



Colourimetric variations in burnt granitic forest soils in relation to fire severity



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ABSTRACT

Forest fires constitute a major environmental problem. Information about fire severity would enable the application of measures to offset the effects of forest fires on the ecosystems. In this study, we evaluated the usefulness of soil colour measurement as a rapid inexpensive method of determining fire severity. For this purpose, we subjected samples of granitic soils (Leptic Umbrisol, Umbric Regosol and Humic Cambisol) from different forest sites to laboratory controlled thermal shock. The thermal shock was performed in topsoil by the action of infrared lamps, which allowed reproducing similar temperatures to those reached in low, moderate and high severity fires. The maximum temperature and the degree hours (DH) reached during the heating were measured as indicators of fire severity. Changes in the colour of the soil and in the contents of organic matter and iron compounds were also analysed. Colour measurements were applied in three different processed burnt samples and results were compared in order to determine the best for the purpose of the study. The results obtained in the present study for granitic soils show that the values of the CIELAB parameters defining the colour of the surface of burnt granitic forest soils increased with the temperature and DH reached. Although the amount of organic matter was significantly correlated with all colour parameters and with temperature and DH reached, the Fe compounds were not significantly correlated with either CIELAB parameters, temperature or DH reached. Determination of variations in the organic matter content appears to be a reliable method of estimating the temperature and degree hours reached in granitic soils during burning.

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1. Introduction

Soil colour is often used to characterize and differentiate soils (Isbell, 2002; Soil Survey Staff, 1999), as the colour is one of the most distinctive morphological features of a soil (Sánchez-Marañón et al., 2004). It is known that soil processes that affect the soil surface can be identified by colour differences (Escadafal, 1993) and that the soil colour can be broadly due to three factors: (i) Fe oxides and hydroxides (red to yellow) (Bigham et al., 1978; Torrent et al., 1980; Schwertmann, 1993; Cudahy and Ramanaidou, 1997; Scheinost and Schwertmann, 1999), (ii) humus (black) (Shields et al., 1968; Al-Abbas et al., 1972; Henderson et al., 1989; Dobos et al., 1990; Schulze et al., 1993; Wills and Burras, 2007) and (iii) silicate and carbonate minerals (white to grey) (Sánchez-Marañón et al., 2004). As the colour of soil is strongly influenced by the type and amount of organic matter and Fe content, both of which are fire-sensitive components, colour and burn severity should be correlated.

Soils affected by forest fire can undergo short-term, long-term or permanent changes, depending chiefly on type of property, severity and frequency of fires, and post-fire climatic conditions (Certini, 2005). The severity is characterised by the maximum temperature reached and the duration of the fire (Certini, 2005). Low-severity fires temporarily affect biological and chemical properties of the soil (Palm et al., 1996). More severe fires can alter characteristics such as structure stability (Badia and Marti, 2003), mineralogy (Schwertmann and Taylor, 1989; Ulery and Graham, 1993; Ulery et al., 1996; Ketterings and Bigham, 2000) and cation exchange (Cancelo-González et al., 2013). Although duration is perhaps the most important component of fire severity in relation to the degree of damage below ground (Certini, 2005), most studies addressing fire severity only consider the intensity and not the duration of fire (Ketterings et al., 2000; Kazuto et al., 2013). However, some recent studies have taken into account the amount of heat supplied to the soil in addition to the temperature reached during wildfire in order to define the thermal shock (Cancelo-González et al., 2012, 2013).

The physical appearance of the soil surface after burning and the visual changes in post-burn colour patterns have been used as indicators of fire severity (Ulery and Graham, 1993; Romanya et al., 1994). Thus, slightly burnt areas (100 to 250 °C and short exposure)

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are characterized by blackened soil due to incomplete combustion of organic matter. Moderate fires (300–400 °C and long exposure) consume plant material, leaving little residual white ash, but do not alter the underlying soil (Wells et al., 1979). Severe fires (long exposure >500 °C) leave white ash and redden the soil. Therefore, fire-related changes in soils are mainly a result of burn severity (Certini, 2005).

Information about fire severity is crucial in forest fire management as the pre-fire level of most properties can be recovered and even enhanced. The response of ecosystems depends on the burnt severity, which can help a better understanding of post-fire development and fire ecology. Ecosystem responses include erosion, vegetation regeneration, faunal recolonization, restoration of community structure and a plethora of other response variables. Predicting how fire intensity or severity will affect these responses is critical to post-fire management (Keeley, 2009).

However, at present there are no tools available that enable rapid quantitative estimation of fire severity. Some attempts have been made to establish the relationship between soil colorimetric variations and burn intensity. Ketterings and Bigham (2000) studied the properties of some soils before and after burning in Sumatra, Indonesia, to analyse the effects of fire severity and fertility on soil colour and the dependence of post-burn colour on organic matter and iron oxide content. These authors concluded that the usefulness of post-burn soil colour measurements for identifying heat-induced changes in soil fertility is limited by the fact that fire severity is determined both by peak temperature and the duration of exposure. At higher temperatures, soil carbon was mostly depleted and reddening of the soil matrix occurred, Munsell values and chromas decreased and hues became yellower with heating to 600 °C. In laboratory-based tests, these authors observed pronounced changes in colour parameters with time of exposure to elevated temperatures when the soil was subjected to static heating. As in the field, Munsell hue became yellower as the value and chroma changed with short-term heating to 300 or 600 °C. At 600 °C, reddening did not occur until after ≈45 min of exposure. Sanmartín et al. (2010) analysed the colour variations in blocks of Umbric Regosol after subject them to thermal shock. These authors observed significant differences in every colour parameter of burnt and unburnt samples and in CIELAB h_{ab} and Munsell hue of soils subjected to 200 and 400 °C. More recently, Kazuto et al. (2013) evaluated the colour changes caused by heating at different temperatures in four types of soil: tropical peat (Central Kalimantan, Indonesia), high moor peat (Gifu, Japan), forest soil (Toyama, Japan) and sphagnum peat moss (purchased from a local market in Toyama, Japan). These authors found that the Δa^* and Δb^* values decreased sharply when the samples were heated above the ignition temperature of volatile matter (200 to 250 °C) and that there was a strong negative linear correlation between both parameters and the atomic ratios of H/C and O/C.

The aims of this study were to determine how laboratory thermal shock treatments affect the colour of forest granitic soils with different moisture contents and to evaluate the usefulness of colour measurement as a rapid, inexpensive method of determining fire severity in this type of soil.

2. Materials and methods

2.1. Soil samples

Samples of forest soils developed on granite were collected from three different sites (M1, M2 and M3) in Carnota, Galicia (NW Spain). The main characteristics of the soils are shown in Table 1.



Fig. 1. Controlled burning of soil samples in aluminium trays by using infrared lamps.

Only the upper 4 cm of the soil was sampled because soil heating is maximal in the uppermost layer (DeBano et al., 1979; Campbell et al., 1995; Ketterings et al., 2000). In the laboratory, the samples were dried at room temperature and sieved to obtain the <2 mm fraction. Distilled water was added to some of the dried, sieved soil, to produce samples of moisture contents 0, 25 and 50% (vol:vol), which represented different environmental conditions. Two replicate samples of each of the soils with moisture contents of 0, 25 and 50% were placed in 159 × 109 × 38 mm aluminium trays in order to be exposed to three different thermal shocks (i.e. 3 soils × 2 replicates × 3 soil moisture × 3 thermal shocks = 54 samples in total).

2.2. Thermal shocks

The soil samples on the aluminium trays were heated by five infrared lamps (Philips IR375CH) placed 10 cm above the soil surface (Fig. 1). The soil temperature was measured every 5 min with two thermocouples inserted in each subsample at a depth of 1 cm. Heating was maintained until temperatures of 100, 200 or 400 °C (equivalent to low, intermediate and severe fire conditions: Chandler et al., 1983) were reached at this depth. Once the target temperature was reached, the samples were allowed to cool in the trays.

2.3. Calculation of degree hours

A modified degree-hour method (DH) was used to calculate the heat supplied to the soil samples during thermal shock treatment (Cancelo-González et al., 2012). The following equation was used to calculate the degree hours at room temperature (18 °C):

$$DH_{18} = \sum \left(\frac{T_{5(1cm)} - 18}{12} \right)$$

where $T_{5(1cm)}$ is the temperature (°C) recorded every 5 min at 1 cm depth.

2.4. Chemical analysis of soil samples

The soil properties and composition of each sample were analysed before and after the thermal shock treatments. The organic matter content was determined by oxidation of samples with potassium dichromate and sulphuric acid (Gutián and Carballas, 1976). Free iron oxides were extracted with sodium dithionate-citrate-bicarbonate (DCB) (Mehra and Jackson, 1960); amorphous iron oxides were extracted by oxalic oxalate ammonium (Schwertmann and Taylor, 1989). Iron complexed forms were extracted with sodium pyrophosphate (Bascomb, 1968; McKeague, 1967; Jeanroy, 1983). The iron forms were determined by atomic absorption spectrometry (SPECTRAAA220 FS from VARIAN). Soil pH

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