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Fire severity effects on ash chemical composition and water-extractable elements

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ABSTRACT

The effects of fire in the landscape are commonly assessed through the evaluation of ash properties. Among other properties, colour is one of the methods more frequently used. However, little is known about the effect of fire severity on ash chemical and extractable elements. Ash is an important source of nutrients in terms of landscape recovery after fire. In this study we analysed the effects of fire severity (estimated using ash colour) on ash chemical properties, $CaCO_3$, pH, Total Carbon (TC), Total Nitrogen (TN), C/N ratio and some ash water-extractable elements, such as Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Total Phosphorous (TP), Total Sulphur (TS) and Silica (Si) collected in Portugal ($N = 102$) after three wildfires that occurred in the same ecosystem, composed mainly of maritime pine, *Pinus pinaster*, and cork oak, *Quercus suber*. The results showed significant statistical differences among ash colour at a $p<0.05$ for ash water-extractable K and Si, at a $p<0.01$ for ash water-extractable Ca, Mg, Na and TS, and the major differences were observed (at a $p<0.001$) for ash $CaCO_3$, pH, TC, TN, C/N ratio and water-extractable TP. Ash $CaCO_3$, pH and water-extractable TS increased with fire severity and ash TC, TN, C/N ratio and water-extractable TP showed a decrease. In the remaining elements, no trend is identified. Major concentrations of ash TC, TN, C/N ratio and water-extractable Ca, Mg and K were identified in very dark brown and black ash. $CaCO_3$, pH and water-extractable TS were identified in higher quantities in light grey ash. These findings show that fire severity is an important determinant of the type and amount of water-extractable nutrients present in ash that later can be incorporated into the soil and become available for plant growth.

1. Introduction

Fire severity is an important indirect measure of fire effects on vegetation and soil properties. This term was created to describe the effects of fire on ecosystems, especially after wildfires where direct information on fire intensity is absent (Keeley, 2009). It is an indicator of landscape recovery rate and post-fire erosion risk as observed elsewhere (Benavides-Solorio and MacDonald, 2001; Miller et al., 2011). Fire severity depends on complex interactions among temperature, meteorogical conditions prior and during the fire, geomorphology, aspect, slope (Alexander et al., 2006; Maingi and Hanry, 2007), burned species (Úbeda et al., 2009) , amount of fuel, fuel moisture, fuel structure and arrangement, type of ecosystem and season (Keeley, 2009; Verbyla et al., 2008;). Normally, fire intensity is used wrongly as a synonym of fire severity to describe the effects of the fire on the landscape and this leads to some confusion in the terminology. Recently Keeley (2009) and Pereira et al. (2010) have completed overviews and have suggested a correct use of both of these concepts.

Fire severity has been assessed using a variety of methodologies, such as the minimum branch diameter remaining after fire (Perez and Moreno, 1998), fine fuel combustion (Davies et al., 2010), crown scorch (Ramage et al., 2010; Vega et al., 2008), relation to soil properties such as colour (Ketterings and Bigham, 2000), degree of changes in soil organic matter, soil structure, soil iron oxidation, soil hydrophobicity and soil reflectance, that can be observed throughout Near Infrared Spectroscopy (NIR) (Guerrero et al., 2007; Keeley, 2009; Keeley et al., 2008; Mataix-Solera and Doerr, 2004), remote sensing (Miller et al., 2009; Wang and Gleen, 2009) and aerial photo analysis (Hayes and Robenson, 2011; Odion et al., 2010).

In addition to the above-mentioned fire severity indices, ash colour is also an important indicator of fire severity as observed elsewhere (Pereira et al., 2010; Pereira et al., 2011; Úbeda et al., 2009). The presence of ash is one of the key characteristics of burned areas. It is the organic and inorganic residue remaining after organic matter combustion. When organic matter is only heated to the point that vaporization of moisture takes place rather than combustion, the residue is not considered ash (Pereira et al., 2010). Roy et al. (2010) attempted to classify fire severity according to ash colour using a greyscale, however it is important to note that ash is not only black

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or white, and can be reddish or brownish, especially when produced at low temperature/severity, conditions that are likely to occur somewhere in a burned landscape. The previous study (Roy et al., 2010) did not consider other colours than those present in the grayscale, thus perhaps this method is not the most reliable for fire severity analysis. As such, studies that use other methods such as the Munsell colour chart (Bodi et al., 2011; Pereira et al., 2011; Úbeda et al., 2010) might be more suitable to analyse ash colour.

The ash colour is an indirect estimator of the effects of fire on organic matter consumption. Brownish and reddish colours represent low fire severity, black to very dark grey moderate fire severity and dark grey to white ash, high fire severity (Úbeda et al., 2009).

Presently, a great number of studies have been conducted on ash produced in boilers (Callesen et al., 2007; Hartmann et al., 2009; Misra et al., 1993; Pöykiö et al., 2009; Schumann and Sumner, 2000) and some in laboratory environments (Bodi et al., 2011; Gray and Dighton, 2006; Henig-Sever et al., 2001; Liodakis et al., 2009; Pereira, et al., 2009; Soto and Díaz-Fierros, 1993; Úbeda et al., 2009). Some studies have been carried out on ash produced in fires, however, the majority of these studies focused on the physical and hydrological properties of ash and effects on soil (Cerdà and Doerr, 2008; Gabet and Sternberg, 2008; Larsen et al., 2009; Woods and Balfour, 2008, 2010; Zavala et al., 2009). Only a small amount of attention has been paid to ash chemical properties and water-extractable elements (Blank and Zamudio, 1998; Bodi et al., 2011; Khanna et al., 1994) and these studies give little consideration to the effects of the fire severity on ash chemical properties and water-extractable elements.

Since ash colour can be used as a measure of fire severity (Blank and Zamudio, 1998; Bodi et al., 2011; Khanna et al., 1994; Úbeda et al., 2009), the study of the implications of fire severity on ash chemistry and water-extractable components is of major importance because this information allows us to identify the type and amount of elements released into solution when ash is mixed with water. In addition, this can be an important step towards the understanding of the effect of ash produced at different severities on the soil solution and provide field verification of previous laboratory studies (Úbeda et al., 2009). In order to fill this gap in fire studies, the aim of this work was to study the ash chemical composition and its relation to ash colour and fire severity, especially $CaCO_3$ and the combustion of the organic matter (Úbeda et al., 2009), pH, which influences the leachability of ash nutrients, Total Carbon (TC), Total Nitrogen (TN), the nutrient most affected by fire, owing to the low temperature of volatilization (±200 °C) and C/N ratio, which shows the degree of organic matter mineralization (Neary et al., 2005). Previous studies analysing ash produced in the laboratory and collected after prescribed fires showed that $CaCO_3$ was created at temperatures around 350–400 °C and pH increased with the exposure temperature and severity (Úbeda et al., 2009). TC and TN can increase in low severity prescribed fires (Pereira, 2010). Some water-extractable elements were analyzed, namely, Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Total Phosphorous (TP), Total Sulphur (TS) and Silica (Si), that are fundamental for plant nutrition (Varennes, 2003) and vegetation recovery after the fire.

2. Materials and methods

2.1. Study area and sites

Ash samples were collected in three areas recently burned by wildfires that occurred between the end of July and the beginning of August of 2008 south of Lisbon, Portugal (Fig. 1): Quinta da Areia (38° 35′N, 09° 02′W, 42 m a.s.l), Quinta do Conde (38° 34′N, 09° 02′ W, 35 m a.s.l.) and Casal do Sapo (38° 33′N, 09° 02′W, 55 m a.s.l). All three areas are in similar ecosystems. The fire severity was assessed by the colour of the ash and classified following the increasing order: very dark brown (low severity), black (medium severity), very dark grey (medium severity), dark grey (high severity) and light grey (high severity). The Quinta do Conde plot was considered to represent medium severity (17% low severity, 70% medium severity and 13% high severity), and the other study plots represented medium to high severity conditions: Quinta da Areia (3% low severity, 53% medium severity and 44% high severity) and Casal do Sapo (53% medium severity and 47% high severity).

The geologic substrate of the studied areas is mainly composed of Plio–Pleistocene dunes with low cementation and soils are classified as *Podzols* (FAO, 2006) with a higher content of sand, and low values of organic matter, pH, EC and cation exchange capacity (CEC) (Table 1). The average temperature is 14.8 °C and the annual precipitation is 639.2 ± 156.4 mm based on data collected at the meteorological station of Vila Nogueira de Azeitão (36° 31′N, 09° 01′W, 126 m a.s.l) during the period 1971–2000 The vegetation in the sampling areas was mainly composed of maritime pine, *Pinus pinaster*, and in some parts of cork oak, *Quercus suber*.

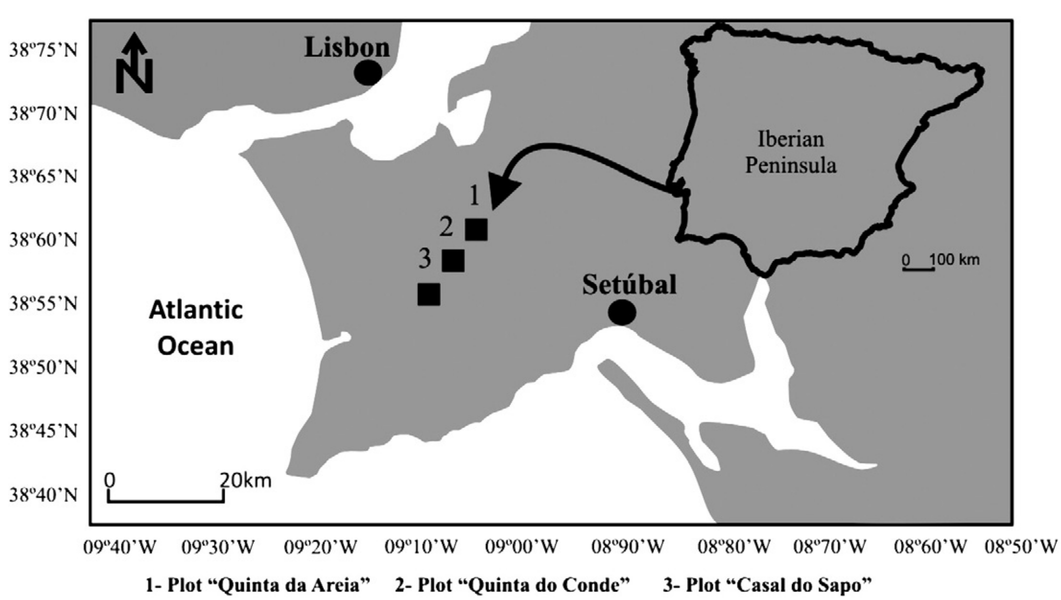

Fig. 1. Location of study sites.