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Immediate effects of prescribed burning in the Central Pyrenees on the amount and stability of topsoil organic matter

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ABSTRACT

Prescribed burning is the deliberate application of fire under selected conditions to accomplish predetermined management objectives. It is generally accepted that controlled use of fire has neutral or even positive effects on soils due to its lower temperature, intensity and severity compared to wildfires. However, very few studies have examined the effects of prescribed burning of shrub vegetation in humid mountain areas on soil properties. The objective of this work was to determine the immediate effects of prescribed burning on the quality and biochemical stability of soil organic matter (SOM) in areas encroached by shrubs in the Central Pyrenees (NE Spain). Soil samples were sampled in triplicate immediately before and after burning from the Ah horizon at 0–1, 1–2 and 2–3 cm depths. We quantified the variations as a direct result of burning in (1) the SOM content, (2) the content and mineralization rates of labile and recalcitrant C pools as inferred from incubation assays (141 days), and (3) the soil biological activity related to C cycling (microbial biomass C and β-D-glucosidase activity). Nearly all the soil properties studied were significantly affected by fire, varying in terms of extent of the effect and the soil depth affected. The total soil organic C (SOC), C/N ratio, β-D-glucosidase activity, C-CO_2 efflux and estimated content of labile SOC decreased significantly up to 3 cm depth. The total N and microbial biomass C were significantly affected only in the upper cm of the soil (0–1 cm). These results describe a short-term stronger impact of the prescribed fire on topsoil properties than usually reported. However, comparing these findings to other studies should be performed with caution because of the different environments considered in each case, as well as the differing soil thicknesses found in the literature, typically between 5 and 15 cm, which can lead to a dilution effect associated with the actual impacts of fire on soil properties. In this sense, the choice of a suitable soil thickness or sampling just after burning can be relevant factors in the detection of the immediate effects of fire. Short- and medium-term monitoring of the soils is needed to assess the suitability of this practice for pasture maintenance and for adapting the frequency of prescribed fires in order to minimize its impact on soil.

1. Introduction

Prescribed burning is defined as the deliberate application of fire to plant fuels in a specific area under selected conditions to accomplish predetermined management objectives, as to reduce hazardous fuels, improve forage for grazing, improve wildlife habitat, manage competing vegetation, perpetuate fire-dependent species, control insects and disease, cycle nutrients, etc. (Wade and Lunsford, 1989). Such controlled use of fire distinguishes it from its non-regulated use in traditional agricultural practices, for example in the management of some grazed shrublands in Europe (Fernandes et al., 2013). In the central Pyrenees in Spain, burning for agricultural management purposes are responsible of between 7 and 16% of uncontrolled fires that occur in the area (De Partearroyo et al., 2012). Prescribed burning is characterized by lower temperature, intensity and severity compared to wildfires, as achieved by controlling fuel, weather and topography (Martínez Ruiz, 2001). It is performed mainly in winter (from November to April), when burning is efficient because the vegetation is dry and humid soil conditions and low temperatures limit the risk of uncontrolled spreading (Martínez Ruiz, 2001). Prescribed burning is considered to affect only the upper centimetres of the soil (San Emeterio et al., 2014). However, the literature includes many studies that assess the effects of fire (both controlled fires and wildfires) over a larger thickness, typically between 5 and 15 cm, which can lead to a dilution effect associated with the actual impacts of fire on soil properties (Badía et al., 2014a).

Very few studies have examined the effects of prescribed burning of shrub vegetation in humid mountain areas on soil properties, with a goal of pasture improvement (San Emeterio et al., 2014). Soils in mountainous areas are characterized by large soil organic matter (SOM)

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accumulation (Körner, 2003); however, it is labile and very sensitive to environmental changes (Saenger et al., 2015). Several recent studies have emphasized the need for research on the response of mountain soils to changes in environmental or land management (Saenger et al., 2013, 2015; Sjögersten et al., 2011). Mountain pastures are often invaded by woody species unless disturbances occur that prevent plant succession. Thus, traditional pasture exploitation has long used fire to keep the best slopes open for grazing (Métailié, 2006). Woody encroachment can produce important effects at the ecosystem scale, such altering water and nutrient cycles in the soil, increasing the number and size of wildfires due to increased flammable biomass, decreasing biodiversity and diminishing livestock resources (i.e., autochthonous livestock breeds) (Montané et al., 2010). Prescribed burning is less expensive and produces less impacts in soil than mechanical treatments for shrub removal (Goldammer and Montiel, 2010) and may be the best tool available to restrain woody encroachment in many of these areas (Lyet et al., 2009).

Fire can affect soils considerably in the short and medium terms, modifying most physical, chemical and biological properties (Cerdà and Robichaud, 2009; Certini, 2005; González-Pérez et al., 2004; Knicker, 2007; Zavala et al., 2014). Research on the impacts of prescribed burning on soils has provided contradictory results, likely due to testing fire effects in variable conditions using different sampling techniques and evaluation strategies. It is generally believed that controlled use of fire has neutral or even positive effects on soils (Fernandes et al., 2013). Prescribed burning produces a short-term enrichment in the bioavailable nutrient content released in solution by ash, such as nitrogen or phosphorus (Canals et al., 2014; Mohamed et al., 2007; Rau et al., 2007), and calcium, magnesium and sodium (Pereira et al., 2011), while partial conservation of the litter layer tends to protect soils from erosion (Fernández et al., 2012; Vega et al., 2005). However, the SOM content is low-affected, or even increased, by the inputs of partially burned material (Knicker, 2007). As a result of fire, SOM undergoes composition modifications (e.g., by increased aromaticity), often leading to pyrogenic compounds that are more resistant to chemical and biological degradation (Knicker et al., 2005). The pyrolyzed material has a low C/N ratio, given that nitrogen is mineralized more rapidly than carbon (Baird et al., 1999). This process of mineralization increases the short-term availability of soluble forms of nitrogen and carbon (Prieto-Fernández et al., 2004). Prescribed burning has immediate effects on soil microbial communities, particularly on fungi (Boerner et al., 2000; Chen and Cairney, 2002); however, its impact on biological activity is reported to be lower than local heterogeneity (Boerner et al., 2000) or seasonal variation (Fontúrbel et al., 2012).

The main objective of this study was to determine the immediate effects of prescribed burning on the quality and biochemical stability of SOM in areas encroached by shrubs in the Central Pyrenees (NE Spain). As a starting hypothesis, we argued that prescribed burning, performed at a low temperature and high soil water content (from November to April in the Pyrenees), will have a limited impact based on both intensity and soil thickness affected. This work aimed to test this hypothesis, focusing on the cycling of organic matter and the biological activity in soil. The following specific goals were pursued: (1) to quantify the variations in SOM content as a direct result of burning, (2) to assess the biochemical stability of SOM immediately before and after burning, and (3) to assess the impact of fire on soil biological activity related to C cycling.

2. Material and methods

2.1. Study area

The study area is located in a large pastureland zone in the municipality of Tella-Sin (Huesca, NE Spain) at 1875 m a.s.l. Mean annual rainfall is 1700 mm and mean annual temperature is 5 °C. Large limestone outcrops alternate with areas of sufficient soil thickness to support high quality pastures dominated by *Festuca nigrescens* Lam. and *Bromus erectus* Huds. Soils are shallow and are classified as Eutric Epileptic Cambisols (loamic, humic) (IUSS Working Group WRB, 2014). The most relevant physicochemical properties of the soil are shown in Table 1. The pastures in the area are currently occupied by approximately 1200 sheep, 400 goats and 100 cattle. This livestock density is approximately one third of that supported 50 years ago. Thus, many pasture areas have been invaded by dense shrubs, including the thorny cushion dwarf *Echinospartum horridum* (Vahl) Rothm. and occasionally by boxwood (*Buxus sempervirens* L.). *E. horridum* is a shrubby Fabaceae endemic in the Pyrenees and the Massif Central (France). It is currently widespread throughout the southern Pyrenean slopes and is expected to spread further in upcoming years (Komac et al., 2011a). It is well adapted to grazed, shallow, highly insulated soils in areas of low relative humidity (Montserrat et al., 1984). It reproduces fast both sexually and asexually, allowing it to competitively exclude neighbouring plants, forming nearly monospecific patches (Komac et al., 2013). *E. horridum* often forms dense thickets covering up to several hectares. Large amounts of litter accumulate under these canopies, promoting the spread of wildfires in these areas. In turn, germination of *E. horridum* is stimulated by fire, making it capable of regenerating quickly after fires (Montserrat et al., 1984).

2.2. Field work and sample preparation

In April 2015, controlled burning was performed in a south-exposed experimental area of 12.5 ha, with an average altitude of 1820 m a.s.l. and slope ranging from 10 to 40% (Fig. 1). Soil temperature was recorded during the burn using thermocouples located at 1 and 2 cm depths in the Ah horizon (Fig. 2). The highest temperatures recorded during the fire were 397 °C at 1 cm and 121 °C at 2 cm, decreasing to the pre-burning temperatures 96 min after the start of burning. Fire severity was estimated as low-moderate based on the observation of the following indicators (Parsons et al., 2010): i) presence of a surface litter charred; ii) shrub stems charred and finer fuels (grasses, forbs and small stems) mostly consumed; iii) ash colour on the surface blackened with gray patches and iv) soil structure very slightly altered. The sampling sites were selected at regular intervals along a northeast–southwest transect from the highest to the lowest site. Soil samples were collected in triplicate from the Ah horizon at 0–1, 1–2 and 2–3 cm depths at the same sites immediately before and after burning, i.e., few hours later the same day of burning. The choice of these soil depths is based on previous studies that suggested fire effects on soil are negligible below these depths (Aznar et al., 2013; Badía et al., 2014a; 2014b). In total, we collected 9 + 9 soil samples (before + after burning). Samples were sieved (2 mm mesh) and stored at 4 °C until analysis.

Table 1
Physical and chemical characteristics of the *Eutric Epileptic Cambisols* at the study area.

Horizon	Ah_1 (0–5 cm)	Ah_2 (5–10 cm)	Bw_1 (10–30 cm)	Bw_2 (30–40 cm)
pH (H_2O, 1: 2.5)	6.0	6.4	6.5	7.6
pH (KCl, 1: 2.5)	5.3	5.5	5.5	6.7
$EC_{1:5}$ (dS m^{-1})	0.32	0.27	0.25	0.27
CEC (cmol (+) kg^{-1})	23.7	19.8	18.1	14.4
Total oxidizable C (g kg^{-1})	85.4	40.5	29.2	22.0
C/N	14.8	11.7	11.2	9.7
Clay (g kg^{-1})	300	333	295	273
Silt (g kg^{-1})	532	508	537	568
Sand (g kg^{-1})	169	159	169	159
Textural class (USDA)	Silty clay loam			
FC (g kg^{-1})	490	339	306	299
PWP (g kg^{-1})	321	195	164	176
AWC (g kg^{-1})	169	144	142	123

EC: electrical conductivity; CEC: cation exchange capacity; FC: water content at field capacity; PWP: water content at permanent wilting point; AWC: available water holding capacity.