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Thermal analysis as a predictor for hydrological parameters of fire-affected soils

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ABSTRACT

Soil burn severity indexes have been developed to rapidly assess ecosystem damage from vegetation fires and predict associated risks during the post-fire period. In terms of the hydrological impacts of fire, the lack of measurable relationships between the commonly determined parameters and post-fire hydrological responses has limited their potential to predict and mitigate post-fire hazards. This study examines the link between post-fire organic matter characteristics, and main soil physical and hydrological properties (clay content, bulk density, aggregate stability, water retention, water repellency, rainfall–runoff ratio and sediment concentration in runoff) in order to explore the potential use of organic matter characteristics as a proxy for the fire impact on hydrology-related soil properties. Soil samples from five fire-affected burned and unburned control sites in Andisols areas of Tenerife (Canary Islands, Spain), studied previously for hydrological processes, were selected and thermogravimetric (TG) analysis was carried out to evaluate fire impacts on their organic matter composition. The TG data were used to perform simple linear regressions with soil hydrological properties. The organic matter composition was relatively homogeneous among the unburned sites, despite substantial within and between site variability regarding other soil properties examined which simplified the assessment of soil burn severity. The fire led to a decrease in the relative amount of the labile organic matter pool and an increase in the recalcitrant and/or refractory pool depending on study site. The TG data, using 10 °C temperature range steps, allowed reasonable prediction of most soil properties and parameters, with R^2 ranging from 0.4 to 0.9 and with $R^2 \geq 0.6$ for 6 of the 8 parameters evaluated. The labile pool and the dehydration range positively affected bulk density, aggregate stability, wilting point and water repellency and negatively field capacity and sediment concentration, whereas the refractory pool showed the opposite trend. The recalcitrant pool was unrelated to other soil properties except for clay content and runoff. These results, in conjunction with the simplicity of the TG analysis suggest that, after an initial calibration step to link TG data to site-specific post-fire soil properties, the novel approach introduced in this study could serve as a useful tool for the rapid and cost-effective evaluation of soil burn severity, and anticipated soil hydrological responses after a fire.

1. Introduction

Post-fire assessments of burned terrain are commonly performed to identify risks to lives, properties and natural or cultural resources by evaluating indirectly the impact of fire on ecosystem dynamics (Parsons et al., 2010). Soil burn severity indexes, which classify fire-related changes of key vegetation and soil parameters presumed to directly influence the post-fire ecosystem response (Keeley, 2009), have been developed for this purpose. However, despite their practical usefulness and importance both in fire research and management, some limitations exist regarding (i) their measurement and (ii) their actual link with the ecological response (Keane et al., 2012; Moody et al., 2013).

From a hydrological perspective a major limitation has been the often poor connection between the soil burn severity indexes and the ecosystem responses in terms of runoff and erosion as highlighted in a comprehensive review by Moody et al. (2013). This limits the usefulness of these indexes in predicting post-fire hydrological behaviour and Moody et al. (2013) have argued that progress requires (i) direct links to be established between the soil burn severity indexes and soil properties related to runoff and erosion, and (ii) these to be included into soil erosion prediction models.

Thermal analysis (TA) techniques, as for example thermogravimetry (TG), have been increasingly used to characterize soil organic matter (SOM) pools as a rapid, inexpensive and information-rich procedure (Plante et al., 2009). TA has proved its usefulness to evaluate SOM quantity and composition (Fernandez et al., 2011) both in unburned (see e.g. Schulten and Leinweber, 1999; Siewert, 2004) and burned soils (see e.g.

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De la Rosa et al., 2008a; Duguy and Rovira, 2010). Due to the notable impact of fire on SOM (Certini, 2005; Gónzalez-Pérez et al., 2004) and the strong influence of SOM on infiltration (Lado et al., 2004; Tejedor et al., 2013) and runoff and erosion related soil properties such as their structure (Giovannini and Lucchesi, 1983; Mataix-Solera et al., 2011), water repellency (Doerr et al., 2000; Martínez Zavala et al., 2009) or water storage capacity (Boix-Fayos, 1997; Stoof et al., 2010), TA may also show a promise as a predictor of soil burn severity and hydrological response. It allows a rapid determination of the fire impacts on SOM and might also enable prediction of other related soil properties relevant to post-fire runoff and erosion dynamics.

The main aim of this study was therefore to evaluate the usefulness of TA to assess fire impacts on soil organic matter composition and explore its potential links with other fundamental soil properties related to post-fire runoff and erosion response.

2. Methodology

2.1. Study region

The volcanic island of Tenerife (Canary Islands, Spain), with a total size of 2057 km^2 and a maximum elevation of 3718 m a.s.l., is situated between 27° 55′ and 28° 35′ N and between 16° 05′ and 16° 55′ W (Fig. 1). The study area is located on the island's northern hillsides, between 950 and 1250 m a.s.l., where the average annual precipitation of 600–1000 mm is supplemented by water from condensation, resulting in up to 5 times the annual rainfall (Marzol Jaén, 2005). Bedrock consists of basaltic pyroclasts and lava flows (0.7–0.01 M years) with subsequent rejuvenations by analogous ashes (<0.01 M years). The vegetation is mainly pine (*Pinus canariensis*) and rainforest (*Laurus novocanariensis*, *Appollonias barbujana*, *Persea indica*, *Ilex canariensis*, *Morella faya*, *Erica scoparia* and *Erica arborea*, among other species). The soils are mostly allophanic Andisols and are classified as Ustands and Udands depending on their soil moisture regime (Soil Survey Staff, 1999). Although occupying much smaller areas, soils of the Inceptisol and Entisol orders (Soil Survey Staff, 1999) are also found.

2.2. Characteristics of the forest fire

A forest fire on 30 July 2007 burned an area of almost 17,000 ha with a perimeter of 90 km (Fig. 1) (Instituto Canario de Estadística, 2013). The fire occurred during a high temperature (30–45 °C) and low relative humidity (5–10%) period with winds occasionally exceeding 50 km h^{-1}. It covered a large elevation range (500–2000 m a.s.l.) with moderately-steep hillslopes (10 to 25°) and different types of vegetation. Forest was the main vegetation type affected (13,500 ha), the majority of which consisted of pine stands (95%) and the remainder rainforest.

2.3. Research design and sampling site selection

For this study, TA and other specific analysis (see Section 2.5) were performed on samples previously obtained and analysed for general soil properties by Neris et al. (2013a). The new data obtained were compared with data produced in this previous work in order to evaluate links between the fire impact on SOM composition and hydrology-relevant soil properties. Five study sites (1–5) had been selected in the fire affected area (Fig. 1) where previous studies provided information on the effects of fire on soil physical and hydrological properties (Neris et al., 2013a). Each site consisted of a burned zone (B) and an unburned control zone (U) with the same soil type and pre-fire vegetation. The control zones had not been burned for at least 20 years. The elevation ranged from 900 to 1200 m a.s.l. and the distance between U and B zones from 150 to 640 m. Firebreaks and ravines had been the main factors stopping the fire and protecting the U zones. Pine forest was the dominant vegetation, with some sites having undergrowth consisting of Fayal-Brezal (*Erica* sp. and *M. faya*). The soils in all five sites were allophanic Andisols (Soil Survey Staff, 1999), but with a wide range of pre-fire soil properties to encompass regionally diverse forest soil characteristics (Table 1). Burn severity was classified as light for sites B1, B4 and B5 and moderate for zones B2 and B3 according to the metric of Ryan (2002) based on the visual evaluation of the vegetation and SOM consumption. Due to access permission issues, soil samples were collected between 8 to 10 months after the fire. In this period, post-fire

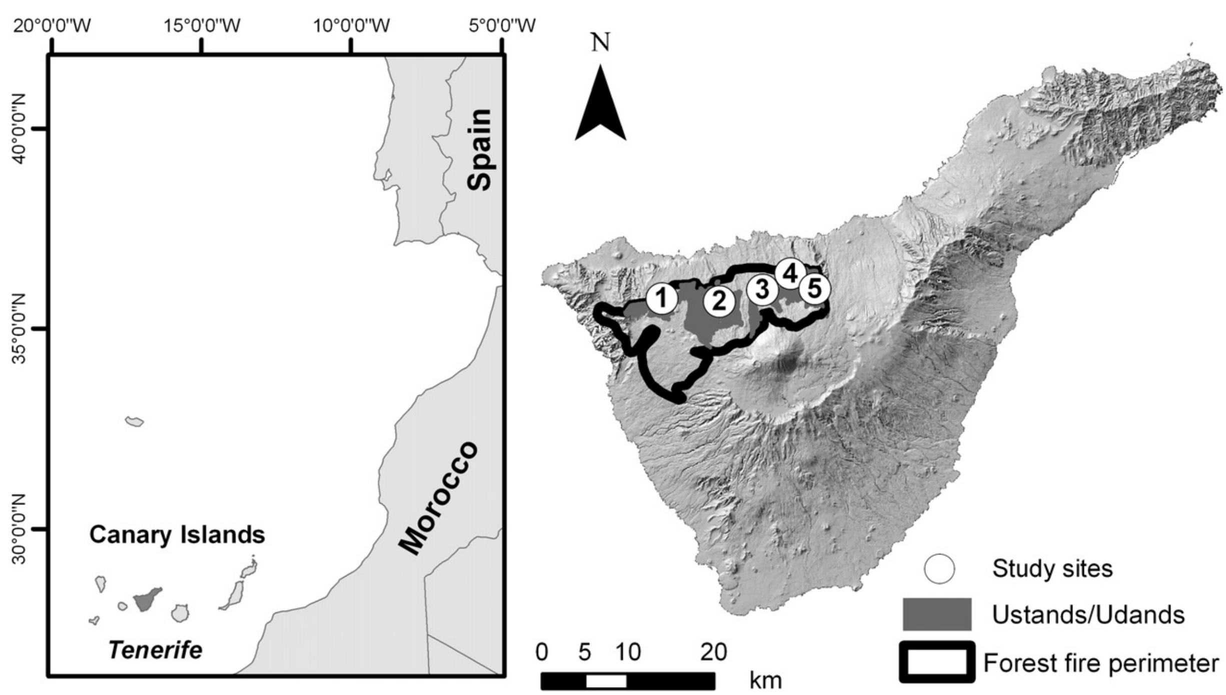

Fig. 1. Location of the island of Tenerife, Andisols (Udands and Ustands), burned area and study sites.