strongly to the correlation of soil lightness and SOM. The authors observed a strong correlation between soil lightness and aryl C ($r = 0.87$, $p < 0.01$). Also Schmidt et al. (1997) identified that charred material and the presence of aromatic C had important implications in the negative correlation between soil lightness and SOM. These results suggest that SOM characteristics exert significant control on soil Munsell colour values. Also, a soil with the same Munsell value may have different concentrations of aromatic compounds that increase SWR, such as humic and fulvic acids. This shows that the Munsell colour value may not be a good variable to estimate SWR.

## 5 Conclusions

Fire darkened the soil and increased for a short period the SOM content (first 2 months after the fire). This increase was likely due to the input of partially burned ash into the surface soil that produced an increase in the SWR, due to the characteristics of the burned material. However, this increase was not homogeneous across all aggregate-size fractions. Finer fractions were more water repellent than the coarser ones. In the burned area, the SWR of the finer fractions was more persistent in time (9 months after the fire) than in the coarser fractions (7 months after the fire). The correlations between Munsell colour value and SOM were negatively significant in all cases in the burned and unburned plots. However, the correlations between Munsell colour value and SWR and Munsell colour value and SOM were only significant in the burned area IAF, 2 and 7 months after the fire (in the last sampling date, only between Munsell colour value and SWR). The partial correlations revealed that the correlation between Munsell colour value and SWR IAF, 2 and 7 months after the fire in the burned plot was strongly controlled by SOM, suggesting that organic matter properties may have implications on SWR.

Future research is needed to understand the persistence of the SWR in different sieve fractions, and the factors that control this dynamic, that may be linked with microbiological activity. The different responses of soil-size fractions to SWR after a fire induce considerable temporal variability of fire impacts on SWR and hydrologically related parameters such as infiltration, runoff and soil erosion.

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