Science of the Total Environment 639 (2018) 175–185

Contents lists available at ScienceDirect

Science of the Total Environment

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

Changes in soil nitrogen dynamics caused by prescribed fires in dense gorse lands in SW Pyrenees

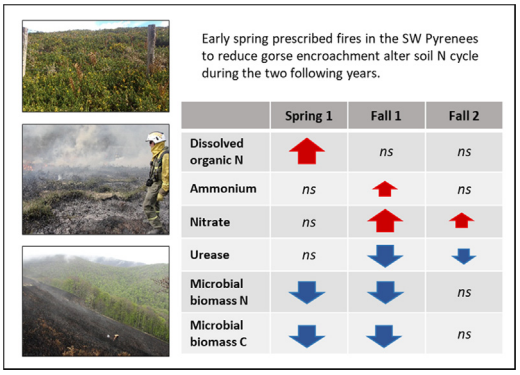
Leire Múgica *, Rosa M. Canals, Leticia San Emeterio

Dpto. Producción Agraria, Universidad Pública de Navarra, Campus de Arrosadia s/n, 31006, Pamplona, Spain
Research Institute on Innovation & Sustainable Development in Food Chain (ISFood), Universidad Pública de Navarra, Campus de Arrosadia s/n, 31006, Pamplona, Spain

HIGHLIGHTS

- Early spring prescribed fires in abandoned, highly-encroached gorse lands.
- Immediate dissolved organic nitrogen and delayed nitrate pulses in burned soils.
- Immediate decline of microbial biomass and a drop of urease activity after 7 months.
- Even the low fire intensity, effects on N cycle were still detected after 18 months.
- Rapid revegetation reduces N loss but post-fire gorse growth questions fire efficacy.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 October 2017
Received in revised form 8 May 2018
Accepted 11 May 2018
Available online xxxx

Keywords:
Shrub encroachment
Ulex gallii
Controlled burnings
Soil N-cycle
Dissolved organic N
Nitrate

ABSTRACT

Rural depopulation, abandonment of traditional land uses and decrease of extensive stockfarming is accelerating shrub encroachment in mountain areas. In NW Spain, gorse (*Ulex gallii* Planch.) is expanding, developing dense shrublands that accumulate high fuel-loads, ignite easily and persist during long periods as alternate stable states. Under this scenario, traditional *bush-to-bush* farming fires are being replaced by high fuel-load burnings performed by specialised teams to reduce fuels and promote mosaic landscapes. This research analyses the effects on soil function and nitrogen (N)-cycling of these new generation of prescribed fires practiced under similar conditions to traditional fires (winter time, moist soils), but differing in the biomass and the continuity of the surface burnt. The results showed significant changes in N-cycle parameters, such as increases in inorganic N and dissolved organic nitrogen (DON), but declines in N microbial biomass and urease activity. At the ecosystem level, potential N losses were high because the pulse of water-soluble forms, DON and nitrate, following fire overlaps with periods of low biological N retention by microorganisms and plants. Although most effects were similar to those observed in traditional burnings done in the same region, the primary concern is the high potential for DON losses following prescribed burning in highly gorse-encroached areas. In N-limited ecosystems, a crucial issue is to attain an equilibrium between frequent burnings, which may prevent an optimal recovery of the soil function, and uneven burnings, which burn high amounts of accumulated fuel and increase the risk of removing large quantities of dissolved N from the ecosystem in a unique fire event. Overall, the use of different techniques combined with fire are needed to promote and consolidate desired changes in dense gorse lands.

* Corresponding author at: Research Institute on Innovation & Sustainable Development in Food Chain (ISFood), Universidad Pública de Navarra, Campus de Arrosadia s/n, 31006, Pamplona, Spain.
E-mail address: leire.mugica@unavarra.es (L. Múgica).

https://doi.org/10.1016/j.scitotenv.2018.05.139
0048-9697/

1. Introduction

Historical fire and grazing regimes are responsible for the mosaic of open landscapes and highly valuable grasslands developed across many natural areas (Vera, 2000; Pausas and Keeley, 2009). The interaction between these two disturbances originated complex landscapes, which ancient humans understood and promoted for their own benefit (Fuhlendorf and Engle, 2004). In European mountain areas, the evolutionary history of fire, herbivory and humanization has been tracked by means of the analysis of coal and pollen fossil records in lacustrine peat sediments (Galop et al., 2013). In the Pyrenees, there is scientific evidence of the use of fire associated to hunting in the Paleolithic (Rius et al., 2012), and to agro-pastoral activities until recent days (Métailié, 2006; Faerber, 2009; Rodríguez et al., 2016), which has caused an impact in the carbon (C) and nitrogen ecosystem stocks (Lo et al., 2015). The socio-economic changes occurring on the half of the 20th century triggered a massive rural exodus, a land-use abandonment and a reduction of extensive stock farming, resulting in an acceleration of shrub encroachment and forest expansion. As a consequence, as in many other European regions, the mosaic of vegetation is being replaced by an homogeneous and more lignified landscape, which affects the diversity and functioning of open ecosystems (Poschlod and WallisDeVries, 2002; Eldridge et al., 2011) and increases the risk of natural fires (Galiana and Lázaro, 2010).

In the western Pyrenees and the Cantabrian coast, gorse shrublands (*Ulex europaeus* L. *and U. gallii* Planch.) have expanded extensively paralleling land-use abandonment. Both species constitute dense covers in nutrient-poor and acid soils, which remain as a stable vegetation community for long periods and holding a scarcely diverse plant community. In former centuries, farmers harvested gorse and use it for cattle bed combined with cereal straw. Afterwards, cattle dung mixed with gorse, straw and urine was applied to soil as manure for crops (Sineiro García, 1982; Pardo de Santayana et al., 2014). However, the abandonment of herbivory and traditional farming in recent decades has favoured the expansion of both species, allowing the build-up of dense shrublands trapped in an alternate stable state with a low potential of successional dynamics (as "landscape traps" concept by Lindenmayer et al., 2011).

Nowadays, prescribed fires (planned use of fire with a preservation purpose), are applied in dense shrublands for pasture reclamation (Armas-Herrera et al., 2016; Faerber, 2009; Fontúrbel et al., 2016). As in the case of traditional burnings, prescribed fires are scheduled in winter and early spring, which ensure dry vegetation, moist soils and low air temperatures. However, the continuity and quantity of fuel load and the large areas affected increase the severity of these fires compared to traditional *bush-to-bush* burnings (which apply fire to shrubs while maintaining herbaceous vegetation intact; San Emeterio et al., 2016) (Fig. 1). The high fire severity of prescribed burnings in gorse-dominated covers may affect soil function differently from traditional fires, alter C and nutrient cycles and influence the whole ecosystem recovery. Consequently, the assessment of the environmental effects of prescribed fires in comparison to traditional burnings is a matter of interest.

Even low severity fires have effects on terrestrial C and N cycles. The impact of fires of different intensity on soil organic matter stocks has been studied in depth in the last decades in different ecosystems (González-Pérez et al., 2004; Knicker, 2007; Badía et al., 2014). As a result, detailed balances estimating C stocks and losses depending on temperatures, oxygen and fuel loads have been implemented (Meigs et al., 2009; Hurteau and Brooks, 2011; Keith et al., 2014). Regarding N, the consequences of fire on the terrestrial N cycle have been less studied, even though changes in the soil biological function and in N stocks may entail critical consequences for ecosystem preservation (Covington and Sackett, 1992; Romanyà et al., 2001). To improve the knowledge on the effects of fire on soil N dynamics is crucial to understand the environmental benefits and shortcomings of burning and its influence on the course of plant succession (Wan et al., 2001; Prieto-Fernández et al., 2004). Our previous research on traditional *bush-to-bush* burnings showed a transient pulse in N availability, a moderate impact in soil microbial biomass N and a slow-down of N-related enzyme activities (San Emeterio et al., 2016). The matter of this research is to determine whether and how more intense prescribed burnings in abandoned, dense gorselands affect soil function and N cycling differently from traditional burnings. We put in question the hypothesis that current prescribed burning practices, developed as a tool for ecosystem restoration, are environmentally comparable to traditional pastoral burnings. We focus on the short- and mid-term effects of prescribed burnings on soil N dynamics and compare them to the effects reported in traditional fires still practiced in some areas of the same region.

2. Materials and methods

2.1. Study area and prescribed fires

The study site was located in Roncesvalles, at the western side of the SCI Roncesvalles-Selva de Irati (protected Natura 2000 site code ES0000126), in the SW Pyrenees (43°1′N 1°19′W). The climate, cold and oceanic, is characterized by snowy winters and cool and misty summers. Mean annual temperature and precipitation are 9.2 °C and 1601 mm, respectively (Espinal climatic station, http://meteo.navarra.es) (Fig. 2). Soils, dominated by clay-loamy textures, are organic, acidic and with high cation exchange capacity (CEC) (Table 2), and are classified as Humic Dystrudept and Typic Udorthent (USDA, 2014). Landscape comprises a mosaic of beech forests, shrublands and grasslands. Gorse (*Ulex gallii* Planch.) is the dominant species in shrublands, and constitutes dense covers which are accompanied by heath species (such as *Calluna vulgaris* (L.) Hull., *Erica vagans* L., *Erica tetralix* L. and *Daboecia cantabrica* (Hudson) C. Koch) at best. Grasslands are very diverse and include perennial grasses (such as *Festuca rubra gr.*, *Agrostis capillaris* L., *Agrostis curtisii* Kerguélen), perennial forbs (such as *Galium saxatile* L. and *Potentilla erecta* (L.) Raeusch.), and a small proportion of legumes (*Trifolium repens* L.).

A sharp reduction of livestock grazing has occurred in the area during the last decades, which has favoured shrub encroachment and gorse expansion in particular. Gorse is a low palatable N_2-fixing shrub that develops tall and dense covers with high fuel loads, which are very flammable and have a high calorific power (Elvira and Hernando, 1989; Marino et al., 2011). Therefore, prescribed, winter burnings are promoted and financially supported by the local government with amelioration purposes, in order to promote diversity by the entry of new species and to decrease the risk of uncontrolled fires that may affect valuable nearby forests.

At the eastern side of the same SCI, in Aezkoa valley, winter burnings are also frequent in highlands. Since census of extensive livestock are still relevant in that area, gorse encroachment is less intense and a traditional use of the fire prevails, which is based on the *bush-to-bush* burning technique (Fig. 1; A, B and C). A recent research was done in the area to determine the effects of the *bush-to-bush* technique in soil N dynamics and function. This research is detailed in San Emeterio et al. (2016) and will be used in the discussion of this manuscript.

In early spring 2014, three heavily gorse-dominated areas (*U. gallii* cover >90%) were selected along a hill in Roncesvalles. They were located at altitudes ranging from 1059 to 1125 m a.s.l. on different slopes (>35%) (Table 1). Selected areas have not been burnt for at least 15–20 years.

Prescribed fires were planned and classified depending on the level of difficulty from low difficulty (Level 1) to high difficulty (Level 3, which entailed a previous field mechanical clearing of fragile areas). Three prescribed burnings were carried out on March 21st, April 10th and April 14th 2014, by specialised burning teams. Soil temperatures were recorded during the first fire using three thermistors (TidbiT© UTBI-001 data-loggers, HOBO) located in the same profile at different