SCAP
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Fire effects on soil quality in *Quercus suber* forests: a long-term assessment

Efeito do fogo na qualidade dos solos de florestas de *Quercus suber*: uma avaliação a longo prazo

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ABSTRACT

Wildfires, despite being a major disturbance factor, have also an essential role in shaping the Mediterranean landscape and its ecological processes. Post-fire soil properties can change significantly, depending on fire charactheristics. However, long term fire effects on soil are still not well understood, particulary in the Mediterranean region and in cork oak forest systems. This study aimed to provide a long-term assessment of soil chemical characteristics in cork oak forests 16 years after a wildfire, at different depths, and of soil resillience to wildfire. The study was conducted in 2020 at Serra do Caldeirão (southern Portugal, Algarve), mainly in Leptosols. Soil sampling was carried out at two depths (0–5 cm and 5 cm–to maximum depth) in plots burned in 2004 (n=25) and unburned plots (n=12), which were used as control. Soil samples were chemically anallysed in the laboratory. Similar results were obtained for burned and unburned plots, for most of the parameters. The exceptions were extractable P (0-5 cm depth) and organic C (both depths), which were significantly higher in burned plots. The results show a natural recovery of soil characteristics after wildfire and, consequently, indicate a considerable soil resilience and the important role of vegetation on the dynamics of post-fire soil recovery.

Keywords: Post fire, Resillience, Leptosols, Coark oak forest, Serra do Caldeirão

RESUMO

Os incêndios, embora devastadores, são parte essencial na formação da paisagem mediterrânica e de alguns processos ecológicos que aí ocorrem. Dependendo das características do fogo, as propriedades do solo podem alterar-se significativamente. Os efeitos do fogo a longo prazo ainda não são bem compreendidos, principalmente na região mediterrânica e em particular em sistemas florestais de sobreiro. Este estudo teve como objetivo avaliar, a longo prazo e a diferentes profundidades, as características químicas dos solos de sobreirais 16 anos após um incêndio, bem como a sua resiliência a esta perturbação. Este estudo realizou-se na Serra do Caldeirão (Sul de Portugal, Algarve). A amostragem de solos decorreu em 2020 e realizou-se principalmente em Leptossolos e em duas profundidades (0-5cm e 5cm – máxima profundidade) em parcelas ardidas em 2004 (n=25) e não queimadas (n=12). As amostras de solos foram caracterizadas quimicamente. Para a maioria dos parâmetros (excepto P extraível e C orgânico) não se verificaram diferenças significativas entre os dois cenários. As concentrações de P extraível (apenas para a camada superficial) e C orgânico (ambas profundidades) foram significativamente maiores nas parcelas queimadas. Os resultados evidenciam a recuperação natural das características químicas dos solos após o fogo e, consequentemente, uma considerável resiliência desses solos, bem como o papel da vegetação na dinâmica de recuperação do solo.

Palavras-chave: Pós-fogo, Resiliência, Leptossolos, Sobreiral, Serra do Caldeirão

INTRODUCTION

Wildfires are affecting large areas of forests and shrublands in the Mediterranean region every year, with large economic and ecological impacts. In the past years, fire regimes have been shifting to large devastating fires, with higher intensity and frequency (Pausas, 2015). Nonetheless, wildfires are an intrinsic process of the mediterranean landscape and vegetation dynamics.

Soil is considered as the largest carbon terrestrial pool (Lal, 2004). Previous studies carried out in Mediterranean ecosystems highlighted a wide variability of the fire effects on soil properties and hydrological processes (Certini, 2005), contributing to soil degradation, including carbon loss.

Fire effects on soils depend on many factors such as fire severity and duration, vegetation type, soil type and pre-fire status, with the strongest impacts on the superficial layer (0-5 cm) (Hrelja *et al*., 2020). However, the fire can reach beyond this superficial layer and affect the deeper soil layers (Úbeda and Outeiro, 2009). For example, a soil layer of up to 30 cm is used to estimate soil carbon stock (FAO, 2019), indicating the importance of knowing fire effects and post fire recovery of soils beyond the superficial layer. Furthermore, there is little knowledge of fire effects on cork oak forests, despite the high ecological and economic importance of these ecosystems.

This study aimed to asses the long-term effect of wildfires in the soil chemical characteristics of cork oak forests and post-fire soil resillience.

MATERIAL AND METHODS

Study area

The study was conducted in Serra do Caldeirão (Algarve, southern Portugal). Serra do Caldeirão is a mountainous region, with a hilly landscape dominated by cork oak forests and shrublands of the *Cistaceae* and *Ericaceae* families. The climate is Mediterranean, classified as Csa according to the Köppen classification (Köppen, 1936). The soils were developed on schist and greywackes, included in the Mira Formation (Oliveira, 1982), being classified mainly as Leptosols (WRB, 2014) although some Cambisols can also occur.

The area was affected by an extreme wildfire in 2004, which caused a severe loss of forest area (≈13600 ha). In the study area 37 plots were selected (each plot with a total area of approximately 441 m^2), based on forest inventory, for soil sampling: 12 plots located in unburned area and 25 plots located in the area burned in 2004 (hereafter named as scenarios). In November of 2020, three soil samples were collected at two depths (0-5 cm and 5 cm to the maximum depth), at each plot.

After air-drying and homogeneization, soil samples (fraction <2 mm) were analysed for: pH and electrical conductivity (1:2.5 m:*V*), cation exchange capacity (extraction with ammonium acetate 1 mol/dm^3), extractable P (Olsen and Sommers, 1982), total N (Kjeldahl method) and organic C by wet digestion method (Springer and Klee, 1954).

A T-test was performed to evaluate significant differences of soil chemical caracteristics analysed (separately for each depth) between burned and unburned plots.

RESULTS AND DISCUSSION

Most of the soils presented a maximum depth up to 47 cm. Soil pH values were slightly acid to neutral, while electrical conductivities (EC) were low (Table 1), independently of the scenario and depth. There were no significant differences between burned and unburned areas for these parameters. Although the increase of soil pH after fire is reported due to ash-bed deposits on the surface (Chambers and Attiwill, 1994), this effect was not detected in the study area, 16 years after the fire.

Similar results for pH and EC between burned and unburned areas were reported by Fonseca *et al*. (2017) in Umbric Leptosols from *Pinus pinaster* forests, three years after fire. For soil developed on limestone of *Quercus coccifera* forests, pH values for the superficial layer (0-5 cm) also showed no significant differences between burned and unburned areas, nine years after fire, and regardless of fire severity, but EC increased (Alcañiz *et al*., 2016).

Table 1 - Chemical characteristics of soils collected, at different depths, in unburned and burned areas (mean ± SD). Values with * and ** indicate significant differences in soil parameters for the same depth at p<0.05 and p<0.01, respectively

Scenarios	Unburned	Burned
	0-5 cm of depth	
pH	6.07 ± 0.44	6.02 ± 0.41
EC (ds/m)	0.09 ± 0.04	0.08 ± 0.03
N_{total} (g/kg)	1.84 ± 0.49**	2.19 ± 0.67**
$P_{extractable}$ (mg/kg)	3.74 ± 2.27*	5.00 ± 2.34*
$C_{organic}$ (g/kg)	27.68 ± 10.95 **	40.12 ± 13.71**
CEC ($cmol_c$/kg)	6.51 ± 2.70	7.51 ± 2.77
	5 cm – maximum depth	
pH	5.74 ± 0.30	5.69 ± 0.36
EC (ds/m)	0.04 ± 0.01	0.05 ± 0.02
$P_{extractable}$ (mg/kg)	2.14 ± 1.15	2.40 ± 0.18
N_{total} (g/kg)	1.28 ± 0.40	1.38 ± 0.31
$C_{organic}$ (g/kg)	11.53 ± 6.00**	18.12 ± 6.54**
CEC ($cmol_c$/kg)	3.53 ± 1.37	3.89 ± 1.78

Cation exchange capacity (CEC) varied from low to very low (5-10 and <5 $cmol_c$/kg) with the depth, being Ca the dominant cation in the exchangeable complex. No significant differences were obtained in CEC values for both scenarios and depths (Table 1). CEC can decrease after fire due to the loss of organic matter. Nonetheless, the signficantly different organic C concentrations found between burned and unburned areas did not match with obtained values for CEC, sugesting a significant contribution of clays fraction to the CEC.

Contrarily to all other parameters analyzed, organic C and extractable P concentrations were significantly different beween burned and unburned plots at the study area.

Organic C concentrations decreased with depth, reaching always higher values in burned areas. This can be explained by the higher plant development of autochthonous species in burned areas in Serra do Caldeirão, such as *Cistus*, *Erica* and *Ulex* genus (data not shown). In fact, it was shown that frequent fires in the study area lead to the encroachment of persistent shrublands (dominated by *Cistus ladanifer*) (Acácio, 2009). High organic C amounts were also obtained in soils collected in *Pinus halepensis* and *Pinus pinaster* forests burned three years after fire, indicating that potsfire recovery of soil organic C depends on the interaction among plant recovery, fire severity and years after fire (Moya *et al*., 2019). Thus, the pattern of organic C recovery in the study area seems to be influenced by the soil-plant interaction.

Extractable P concentrations were very low, independently of the scenario, and showed a similar tendency to organic C concentration only the superficial layer, (higher in the burned areas; Table 1). These results are in concordance with the data obtained for a *Quercus coccifera* forest with similar shrub composition, where significant increases of extractable P in burned areas were identified nine years after fire (Alcañiz *et al*., 2016).

On the other hand, similar extractable P concentrations from superficial soil layer (0-5 cm) were obtained for burned and unburned areas, three years after fire on shrublands dominated by *Cistus*, while P increased on deeper layers (5-20 cm) of burned areas (Fonseca *et al*., 2017). The plant colonization of the burned area and consequent input of litter can be a possible explanation for P increase, as well as the effect of root systems on deeper levels leading to more plant uptake (Guerrero *et al*., 2005). Plant-soil interaction also plays a major role in the recovery of this soil parameter after fire. Moreover, Moya *et al*. (2019) showed that P can be affected by the interaction between fire severity and fire year but concentrations can increase three years after fire.

CONCLUSIONS

Sixteen years after the wildfire, soils in burned cork oak forests showed similar chemical characteristics to the unburned areas, independently of the soil depth. Important exceptions were obtained for organic C concentrations for all depths and extractable P only for superficial layer and can be related to the high plant development in burned areas. In fact, plant-soil interaction plays an important role in the soil recovery after fire.

In general, the edaphic processes in the burned cork oak forests from Serra do Caldeirão seem to be relatively dynamic, allowing the natural recovery of the system. The high resilience of this ecosystem and the consequent stimulation of post-fire plant development contributed to the increase of organic matter and its decomposition in soils from burned areas.

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