Science of the Total Environment 644 (2018) 583–593

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Effects of prescribed burning for pasture reclamation on soil chemical properties in subalpine shrublands of the Central Pyrenees (NE-Spain)

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HIGHLIGHTS

- Prescribed burning is used to remove shrubs and recover subalpine pastures.
- We studied its effect on soil chemical properties immediately and one year after.
- Fire had few direct effects on nutrient content but it decreased one year later.
- New SOM inputs induced changes in cation exchange capacity and exchangeable cations.
- Research further in time is needed to assess the sustainability of this practice.

GRAPHICAL ABSTRACT

Changes in the studied soil properties immediately (B0) and one year (B12) after burning as compared to unburned soils.

	Buisán		Tella	
	B0	B12	B0	B12
Soil organic C	-	-	-	-
Total N	-	-	-	-
pH	+	+	=	+
Electrical Conductivity	=	-	=	-
Σ Exchangeable Cations	-	=	=	-
Cation Exchange Capacity	=	-	=	=
Σ Water-extractable cations	=	-	=	-
$N\text{-}NH_4^+$	=	+	=	+
$N\text{-}NO_3^-$	=	=	=	-
Available P	=	-	=	=

ARTICLE INFO

Article history:
Received 27 April 2018
Received in revised form 15 June 2018
Accepted 29 June 2018
Available online xxxx

Keywords:
Soil nutrients
Cation exchange capacity
Prescribed fire
Shrub encroachment
Pasturelands

ABSTRACT

The abandonment of the traditional pastoral activities in the subalpine grasslands of the Central Pyrenees (NE-Spain) has resulted in shrub encroachment processes that are dominated by species such as the *Echinospartum horridum*. Therefore, prescribed burning has been recently readopted in this region as a management tool to stop the spread of shrubs and recover grasslands. We aimed to assess the effect that this practice may have on soil chemical properties such as SOC, N, pH, EC, water-extractable and exchangeable cations (Ca^{2+}, Mg^{2+} and K^+), cation exchange capacity, inorganic N forms ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) and available P. We studied two prescribed burnings conducted at the subalpine level of the Central Pyrenees in the municipalities of Tella-Sin (April 2015) and Buisán (November 2015). At each site, the topsoil was sampled in triplicate at soil depths of 0–1, 1–2 and 2–3 cm immediately before (U), immediately after (B0) and one year after (B12) burning, and litter and/or ashes were removed prior to sampling. The results indicate that in the B0 samples, burning significantly reduced the SOC and N contents as well as the exchangeable Ca^{2+} and Mg^{2+} at 0–1 cm, whereas the rest of the studied properties remained virtually unchanged. However, in the B12 samples we detected a decrease of nutrient content that was probably related to leaching and/or erosion processes.

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https://doi.org/10.1016/j.scitotenv.2018.06.363
0048-9697/

1. Introduction

Pasturelands in the Central Pyrenees (NE-Spain) have traditionally been maintained by livestock grazing and occasional burnings (Nadal-Romero et al., 2018). However, due to rural exodus and the reduction in livestock densities, this activity has suffered from remarkable reductions over the past decades (Komac et al., 2013). The mesophytic pastures that can be found in the Pyrenees below the timberline require shrub management (i.e., grazing, burning or clearcutting) for survival (Halada et al., 2011); therefore, the reduction in grazing activity led to shrub encroachment processes that were dominated by species such as *Echinospartum horridum* (Vahl) Rothm (Komac et al., 2013; Nuche et al., 2018). The development of this species poses a threat to biodiversity and an increase in flammability risks (Caballero et al., 2010) because it forms large and dense monospecific covers (Komac et al., 2011).

A suitable procedure to reduce shrub encroachment in grazing lands can be the use of prescribed burnings (Goldammer and Montiel, 2010), which are defined as the planned use of fire to achieve precise and clearly defined objectives (Fernandes et al., 2013). Nevertheless, fire can affect most soil properties directly by burning and indirectly as a consequence of the new post-fire conditions (Santín and Doerr, 2016). The extents of the effects of fire on soils are highly influenced by environmental conditions; so, prescribed burnings are conducted when the soil and fuel moisture, temperature and topography conditions are favorable, to limit the impact of the burnings on soils and prevent fire from escaping (Vega et al., 2005; Molina, 2009). However, prescribed burnings show contrasting effects on soil properties, as has been recently reviewed in Alcañiz et al. (2018).

Previous works dealing with prescribed burnings of *Echinospartum horridum* in the Central Pyrenees have shown that this practice may severely affect soil organic matter (SOM) content (Armas-Herrera et al., 2016, 2018; Girona-García et al., 2018a, 2018b) in the first few centimeters of the topsoil. The combustion of SOM and vegetation may produce an increase in the available nutrients by either the mineralization of organic compounds or the production of ashes (González-Pérez et al., 2004; Knicker, 2007). Then, the incorporation of ashes into the soil can lead to increases in pH and electrical conductivity (EC) (Certini, 2005). The literature shows that the available concentrations of Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} are commonly increased after prescribed burning (Arocena and Opio, 2003; Lavoie et al., 2010; Alcañiz et al., 2016). Inorganic N forms can also increase after burning from either the contribution of ashes or the mineralization of soil organic N. For this reason, it is common to detect ammonium gains immediately after burning that will result in nitrates increases via nitrification over time (Gundale et al., 2005; San Emeterio et al., 2016). Fire may also boost the contents of available P in the soil via both the contributions of ashes as well as the mineralization of its organic forms that can occur even at relatively low temperatures (Úbeda et al., 2005; Badía-Villas et al., 2014; Larroulet et al., 2016; García-Oliva et al., 2018). This enrichment in nutrients produced by fire may promote the rapid establishment of herbaceous species. However, another consequence of SOM destruction is the loss of adsorption sites in the soil, thereby reducing the cation exchange capacity (CEC) (Badía and Martí, 2003). In this way, depending on the severity and recurrence of burning, these practices could also lead to nutrient losses (Wanthongchai et al., 2008). Nevertheless, the CEC usually remains unchanged after prescribed burning (Larroulet et al., 2016; Fonseca et al., 2017).

The main objective of our study was to detect the effects of prescribed burning of *Echinospartum horridum* for pasture reclamation on soil chemical properties, focusing on soil nutrient content and availability, at the subalpine level of the Central Pyrenees (NE-Spain). We analyzed the immediate effects of burning on total soil organic C (SOC), total N, pH, EC, water-extractable and exchangeable cations, CEC, inorganic N forms (N-NH_4^+ and NO_3^-) and available P, as well as their changes one year after the fire at soil depths of 0–1, 1–2 and 2–3 cm.

2. Material and methods

2.1. Study sites

The study sites are located in two subalpine areas of the Central Pyrenees (NE-Spain) in the municipalities of Buisán and Tella-Sin (Fig. 1). The Buisán plot is located in an area with a mean slope of 10% at 1760 m.a.s.l., while the Tella plot was located on a steeper slope of 25% at 1875 m.a.s.l., and both sites face south. The mean annual temperature in Buisán is 6 °C and 5 °C in Tella. The mean annual precipitations are 1500 mm (Buisán) and 1700 mm (Tella). The topsoil Ah horizons (0–5 cm) of both sites are characterized by high SOM contents, high CEC and fine textures; the pH in Buisán is neutral whereas it is moderately acidic in Tella. Soils in Buisán are classified as Eutric Cambisol and those in Tella as Eutric Epileptic Cambisol (IUSS Working Group WRB, 2014), and the complete soil characterization of the study sites can be found in Armas-Herrera et al. (2016) and Girona-García et al. (2018a), respectively. In Buisán and Tella, the bedrock is composed of fine detritic sediments over clayey limestones alternated with Eocene marls. As a consequence of the decreased grazing activity and the prohibition of fire after 1980, these areas have been invaded by *Echinospartum horridum*, which covered >75% of the surface area before the prescribed burning was conducted. Pastures in the study sites that surround the *Echinospartum horridum* shrubs are composed of herbaceous species such as *Bromus erectus* Huds., *Festuca nigrescens* Lam., *Agrostis capillaris* L., *Briza media* L., *Onobrychis pyrenaica* (Sennen) Sirj., *Trifolium pratense* L. and *Trifolium repens* L.

2.2. Prescribed burning characteristics

The prescribed burnings were conducted in April 2015 (Tella) and November 2015 (Buisán) by qualified firefighters of the EPRIF (Wildfire Prevention Team) of Huesca and BRIF (Reinforcement Brigades against Wildfires) of Daroca units. The environmental conditions met the established parameters for *Echinospartum horridum* burning: no heavy rainfall took place prior to the burning date, the temperature was between 5 and 15 °C, the relative humidity of the air was 35–70%, and the wind speed ranged from 5 to 10 km/h. An approximation of the temperatures reached during burning at each site was obtained via type-K thermocouples placed in one sampling point at each of the different soil depths (Table 1). The Buisán burning was performed by applying the point source fire technique and creating a grid of spot ignitions that burned from the east to the west flanks that followed a slow progression (0.63 ha h^{-1}). In Tella, a backing fire was ignited to spread against the wind and downslope, and it was faster (2.82 ha h^{-1}) than that in Buisán. At both sites, the aerial biomass of *Echinospartum horridum* was mostly eliminated by burning, resulting in burned trunks, partially charred litter and patches of black and gray ashes.

2.3. Soil sampling

At each burning site, we chose three representative sampling spots that were covered by *Echinospartum horridum* prior to burning. At each of these points, after removing the shrubs and organic layers from an approximate surface area of 0.25 m^2, the topsoil Ah horizon was carefully sampled at depths of 0–1, 1–2 and 2–3 cm (Fig. 2). These samplings were carried out early in the morning immediately before the prescribed burnings were conducted, and unburned (U) samples were collected and considered the control. To detect the immediate effects of fire (B0), we sampled points adjacent to U shortly after burning (<2 h), after removing ashes and charred remains. Additionally, in both study sites, points contiguous to U and B0 were sampled one year later (B12) to assess the short-term evolution of soil properties after burning.