Immediate effects of prescribed burning on C-related topsoil properties in Central Pyrenees

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Abstract. Prescribed burning, i.e. the deliberate use of fire under specific conditions, is a management tool for recovering pasturelands affected by shrub encroachment. The objective of this work is to determine the immediate effects of prescribed burning on topsoil properties related to C cycle in soils covered with dense scrubs (*Echinospartum horridum*) in Tella (Huesca, Central Pyrenees, Spain). Soils were sampled in triplicate immediately before and after burning at 0-1 cm, 1-2 cm and 2-3 cm depths. We analysed the content of total oxidizable C (TOC); the content and mineralization rates of labile and recalcitrant C pools C, as inferred from incubation assays (141 days); microbial biomass C (MBC); and the β-D-glucosidase (GL) activity. All studied soil properties were significantly affected by fire, varying in terms of intensity and affected depth. Fire produced a significant decrease in TOC (-41% on average), similarly affecting the upper 3 cm of soil. The content of labile C decreased considerably (-87% on average) at depths up to 3 cm, but its mineralization rate increased (+ 150% on average). The MBC was particularly affected at 0-1 cm (-53%), while GL activity showed significant decreases throughout the upper 3 cm (-49% on average). These results show a strong impact on the studied soil properties just after burning. Monitoring the evolution of these soils is necessary to assess their resilience in the short and medium terms, and check the sustainability of controlled burning for pasture management in the Pyrenees.

Keywords. Pastureland – Controlled fire – Soil organic matter – Soil biological activity – Carbon mineralization.

Effets immédiats du brûlage dirigé sur des propriétés du sol superficiel liées au C dans les Pyrénées Centrales

Résumé. *Le brûlage dirigé est un outil de gestion permettant le rétablissement des pâturages touchés par l'embroussaillement. L'objectif de ce travail est de déterminer les effets immédiats du brûlage dirigé sur les propriétés du sol superficiel liées au cycle du C dans des sols couverts par le genêt hérissé (*Echinospartum horridum*) à Tella (Huesca, Espagne). Les sols ont été échantillonnés en triple avant et après un brûlage sur 0-1 cm, 1-2 cm et 2-3 cm de profondeur. Nous avons analysé la teneuren C oxydable total sur sol (COT); la teneur etle taux de minéralisation du C labile et récalcitrant, déduit à partir de tests d'incubation (141 jours); le C issu de la biomasse microbienne (CBM); l'activité des β-D-glucosidase (GL). Toutes les propriétés du sol étudiées ont été significativement affectées par le feu, variant en termes d'intensité et de profondeur affectée. Le feu a produit une diminution significative du COT (-41% en moyenne) et identique dans les premiers 3 cm de sol.Le contenu de C labile a considérablement diminué (-87% en moyenne) jusqu'à 3 cm, mais son taux de minéralisation a augmenté (+ 150% en moyenne). Le CBM a été particulièrement touché sur 0-1 cm (-53%), tandis que l'activité des GL a montré des diminutions significatives sur les premiers 3 cm de sol (-49% en moyenne). Ces résultats montrent un fort impact du brûlage sur les propriétés des sols étudiés. Le suivi de l'évolution de ces sols est nécessaire afin d'évaluer leur capacité de résilience dans les court et moyen termes et de vérifier la viabilité du brûlage dirigé pour la gestion des pâturages dans les Pyrénées.*

Mots-clés. *Pâturages – Feu contrôlé – Matière organique du sol – Activité biologique du sol – Minéralisation du carbone.*

I – Introduction

Pastureland area in the Central Pyrenees has greatly declined in recent decades in favour of thorny shrubs as “erizón” (*Echinospartum horridum*), mainly due to the abandonment of traditional practices of forestry and livestock farming related to rural exodus. The effects of shrub encroachment include alteration of the nutrients and water cycles in soil, increased fire risk and loss of biodiversity and livestock resources (Montané *et al.*, 2010). Prescribed burning is a useful tool for recovering pasturelands degraded by shrub encroachment (Fernandes *et al*., 2013). These controlled fires are characterised by lower temperatures (normally not exceeding 400 ºC) and being of lesser intensity and severity than wildfires. Although there is extensive information on the environmental effects of controlled fire under Mediterranean climate, very few studies have investigated controlled burning of scrubland in humid environments and aimed at pasture improvement (San Emeterio *et al*., 2014). The general objective of this work is to investigate the immediate effects of prescribed burning on the quality and biochemical stability of soil organic matter (SOM) in soils covered by scrubs in the central Pyrenees (NE Spain). Specific aims include: (1) to quantify the variation in the SOM as a result of burning, (2) to evaluate the biochemical stability of SOM before and after burning through mineralization assays in laboratory, and (3) to assess the impact of fire on soil biological characteristics related to C cycle (microbial biomass C and β-D-glucosidase activity).

II – Materials and methods

The study area is located within a large pastureland area in the municipality of Tella-Sin (Huesca, Spain) in the central Pyrenees, at 1875 m a.s.l. The mean annual rainfall is 1700 mm and the mean annual temperature is 5ºC. Large limestone outcrops alternate with areas of thin soils (classified as Eutric Epileptic Cambisols (IUSS, 2014) sufficient to support pastures of great quality, dominated by *Bromus* and *Festuca*. In April 2015, a controlled burning was performed in an experimental area of 12.5 ha, south-exposed, with an average altitude of 1820 m a.s.l. and slope ranging from 10 to 40 %. The highest temperatures recorded during fire were 397ºC and 121ºC at 1 cm and 2 cm depth, respectively, decreasing back to temperatures of 25ºC 96 minutes since the start of burning. We collected soil samples from the Ah horizon in triplicate immediately before and after burning at 0-1, 1-2 and 2-3 cm depth. We analysed the following soil properties: total oxidizable C (TOC) and total N; microbial biomass C (MBC) (Vance *et al*., 1987); mineralization of soil organic C during incubation assays and β-D-glucosidase (GL) activity (Eivazi and Tabatabai, 1988). The amounts of C-CO_2 emitted during the incubation were fitted to a double exponential decay model (labile and recalcitrant pools) using XLSTAT (version 2015, Addinsoft SRL, Paris). From this model, the content of potentially mineralizable C (PMC) and mean residence time (MRT) of the labile fraction were obtained. To determine the impact of fire at different soil depths, we compared, for each soil layer, the values of the soils properties studied before and after burning using Mann-Whitney U tests.

III – Results and discussion

All the soil properties studied were significantly affected by fire at varying intensities and depths (Table 1). The TOC and the C/N ratio significantly decreased after burning, affecting similarly the first three cm of soil. In general, it is considered that the combustion of the organic matter starts to be significant at around 200-250 ºC, leading to total disappearance at about 500ºC (Certini, 2005). In our experiment, temperature reached nearly 400ºC at 1 cm depth, which would explain the sharp decline in the organic matter content. Fire affected the MBC at 0-1 cm depth (-53%), although a decreasing trend can also be seen at 1-2 cm depth, while the GL activity decreased significantly at depths up to 3 cm (-49% on average). It is generally accepted that the most immediate effect of fire on soil microorganisms is a reduction in their biomass, leading to complete sterilization of the up-

per 2-3 cm of soil in extreme cases (Knicker, 2007). It has been suggested that high soil moisture might also intensify the heat transfer in soil and thereby increase microbial mortality (Certini, 2005). In our study, the combination of relatively high temperatures at 1 cm depth and high soil water content before burning contribute to explain the decrease in the MBC. The impact of fire on GL activity can be explained by both the thermal denaturation of the enzyme due to high soil temperature and the inactivation of enzymes associated with soil colloids (Knicker, 2007). Burning decreased the $C\text{-}CO_2$ efflux (-50% on average), affecting similarly the upper three cm of soil (Fig. 1). The labile PMC content decreased considerably (-87% on average) up to 3 cm, and its mean residence time (MRT) decreased (-48% on average). Severe fire is known to cause important losses of most labile forms and accumulation of refractory organic materials, resulting in decreased respiratory rates of burned soils relative to unburned soils (González-Pérez *et al.,* 2004), which seems to be the case here.

Table 1. Mean values of soil properties at different depths immediately before and after the prescribed fire

	0-1 cm		1-2 cm		2-3 cm	
	Unburned	**Burned**	**Unburned**	**Burned**	**Unburned**	**Burned**
SWC, %	100 ± 32 a	74.5 ± 29 a	108 ± 46 a	78.6 ± 36 a	84.2 ± 39 a	59.0 ± 14 a
TOC, g/kg	248 ± 36 a	139 ± 21 b	209 ± 24 a	130 ± 33 b	174 ± 33 a	104 ± 13 b
C/N ratio	12.7 ± 1.84 a	9.3 ± 0.9 b	12.1 ± 1.76 a	10.1 ± 0.48 b	12.1 ± 1.42 a	9.7 ± 0.1 b
MBC, g/kg	15.9 ± 2.3 a	7.4 ± 4.7 b	13.1 ± 5.5 a	8.6 ± 2.2 a	8.9 ± 1.9 a	8.0 ± 3.2 a
GL, µmol PNP g/h	32.2 ± 4.9 a	13.9 ± 4.6 b	24.5 ± 4.2 a	15.3 ± 8.5 a	20.6 ± 5.2 a	9.5 ± 1.2 b
$C\text{-}CO_2$ efflux, mg/kg/ day	81.7 ± 14 a	43.3 ± 6.6 b	60.7 ± 11.2 a	37.9 ± 2.1 b	52.5 ± 11.5 a	23.4 ± 6.7 b
Labile PMC, g/kg	9.36 ± 3.2 a	2.46 ± 0.5 b	11.5 ± 7.0 a	2.32 ± 0.5 b	28.6 ± 24.5 a	1.6 ± 0.4 b
MRT of the labile PMC, days	61.3 ± 10 a	32.2 ± 7.1 a	106 ± 59 a	65.2 ± 24 a	195 ± 143 a	49.1 ± 16 a

SWC, soil water content; TOC, total organic C; MBC, microbial biomass carbon; GL, β-D-glucosidase activity; PMC, potentially mineralizable C; MRT, mean residence time. Values followed by different letters indicate significant differences between unburned and burned samples (Mann-Whitney U tests, P <0.05).

IV – Conclusions

Our results showed a strong immediate impact of prescribed fire on the soil properties studied. These effects were greater than expected for a controlled burning. Monitoring the evolution of these soils with time will allow us to assess their resilience after prescribed burning, and to check the sustainability of this technique for managing mountain pastures in the Pyrenees.

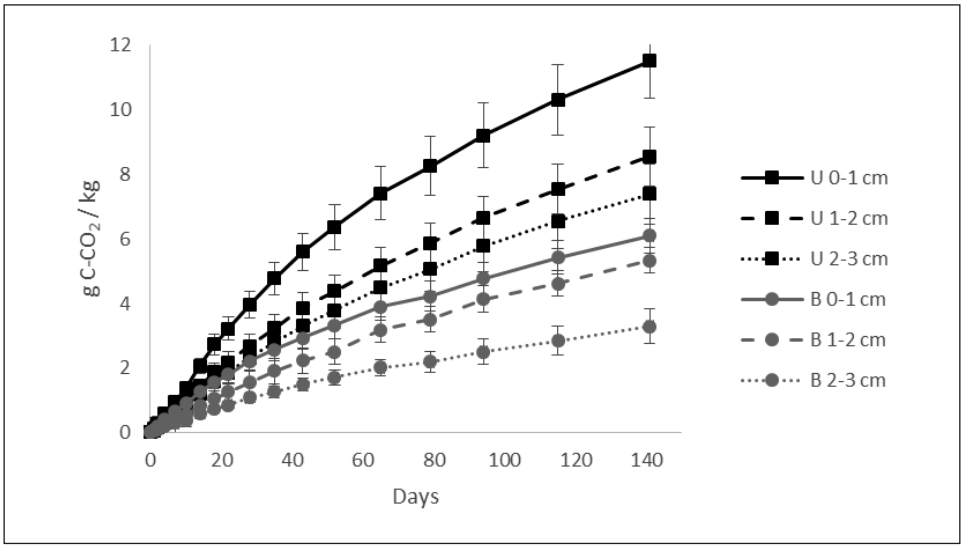

Fig. 1. Accumulated soil organic carbon (g C-CO_2 / kg) mineralized after 141 days of incubation. U, unburned soil; B, burned soil.

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References

Certini G., 2005. Effects of fire on properties of forest soils: a review. *Oecologia*, 143, 1-10.

Eivazi F. and Tabatabai M.A., 1988. Glucosidases and galactosidases in soils. *Soil Biology and Biochemistry*, 20, 601-606.

Fernandes P.M., Davies, G.M., Ascoli D., Fernández C., Moreira F., Rigolot E., Stoof C.R., Vega J.A. and Molina D., 2013. Prescribed burning in southern Europe: developing fire management in a dynamic landscape. *Frontiers in Ecology and the Environment*, 11, 4-14.

González-Pérez J.A., González-Vila F.J., Almendros G. and Knicker H., 2004. The effect of fire on soil organic matter – a review. *Environment International*, 30, 855-870.

IUSS Working Group WRB, 2014. World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. *World Soil Resources Reports,* No 106. FAO, Rome.

Knicker H., 2007. How does fire affect the nature and stability of soil organic nitrogen and carbon? A review. *Biogeochemistry*, 85, 91-118.

Montané F., Casals P., Taull M., Lambert B., Dale M.R., 2010. Spatial patterns of shrub encroachment in neighbouring grassland communities in the Pyrenees: floristic composition heterogeneity drives shrub proliferation rates. *Plant Ecology*, 211, 267-278.

San Emeterio L., Múgica L., Gutiérrez R., Juaristi A., Pedro J. and Canals R.M., 2014. Cambios en el nitrógeno edáfico tras la realización de quemas controladas para mejora de pastos pirenaicos. *Pastos*, 43, 44-53.

Vance E.D., Brookes P.C. and Jenkinson D.S., 1987. *Soil Biology and Biochemistry*, 19,703-707.