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Monitoring of soil Greenhouse Gases emissions from a controlled burnt area combined with guided herbivory

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Abstract Rural depopulation as well as the intensification of farming systems in southern Europe have led to important changes in landscape and the ecosystem services they provide. Indoors livestock production is translated into a reduction or absence of grazing which ends up with a rapid expansion of bushes and extensive processes of natural forestation. This causes loss of biodiversity and accumulation of biomass fuel increasing the risk of big fires and therefore negatively affecting these lands.

Within the Open2Preserve project, different regional pilot experiences (France, Spain, and Portugal) were established. These pilots aimed at combining an initial prescribed burning to enhance forage quality followed by a grazing to both reduce fire risk and increasing the economic return of farmers, while reducing mechanical costly clearances to be developed there. We aim at evaluating the effect of horse grazed and un-grazed areas on greenhouse gases (GHGs) emissions in a mountain area of the Galicia region (NW Spain) after prescribed burning implementation A monitoring of GHG (CH_4, N_2O and CO_2) soil emissions during 16 weeks along the year 2020 was carried out.

Keywords: Understory, fire control, grazing, shrubland.

1. Introduction

The European Mediterranean region has a long history of natural wildfires that play a role in the vegetation dynamics of the area. However, currently uncontrolled wildfires threaten not only natural vegetation, landscape biodiversity, communities and economies, but they also release large amounts of greenhouse gases, thus contributing to global temperature increase. Higher temperatures and drier summers have increased the risk of wildfires in European Mediterranean areas. Moreover, the increasing abandonment of mountain areas is leading to the expansion of uncontrolled and high fuel loads. Planning and implementing management operations aimed at reducing the flammable load of biomass can significantly help to reduce negative impacts of uncontrolled wildfires (Corona et al., 2015, Rodríguez-Rigueiro et al., 2021).

Pyric herbivory (combined with controlled and prescribed fire) has demonstrated benefits in the management of mountain areas reducing fuel biomass at the same time than producing an economical return to the local communities (Rigueiro-Rodríguez et al., 2012).

Despite the controlled burning conditions, prescribed burning can still have significant effects on soil water content and soil temperature (that are considered, together with fine root activities, key driving factors of fires on CO_2 efflux) (Zhao et al 2015). The combustion event (even at low intensities) would also result in amounts of charcoal and dying plant roots (Kim et al., 2011) and therefore alter root activities, organic matter decomposition, availability of substrate and soil C and N dynamics (Certini, 2005; Wang et al., 2014). All these parameters are closely related to three major greenhouse gas exchanges at soil-atmosphere interface, namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In this work we monitored the Greenhouse gases fluxes from soils one year after prescribed burning combined with horse and cattle grazing during 16 weeks along the year 2020.

2. Material and methods

2.1. *Study site and experimental set up*

The experiment was conducted in O Cerredo (Rao) Forest Community (Navia de Suarna (Lugo) in the region of Galicia (northwestern Spain) European Atlantic Biogeographic Region) at an altitude of 1394 m to 1392 m a.s.l. This area is included in several Protection networks: Biosphere Reserve, ZEC (Special conservation area), ZEPA (Special Protection Area for Birds), ZEPVN (Zone of special protection of the natural values). Most of vegetation is scrub (85%, according to the SIOSE of 2014), being the majority *Erica australis* and *Erica arborea*, which have a homogeneous distribution, among which are also homogeneous and to a lesser extent *Calluna vulgaris*, *Cytisus scoparius*, *Chamaespartium tridentatum* and *Daboecia cantabrica*. In addition, there are some Ulex minor spots that account for 5% of the scrub.

In March 2019 a controlled burning of 2 ha was realized. Horse grazing (3 horses ha^{-1}) was carried out in 1 ha for 37 days in September 2019. In June 2020, horse grazing (3 horses ha^{-1}) was carried out for 15 days and cattle grazing (3 cows ha^{-1}) for 36 days.

2.2. Greenhouse gases (GHG) fluxes

GHG were sampled using the closed chamber technique (Hutchinson and Moiser, 1981). Four polyvinyl chloride (PVC) rings (25 cm internal diameter) per plot were inserted 5 cm into the soil in June 2020 and were only removed in the grazed plots when animals were inside. Each PVC chamber (25 cm height) was covered with a reflective layer of aluminium film to avoid increases of the internal temperature, which was measured by introducing thermometers before the chambers were closed. In each soil gas sampling, 20 mL of gas were collected at 0, 20 and 40 min after chamber closure and transferred to an evacuated 12-mL Exetainer ® borosilicate glass vial (model 038 W, Labco, High Wycombe, UK).The concentration of CO_2, CH_4 and N_2O were measured with a gas chromatograph system (Agilent 7890B, Agilent, Santa Clara, CA, United States) equipped with a flame ionization detector (FID) coupled to a methanizer + an electrical conductivity detector (ECD).

Gas fluxes were calculated taking into account the linear increase in the gas concentration inside the chamber with time (40 min) and correcting the values for air temperature.

2.3. Soil characteristics

The soil pH was measured in H2O using a 1:2.5 soil:solution ratio (Faithfull, 2002). Soil total N and P were analysed after a microkjeldahl digestion (Castro et al 1990) in a TRAACS-800+ analyser (Bran Luebe (1979)). K was measured after a microkjeldahl digestion by atomic emission spectrometry. Available cations were measured after extraction by the Mehlich method (Monterroso et al 1999) by atomic spectrometry. The soil organic carbon (SOC) in the soil was estimated by oxidation of the total organic matter with potassium dicromate and sulphuric acid. The excess of dicromate was titrated with Mohr salt (Kowalenko, 2001).

3. Results

Soils presented a very acidic pH (between 3.94 and 4.17) and this tended to be lower in the unburning soils. Soil C was high (between 11.9% and 18.4 %) and tended to be higher in the unburning soils. No differences were found in the Total soil N among treatments although this was slightly lower in the prescribed fire than in prescribed fire + grazing and unburning treatments. Significant differences were found in total soil P, K and Ca: soil P and K were higher in the burned treatments (both including grazing or not) than in unburning treatment while total Ca was higher in the unburning treatment (Table 1)

Table 1. Soil characteristics

	Prescribed fire + grazing	**Prescribed fire**	**Unburning**
pH	4.17 ± 0.31	4.11 ± 0.31	3.94 ± 0.04
%			
N	0.97 ± 0.14	0.78 ± 0.18	0.92 ± 0.21
P	0.060 ± 0.008 a	0.056 ± 0.006 a	0.042 ± 0.002 b
K	1.08 ± 0.15 a	0.96 ± 0.33 a	0.49 ± 0.12 b
Ca	0.094 ± 0.032 b	0.094 ± 0.036 b	0.166 ± 0.039 a
C	13.1 ± 1.6	11.9 ± 5.4	18.4 ± 1.3

Soil CO_2 fluxes ranged from 712 mg CO_2-C m^{-2} d^{-1} (in the prescribed fire + grazing treatment on 15th October) to 3902 mg CO_2-C m^{-2} d^{-1} (in the prescribed fire + grazing treatment on 26th June). Soil CO_2 fluxes were significantly higher in the prescribed fire treatment (mean of 2671 mg CO_2-C m^{-2} d^{-1}) than in prescribed fire + grazing or unburning treatments (2130 mg CO_2-C m^{-2} d^{-1} and 2197 mg CO_2-C m^{-2} d^{-1} respectively) (Figure 1).

Soil CH4 fluxes were mainly negative and ranged from -1.85 mg CH_4-C m^{-2} d^{-1} (in the prescribed fire + grazing treatment on 7th august) to 0.72 mg CH_4-C m^{-2} d^{-1} (in the prescribed fire + grazing treatment on 15th October). No significant differences were found among treatments: mean of -0.512 mg CH_4-C m^{-2} d^{-1} in prescribed fire + grazing, -0.536 mg CH_4-C m^{-2} d^{-1} in prescribed fire and slightly higher in unburning soils (-0.337 mg CH_4-C m^{-2} d^{-1}) (Figure 1).

Soil N_2O fluxes were close to 0 in all treatments with almost not net exchange soil-atmosphere. N_2O fluxes ranged from -0.067 mg N_2O-N m^{-2} d^{-1} (in the unburned treatment on 9th June) to 0.24 mg N_2O-N m^{-2} d^{-1} (in the prescribed fire + grazing treatment on 26th June). No significant differences were found among treatments although emission flux tended to be higher in the prescribed fire + grazing treatment (mean of 0.048 mg N_2O-N m^{-2} d^{-1}) than in prescribed fire and Unburning treatments (mean of 0.013 mg N_2O-N m^{-2} d^{-1}) (Figure 1).

4. Discussion

Soil CO_2 production is a consequence of root respiration and microbial decomposition of organic matter and is strongly influenced by soil characteristics such as temperature and water content (Davidson and Janssens, 2006). Soil aboveground processes (such as the type and development degree of the vegetation) can influence the above defined soil structural variables. Other external factors (such as animal grazing) can affect GHG fluxes indirectly by influencing the crop development (Ball et al., 2008) or directly by deposition of wastes or ground trampling.

Currently, the available information about the effects of guided herbivory and interaction effects between prescribed fires and herbivory on soil CO_2, CH_4 and N_2O emissions is scarce.

Some studies point out that the reduced microbial respiration after prescribed burning could contribute to decreased CO_2 efflux (Sullivan et al 2011). However, an increase in soil CO_2 emissions compared to unburnt area was found in the present study that could be attributed to an increase in microbial activity due to the release of a high amount of easily decomposable organic matter after fire. Moreover, ashes can act as fertilizer for crops by releasing the nutrients present in the biomass and further improve plant growth. Besides the direct release of organic matter to soils from burnt biomass, the increase in shrub growth can lead to the increase in root-derived CO2 which is source for growing and activity of soil microorganisms. Similarly, Fest et al. (2015) also reported that low intensity burning slightly increased soil CO_2 flux in temperature eucalypt forest systems. This was attributed to the higher inputs of easily decomposable compounds, higher soil surface temperature by decreased plant canopy cover or different C allocation in below- and aboveground tissues (Fest et al., 2015).

Over the entire measurement period, soil acted as a sink of CH_4 some exception in the last months of sampling. Soil may act as a sink or as a source of CH_4, depending on the O_2 availability for microbial activity. Hence, soil methanogenesis (production of CH_4) requires strict anaerobiosis and low oxidation-reduction potentials (Le Mer and Roger, 2001) that can still take place in some specific microniches in well oxygenated soils. Studies have reported both positive (Sullivan et al., 2011) and no significant impact of fires on forest soil CH_4 uptake (Kim et al., 2011).

Finally, there were practically no soil N_2O emissions and only some positive emissions were found in the first days of sampling (corresponding to the moment of cattle grazing). These emissions were found in only one of the four sampling cameras (data not shown) and this could be due to the presence of heterogeneously distributed excreta patches of grazing animals. The emission of N_2O from excreta patches is mainly caused by increased nitrification and denitrification, in association with the increased abundance of ammonia-oxidizing bacteria (AOB) and denitrifying bacteria (Cai et al 2017).

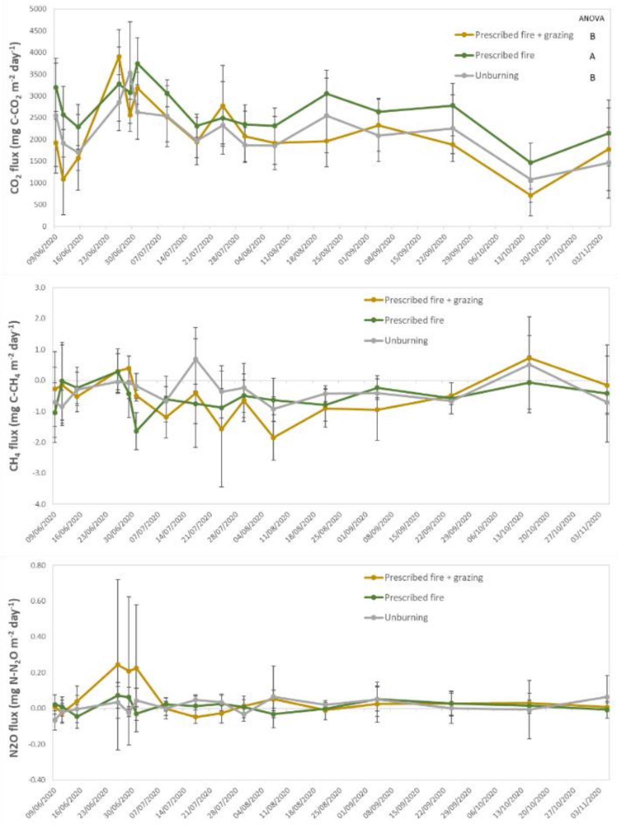

Figure 1. Evolution of CO_2, CH_4 and N_2O daily fluxes from soils.

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