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Soil properties, phosphorus fractions and sorption after wildfire in north-central Portugal

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ABSTRACT

This study examined soil physico-chemical properties, P fractions, and P sorption–desorption at two depths (0–3 and 3–6 cm) after a wildfire in a *Pinus pinaster* stand in north-central Portugal. Depending on fire severity, soils from three sites were considered for this study: long-unburned (US), low crown consumption (LCC) and high crown consumption (HCC). The fraction of fines (0–3 and 3–6 cm), total Mn concentration (0–3 and 3–6 cm), and Fe oxyhydroxide content (0–3 cm) were significantly larger for burned (LCC and HCC) than for unburned soils (US). On the contrary, the total organic content (TOC; 0–3 cm) of US was significantly larger than that of LCC and HCC. Organic P showed the same pattern as TOC, while no significant differences were determined for the rest of the P fractions. With respect to P sorption, faster kinetics and larger capacity onto LCC and HCC soil were respectively related to their higher percentage of fines, and to their higher concentrations of Fe and Mn oxyhydroxides, as compared to US. Meanwhile, desorption of P pointed to less tight binding of P on both LCC and HCC soil than on US soil. Finally, only the Fe oxyhydroxide content at 0–3 cm depth, and both the fraction of fines and the P sorption velocity at 3–6 cm depth, were sensitive to fire severity. It was concluded that wildfire had significant short term effects on soil P fractions and P sorption–desorption, which were highly related to direct effects on soil physico-chemical properties, and which may have relevant consequences at an ecosystem level.

1. Introduction

Wildfires constitute one of the most important environmental phenomena in Mediterranean countries. In addition to causing huge economic costs and losses, fires can also pose a serious threat to soils and the ecosystem services that they provide. Heat-induced changes in soil properties can cause mortality in soil microbial communities (Hebel et al., 2009; Weber et al., 2014), the destruction of soil structure, the loss of organic matter, and the loss of mineral nutrients (Durán et al., 2008 and references therein). Many of these direct impacts can be further aggravated by fire-enhanced erosion (e.g. Malvar et al., 2013; Prats et al., 2013).

The direct impacts of wildfires typically vary markedly across the landscape, due to a variety of factors such as fuel load, slope angle, and fire spread behaviour (e.g. Bradstock et al., 2010; Fernandes and Rigolot, 2007). While fire severity is related to fire impact, it is also related to ecosystem's responses to fire, such as vegetation recovery or soil erosion impacts (Hebel et al., 2009; Keeley, 2009; Maia et al., 2012a; Weber et al., 2014). For example, a rapid and complete recovery of the vegetation after fire is a strong indicator that key ecosystem properties such as plant water and nutrient availability were not severely affected by the fire or quickly recovered to pre-fire levels (Certini, 2005; Romme et al., 2009).

Regarding soil nutrients, forest fires can reduce on-site nutrient pools directly through oxidation and volatilization, and indirectly through leaching and ash transport by wind and water erosion (Bodí et al., 2014). Fire impacts on nutrients occur on the forest floor and in the mineral soil (Murphy et al., 2006; Johnson et al., 2008). Although the total nutrient pool often decreases with fire, it is known that the deposition of an ash layer and heating of soil organic matter (SOM) increase nutrient availability during the initial post-fire period (Wan et al., 2001; Scharenbroch et al., 2012).

Phosphorus (P) is an essential element for plant growth as it is ubiquitous in biological structures and cellular metabolism (Sterner and Elser, 2002). However, P is a relatively rare element, and typically is a limiting nutrient in freshwater ecosystems as well as in many terrestrial ecosystems, including forests (Sullivan et al., 2014). Ketterings et al. (2002) highlighted that P losses due to leaching, erosion, and/or logging tend to be limited in forests, and consequently P tends to accumulate in

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the aboveground biomass. The litter layer is also a relevant component in the P cycle in forests, as it allows bypassing the mineral soil where P sorption and fixation capacities are typically high because of low-activity clays and low pH (Tiessen et al., 1994). In the mineral soil the pools of labile and soluble inorganic P are governed by mineralization processes, while a pool of occluded organic P may gradually build up (Ketterings et al., 2002).

Forest fires cause losses of the P in plant biomass and litter due to combustion and also losses from soil organic pools, either through combustion or through enhanced mineralization of SOM. The P of the soluble pool may be taken up by plants, be chemisorbed to the surface of Fe, Mn, and Al oxides, and precipitate as relatively insoluble phosphates (Ketterings et al., 2002). Since adsorption and precipitation processes are not easily measured separately, they are usually referred by P sorption or P fixation in a collective manner (Sposito, 1984), both playing a key role in P retention and mobility (Riggle and Wandruszka, 2007). Regardless, possible fire-induced changes cannot be readily assessed by analysing total P concentrations, but should be assessed by determining the different pools of bioavailable, organic, and inorganic P, as well as the P sorption characteristics of the soil.

Few studies have been conducted on the effects of fire on forest soils P, despite the importance of soil nutrient status for the post-fire management of forests and the fact that P availability may limit forest production (Binkley and Fisher, 2013). This is especially true for short term effects, which should be considered for the rapid implementation of management measures to mitigate the long term effects of wildfires. For example, Maia et al. (2012a,b) showed that, immediately after wildfire, viable seed densities were higher at burned than at unburned sites, and that the density varied with fire severity. This could be at least partially related to the short term effects of fire on soil P pools and sorption. In fact, some studies using oven heated soils have pointed to heating related changes in the soil P pools (Galang et al., 2010) and P sorption (Ketterings et al., 2002; Serrasolses et al., 2008). With respect to field studies, most of results in the literature focus on the long term effects of fire (Romanyà et al., 1994), and primarily either on P pools (Giardina and Rhoades, 2001; Turrion et al., 2010) or on P sorption (Ketterings et al., 2002).

In this context, the main aim of this study was to study the direct impacts of wildfire on the different P pools and dynamics in the topsoil. For this purpose, a *Pinus pinaster* plantation, for which P can markedly improve pine growth (Trichet et al., 2009), was selected as study site. The specific objectives were:

1. To determine which soil properties, among those sensitive to fire and/or its severity, may be related to differences between P pools and dynamics.
2. To evaluate the effect of fire severity, at the 0–3 cm and 3–6 cm soil layers, on: a) soil P-pool and b) soil P-sorption.

2. Materials and methods

2.1. Study area and site

This study was carried out in a forested area near the village of Colmeal in the Coimbra District of north-central Portugal (Fig. 1). In the study area (40°08′45.77″N, 7°59′08.22″W), around 70 ha of mainly eucalypt (*Eucalyptus globulus* Labill.) and Maritime Pine (*P. pinaster* Ait.) plantations were burned by a wildfire on August 24, 2008. The most extensive plantation in the burned area – composed of *P. pinaster* – was selected for this study for three reasons (Maia et al., 2012a): (i) it constituted a fairly homogeneous stand prior to the fire; (ii) it had clear signs of contrasting fire severities; and (iii) the fire did not affect the entire stand, allowing an assessment of the effects of wildfire to be made against long-unburned conditions.

The climate of the study area can be classified as Meso-Mediterranean (Rivas-Martínez et al., 2002) with wet winters and dry summers, with the bulk of wildfires occurring in the summer period. The mean annual temperature is between 10.0 and 12.5 °C, and the average annual rainfall is between 1400 and 1600 mm (APA, 2011: 1931–1960). The soils at the study site are predominantly Leptosols (WRB, 2007). The soil texture of the top 6 cm of these profiles is typically sandy loam, with the sand, silt, and clay fractions amounting to roughly 50–60, 30–35 and 10–15%. The underlying rocks are pre-Ordovician schists of the Hercynian Massif (Ferreira, 1978).

At the time of the wildfire, the plantation at the study site was roughly 25 years old, had a density of roughly 17,000 trees ha^{-1} and was being managed by the Portuguese National Forestry Authority (Maia et al., 2012a). The understory vegetation mainly consisted of woody shrubs species and, in particular, *Arbutus unedo* L., *Erica australis* L., *Calluna vulgaris* (I.) Hull and *Pterospartum tridentatum* (L.) Willk, but did include some cover by the perennial grasses *Agrostis curtisii* Kerguélen and *Agrostis delicatula* Pourr. Ex Lapeyr (nomenclature is according to Tutin et al. (1964–1980)).

2.2. Experimental design

This study is part of a larger research project carried out in this study site after the wildfire occurred on August 24, 2008. A full description of the full research project may be found in Maia et al. (2012a,b), Prats et al. (2013) and Campos et al. (2012).

As detailed in Maia et al. (2012a), after the wildfire a total of six transects of about 30 m were laid out in a down- to upslope direction in the

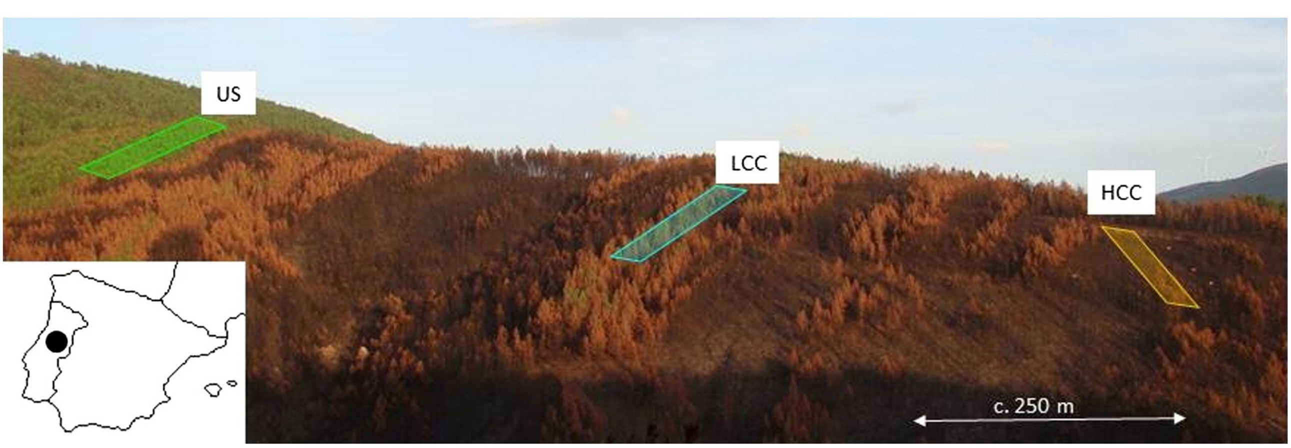

Fig. 1. Location of the study area and of the three transects with contrasting fire severities, classified as HCC—high crown consumption and LCC—low crown consumption, and the long-unburned transect (US) of the *Pinus pinaster* stand.