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of Fire Effects on Soil Properties**

António Bento Gonçalves, António Vieira (Eds.)

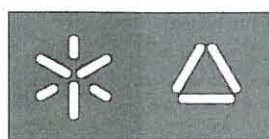
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Soil properties in burned and unburned Mediterranean shrublands of Montesinho Natural Park, Northeast Portugal

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Introduction

Large areas of shrubland are being destroyed by fire every year in the Mediterranean region, where this is a most relevant environmental problem. Anthropogenic fire in shrublands for obtain better pastures for cattle, is relatively common practice in the Montesinho Natural Park (PNM), Northeast Portugal. During burning, plant cover and litter layers are consumed, and the mineral soil is heated, resulting in changes to physical, chemical, mineralogical, and biological soil properties (Hubbert et al., 2006). The combination of combustion and heat transfer produces temperature gradients in soil (Certini, 2005). The extent and duration of the fire effects on soil properties depend on fire behavior, specially related to fire severity, as well as the climatic conditions, mainly to the characteristics of subsequent rainfall events (De Luís et al., 2001; Certini, 2005). A direct effect of fire on soil surface is the creation a continuous film water-repellent which reduces permeability and increase runoff (Imeson et al. 1992). In Mediterranean ecosystems, where the torrential rainfall events are frequent in autumn and winter (from October to March), this is a critical period, when the soil susceptibility to water erosion processes is increased after a fire (Andreu et al., 2001). The frequency increase of fires and intense rainfalls have a larger potential to reduce soil fertility by erosion and nutrient losses (Thomas et al., 1999).

The effect of fire on the organic matter content is deeply variable, and depends on several factors including fire type, intensity, duration and even slope (González-Pérez et al., 2004). Depending on fire severity, the organic matter can suffer slight distillation, charring, or complete oxidation (Certini, 2005). Fire induced changes to cycles of soil nutrients (Certini, 2005) and the majority of nutrient elements released from burned vegetation are in forms which are easily dissolved, with exception of soil phosphorus that increased the insolubility after fire. In sum, fires caused modifications on physical and chemical soil properties that, in turn, affect soil water permeability, capacity to absorb rainfall, support the various life forms and resistance to erosion and leaching processes.

Objectives

The aim of this study was to compare physical and chemical soil properties in burned and unburned shrubs areas under Mediterranean climate conditions, 6 months after the fire.

Methodology

The study site was selected on the basis of having adjacent burned and unburned shrubs areas on similar climatic, soil conditions and species composition in Montesinho Natural Park. The shrub vegetation consisted mainly of *Cytisus multiflorus* and *Ulex europaeus*. Climate is Mediterranean, with 12° C mean annual temperature and 740 mm mean annual



rainfall, concentrated from October to March (INMG, 1991). The fire occurred in early October 2009 and the soil samples were collected in March 2010. During this period the precipitation was 1384 mm and in October was 151 mm (<http://esa.ipb.pt/clima.php>). Thus, the properties of ash and soil may have been strongly modified by erosion and leaching (Gimeno-García et al., 2007).

In burned and unburned areas, disturbed soil samples were collected at depths 0-5, 5-10, 10-15, 15-20 and 20-30cm (n = 8 in each case), to assess organic matter, nutrients concentration, soil pH and soil texture. Bulk density and permeability were determined in undisturbed samples, collected in 100 cm³ cylinders (bulk density in the same depths above referred and permeability in the 0-5 cm layer). Porosity was calculated from bulk density assuming a particle of 2.65 g cm⁻³ (Ekinci, 2006; Hubert et al., 2006). Burn severity was estimated qualitatively from post-fire fuel size diameter and degree of litter consumption (Hubbert et al., 2006; Are et al., 2009).

Results and Conclusions

After the fire, increases in average bulk density are observed, ranging from 5% to 10% for layers 20-30 cm and 0-5 cm respectively, with a corresponding decrease in porosity and permeability (Table 1). Similar results were obtained by Hubbert et al. (2006).

Table 1. Soil bulk density, total porosity and permeability (n = 8 in each case) before and after burning (mean ± standard deviation)

Depth (cm)	Burned			Unburned		
	Bulk density (g cm ⁻³)	Total porosity (%)	Permeability (cm h ⁻¹)	Bulk density (g cm ⁻³)	Total porosity (%)	Permeability (cm h ⁻¹)
0-5	1.30 ± 0.22 ^a	51.05 ± 8.19 ^a	47.12 ± 24.52 ^a	1.17 ± 0.22 ^a	55.76 ± 6.29 ^a	51.68 ± 34.87 ^a
5-10	1.30 ± 0.27 ^a	50.80 ± 4.90 ^a		1.21 ± 0.13 ^a	54.29 ± 10.25 ^a	
10-15	1.41 ± 0.14 ^a	46.84 ± 7.02 ^a		1.29 ± 0.19 ^a	51.16 ± 5.12 ^a	
15-20	1.35 ± 0.11 ^a	49.03 ± 8.75 ^a		1.27 ± 0.23 ^a	52.23 ± 4.25 ^a	
20-30	1.42 ± 0.14 ^a	46.58 ± 4.20 ^a		1.35 ± 0.11 ^a	49.11 ± 5.12 ^a	

For each line and variable, different letters indicate significant differences between burned and unburned areas ($P < 0.05$)

The soil textural classes were not affected by fire. However, there were slight changes in silt and clay contents, which in general, varied in opposite directions, with gains of silt and losses of clay in soil (Table 2). The decrease in clay content suggested that there was formation of stable aggregates of finer particles into larger silt-size particles, which resulted in an increase of silt after burning (Hubbert et al., 2006; Are et al. 2009). Also, González-Pérez et al. (2004) referred that soils tend to coarser textures after fire.

Table 2. Effects of burning on particle-size distribution (mean ± standard deviation)

Depth (cm)	Burned				Unburned			
	Sand	Silt	Clay	Textural classes	Sand	Silt	Clay	Textural classes
0-5	44.0 ± 3.4 ^a	34.8 ± 1.9 ^b	21.2 ± 2.7 ^a	Loam	48.8 ± 2.8 ^b	30.5 ± 2.3 ^a	20.7 ± 2.3 ^a	Loam
5-20	44.7 ± 3.6 ^a	34.5 ± 2.7 ^a	20.8 ± 1.4 ^b	Loam	45.4 ± 3.1 ^a	31.9 ± 2.5 ^a	22.7 ± 2.0 ^a	Loam
20-30	40.6 ± 2.5 ^a	39.2 ± 3.5 ^b	20.2 ± 5.2 ^a	Loam	47 ± 2.3 ^b	30.6 ± 1.8 ^a	21.9 ± 2.3 ^a	Loam

For each line and variable, different letters indicate significant differences between burned and unburned areas ($P < 0.05$)

Results concerning soil chemical properties as affected by fire are presented in Table 3. Burning leads to a decrease in sum exchange bases with reflexes in soil pH values. Soil



pH decreased in all layers after fire, but this decrease is more visible in 0-5 cm. Decreases in pH after the fire were also reported by others authors (Rashid, 1987; Franco-Vizcaíno and Sosa-Ramirez, 1997). The temperatures reached by fire were low, indicated by incomplete combustion of the fuel resulting in lower release of bases. Giovannini and Lucchesi (1997) observed that the soil pH decreased at temperatures up to 395°C, followed by a clear increase at higher temperatures. In deep layers the pH values remain similar to the unburned area meaning a progressive increase with time apparently due to the infiltration of dissolved salts (Rashid, 1987).

Soil organic matter (SOM) increased in the first 15 cm, decreasing in deeper layers. In field observations it was visible huge quantities of charred materials deposited on surface soil. After a moderate fire, an increase of SOM is usually observed suggesting a substantial inclusion of charred plant materials (González-Pérez et al., 2004) and the presence of residual ashes (Pardini et al., 2004). In soil layer 0-5 cm, a coupled increase in SOM and in total N content was found. Although, burning usually results in losses of N by volatilization (Wienhold and Klemmedson, 1992), the frequent entrance in the burnt areas of N-fixer species (Johnson and Curtis, 2001), can explain the high increase of total N in upper layer (0-5 cm).

Phosphorus extractable decreased in all layers after the fire, while potassium increased, with exception of the first layer (0-5 cm). Despite effect of fire in phosphorus solubility decrease (Rashid, 1987) this and other nutrients are generally deposited on the soil in ash, where they are susceptible to loss by erosion and leaching (Wienhold and Klemmedson, 1992). As heavy rains fell, summing a total of 1384 mm from the moment which fire occurred (October 2009) to the moment of soil sampling (March 2010), soil erosion and leaching can have been relevant and the accumulation of some elements can have occurred within the soil profile.

Table 3. Chemical soil properties in burned and unburned shrublands six months after burning (mean \pm standard deviation)

Depth (cm)	pH (H ₂ O)	SOM (%)	Total N (%)	Extractable P (mg kg ⁻¹)	Extractable K (mg kg ⁻¹)	Sum exchange bases (cmol (+) kg ⁻¹)
Burned						
0-5	4.78 \pm 0.32 ^a	7.55 \pm 3.36 ^b	0.12 \pm 0.14 ^b	14.25 \pm 4.90 ^a	147.13 \pm 39.49 ^a	3.92 \pm 0.78 ^a
5-10	4.69 \pm 0.27 ^a	4.03 \pm 0.84 ^a	0.06 \pm 0.09 ^a	9.17 \pm 7.39 ^a	118.88 \pm 25.12 ^a	3.10 \pm 0.42 ^a
10-15	4.69 \pm 0.28 ^a	3.28 \pm 0.46 ^a	0.02 \pm 0.02 ^a	8.23 \pm 7.12 ^a	112.63 \pm 20.74 ^a	2.96 \pm 0.26 ^a
15-20	4.74 \pm 0.28 ^a	2.05 \pm 0.79 ^a	0.01 \pm 0.01 ^a	10.67 \pm 8.91 ^a	102.88 \pm 17.99 ^a	3.03 \pm 0.27 ^b
20-30	4.70 \pm 0.23 ^a	1.25 \pm 0.97 ^a	0.01 \pm 0.01 ^a	8.03 \pm 4.52 ^a	83.13 \pm 8.34 ^a	2.88 \pm 0.26 ^a
Unburned						
0-5	5.18 \pm 0.38 ^b	4.84 \pm 0.54 ^a	0.03 \pm 0.02 ^a	34.26 \pm 25.18 ^b	164.88 \pm 50.67 ^a	4.50 \pm 0.59 ^a
5-10	4.85 \pm 0.18 ^a	3.40 \pm 0.62 ^a	0.14 \pm 0.18 ^b	20.71 \pm 24.12 ^a	105.75 \pm 52.42 ^a	3.08 \pm 0.31 ^a
10-15	4.87 \pm 0.28 ^a	3.02 \pm 0.66 ^a	0.03 \pm 0.01 ^a	23.20 \pm 22.90 ^a	92.75 \pm 54.16 ^a	2.83 \pm 0.20 ^a
15-20	4.84 \pm 0.19 ^a	3.01 \pm 0.92 ^b	0.02 \pm 0.01 ^a	16.24 \pm 17.04 ^a	87.75 \pm 51.98 ^a	2.70 \pm 0.19 ^a
20-30	4.75 \pm 0.09 ^a	2.87 \pm 0.61 ^b	0.09 \pm 0.09 ^a	11.98 \pm 9.44 ^a	84.63 \pm 45.62 ^a	2.82 \pm 0.30 ^a

For each column of the same depth and variable, different letters indicate significant differences between burned and unburned areas ($P < 0.05$)

The climatic conditions after fire (with high precipitation amounts, eventually leading high leaching rates and surface erosion) and low fire severity (indicated by the presence of incompletely burnt materials), and consequently lower ash deposition, may partly explain the changes in soil properties found among burned and unburned shrublands.



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