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Sustainability of traditional pastoral fires in highlands under global change: Effects on soil function and nutrient cycling

L. San Emeterio[a,b,*], L. Múgica[a,b], M.D. Ugarte[c,d], T. Goicoa[c,d], R.M. Canals[a,b]

[a] Dpto. Producción Agraria, Universidad Pública de Navarra, Campus de Arrosadia s/n 31006, Pamplona, España
[b] Research Institute on Innovation & Sustainable Development in Food Chain (ISFood), Universidad Pública de Navarra, Campus de Arrosadia s/n 31006, Pamplona, España
[c] Dpto. Estadística e Investigación Operativa, Universidad Pública de Navarra, Campus de Arrosadia s/n 31006, Pamplona, España
[d] Institute for Advanced Materials (InaMat), Universidad Pública de Navarra, Campus de Arrosadia s/n 31006, Pamplona, España

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ABSTRACT

In Europe, rural depopulation and the abandonment of pastoral practices in mountain areas trigger deep changes in the landscape, which result in the accumulation of lignified fuels and the increased risk of fires, a sensitive issue in southern areas of the continent. From prehistory, a pyric herbivory has been practiced in European mountain regions. Pastoral fires created open communities, amenable to wild and domestic grazing, and herbivores perpetuated them by controlling fuel accumulation. In the last decades, the declining of extensive herbivory has given a prominent role to prescribed fires in order to preserve open communities. As a consequence, a new scenario of increased burning frequency and reduced herbivory emerges, which may affect the soil function in different ways. Our aim was to evaluate the effects of experimental burnings on soil function and nutrients cycling of a mountain gorse (*Ulex gallii* Planch.) shrubland, with the absence/presence of extensive grazing. We performed traditional "bush-to-bush" burnings in three experimental mountain plots and analysed seasonally along a 2-year period the soil function in relation to C-cycle (dissolved organic C, microbial biomass C and glucosidase activity), N-cycle (inorganic N forms, dissolved organic N, microbial biomass N and urease activity), P-cycle (phosphatase activity) and overall bacterial catabolic activity. Fire effects were time dependent and extensive grazing had a low influence on them. Fire originated a transient pulse of inorganic-N forms in the short term, which disappeared after 1 year, and increased dissolved organic N forms, which attenuated with time. In burned areas, a decrease of total N and microbial biomass N, and a slow-down of N- and P-cycle enzymatic activities were observed in the mid-term coinciding with a decrease of soil moisture. Since a higher burning frequency is a feasible situation that may affect mountain, nutrient-poor soils, the enduring effects of prescribed fires need to be taken into account to establish the optimal date of burning and the adequate recurrence regime that avoid negative impacts on the soil function and minimize the loss of nutrients from the soil reservoir.

1. Introduction

During millennia, fire and herbivory have been the main disturbances structuring and creating landscapes in Europe (Pausas and Keeley, 2014; Vera, 2000). Since prehistoric times, natural and anthropogenic fires opened the landscape and created grasslands, amenable to wild and domestic herbivores, which conversely preserved them by grazing (Rius et al., 2009). Nowadays, despite the multiple ecosystem services they provide (carbon sequestration and storage, biodiversity, habitat and food for wild and domestic herbivores, water supply, soil protection, wildfire control, leisure areas, cultural landscape), these grasslands are among the most endangered ecosystems in Europe, mostly due to the abandonment of traditional farming practices and the decrease of extensive livestock systems (Asner et al., 2004; Sebastià et al., 2008).

Mountain areas are particularly prone to global change (Huber et al., 2005). Abrupt transformations in the landscape and a rapid forest and shrub expansion are processes well documented in European mountain regions in the last decades (Molinillo et al.,

* Corresponding author.
E-mail address: leticia.sanemeterio@unavarra.es (L. San Emeterio).

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1997; Roura-Pascual et al., 2005; Valese et al., 2014). Rural depopulation and the loss of economic profitability have triggered a decrease in livestock censuses and a deep farming reorganization, which have led to a decline in shepherding and in an heterogeneous use of grassland surfaces (Lasanta and Vicente-Serrano, 2006; MacDonald et al., 2000).

In these situations, fire emerges as a key tool to prevent shrub encroachment and avoid fuels build-up. Because of this, prescribed fires are supported and financed by national and regional governments (Ascoli et al., 2013; Coughlan, 2013). In the Pyrenees, fires are performed after snow melting, in winter time, when dry vegetation and wet and cold soils guarantee the efficiency of burning, avoid the risk of spreading, and minimize the impact on the soil. Despite the interest, prescribed burnings as a unique tool for controlling shrub encroachment in grasslands have showed ineffective results (Briggs et al., 2005; Guedo and Lamb, 2013; Heisler et al., 2004, 2003) and pyric herbivory, the combination of fire and guided grazing practices, has been proposed as the main effective restoration measure for ecosystems with a long history of fire and grazing (Ascoli et al., 2009; Fuhlendorf et al., 2009). Although pyric herbivory has been traditionally used in the Pyrenees to preserve the landscape and the ecosystem services associated, the current scenario of herbivore pressure decrease is leading to the failure of the fair fire-herbivory balance. As a consequence, a high burning recurrence is occurring, in order to control vegetation regrowth. This new situation calls into question the appropriateness of the burning practice and its long-term sustainability, and increases the chances of hazardous pastoral fires, a delicate, sensitive issue in southern European countries (Ruiz-Mirazo et al., 2012).

The burning practice, apparently safe and harmless, may become detrimental when key determinants, such as timing and recurrence, are unsatisfactory. For instance, the preservation of the soil function is essential to the ecosystem and fires may affect it in different ways (Bento-Gonçalves et al., 2012; Certini, 2005; Doerr and Cerda, 2005). While most studies have focused on the apparent consequences of wildfires in soils of fire-prone Mediterranean ecosystems (Carreira et al., 1994; Goberna et al., 2012; Mataix-Solera et al., 2002; Uribe et al., 2013), the enduring effects of prescribed burnings in the soil function of temperate ecosystems have been less studied, and need a comprehensive research in order to implement the most sustainable and environmentally friendly practices that guarantee the preservation of the ecosystem' potential (Fontúrbel et al., 2012; Marcos et al., 2009; Vega et al., 2014, 2005).

Eventually, despite the single effects of grazing and fire on soil function have been the focus of many studies, their interaction has been scarcely addressed in the scientific literature. Most research has put attention on the effects on vegetation (Alday et al., 2015; Augustine et al., 2010; Savadogo et al., 2007), demonstrating strong interactive effects, positive and negative, with diversity and plant composition at different scales (Meers and Adams, 2003; Noy-Meir, 1995; Savadogo et al., 2007; Teague et al., 2010; Veen et al., 2008). In contrast, fire and grazing combined effects on the belowground ecosystem have captured much less research effort, and have focused on soil chemical and physical parameters (Savadogo et al., 2007; Veen et al., 2008), respiration and CO_2 fluxes (Ward et al., 2007) and on soil microbial biomass (Harris et al., 2008). The aim of this research is to evaluate the effects of traditional burnings in the soil function and the nutrients cycling of mountain gorse (*Ulex gallii* Planch.) shrubland soils, with the absence/presence of extensive grazing in order to enlarge our understanding on the fundamental processes occurring in the soil, a necessary knowledge to base the technical recommendations for the use of fire with preservation purposes in mountain areas.

2. Materials and methods

2.1. Study site

Research was conducted in the Aezkoa Valley, in the western Pyrenees (1100 m a.s.l., 43°0′N, 1°10′W). The climate in the area is strongly influenced by the nearby Atlantic Ocean (55 km in a direct line). Mean annual precipitation for the site is 1900.9 mm, of which 250.7 mm (13% of annual total) occurs during the three driest months (June, July, and August). Mean annual temperature is 9.3 °C, with a long snowy and cold winter and a mild temperate and foggy summer. Soils are deep and mostly developed on sandstones and calcareous clays, with loamy and clay-loamy dominant textural classes. The vegetation of the area is a mosaic of beech forests, shrublands of *Ulex gallii* Planch, and semi-natural grasslands with a high floristic diversity (VV.AA., 2009). Prescribed burnings, allowed and financially supported by the local governments, are frequent every winter to control the important shrub encroachment of *U. gallii.*

2.2. Experimental burnings and assay establishment

In early March 2012, three sites were selected on different, moderate (<10°) slopes, which were relatively close to each other (<1 km linear distance) and oriented S–SW (Ezkanda, Site 1), NE (Azalegi, Site 2) and N-NW (Aritzelate, Site 3). Sites encompassed the most common grassland vegetation in the area: floristically diverse, with dominance of perennial grasses (such as *Festuca* gr. *rubra, Brachypodium pinnatum* and *Agrostis capillaris*) and with moderate *U. gallii* encroachment (25–35% of cover). Each site was subdivided in two plots of 30 m × 30 m and, on 16 March 2012, a controlled burning was applied in one plot of each experimental site using the traditional method of shrub-to-shrub, while the other plot remained unburned. The shrub-to-shrub burning is usually performed by local stakeholders -rangers and farmers- in relatively small areas with moderate shrub encroachment, during winter time. Fire is directly applied to the shrubs with the aid of a flammable fuel such as kerosene and the herbaceous vegetation among the shrubs is mostly maintained intact. Since soils are cold and moist, surface and subsurface temperatures reached during the fire are low. In our experiment, the highest temperature recorded from 16 measurements in a single plot were 71 °C at a depth of 2 cm (measured with a T-bar digital temperature sensor, Multi-thermometer).

The consequence of the burnings was an heterogeneous mosaic, with grass dominated areas not affected by fire, and shrub-dominated areas affected by fire of low (soil covered with dark ashes) and moderate (soil covered with grey ashes) severity. After the experimental fires, a grazing exclusion fence of 15 m × 30 m was established at each site. The fence crossed burned and unburned plots, with the purpose of separating 4 plots of 15 m × 15 m per site with the following treatments: burned and grazed, burned and ungrazed, unburned and grazed, and unburned and ungrazed (Fig. 1). The grazed plots experienced an extensive, mixed herbivory (<1.2 Animal Unit.ha^{-1}), of sheep, cows, and horses during 6 months per year (from May to October), which is the current regime of use of the common lands in the area of study.

Soil samples were taken on six dates during a two-year period, at 10 days, and at 4, 7, 13, 16 and 19 months after burning (Fig. 1). Sampling timetable included all seasons (except winter, when the thick snow layer hindered soil collection), and were performed in similar dates both years. In each plot, three soil samples were collected with cores of 9 cm diameter and 10 cm depth in order to include most of the area of rhizosphere influence. The three samples were mixed and homogenised to give a unique composite sample per plot. In unburned plots, soil was sampled below shrub