Geoderma 305 (2017) 328–335

Contents lists available at ScienceDirect

Geoderma

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

Effects of a high-severity wildfire and post-fire straw mulching on gross nitrogen dynamics in Mediterranean shrubland soil

M. Fernández-Fernández[a,b], T. Rütting[b], S. González-Prieto[a,*]

[a] Instituto de Investigaciones Agrobiológicas de Galicia, CSIC, Apartado 122, E-15780 Santiago de Compostela, Spain
[b] University of Gothenburg, Department of Earth Sciences, Box 460, 405 30 Göteborg, Sweden

ARTICLE INFO

Handling Editor: Jan Willem Van Groenigen

Keywords:
Autotrophic nitrification
Emergency stabilization techniques
Heterotrophic nitrification
Mineralisation-immobilisation turnover
^{15}N tracing

ABSTRACT

Little is known about the combined impacts of fire and straw mulching, a widely used post-fire emergency measure, on the soil nitrogen (N) cycle. Unburnt (US) and severely-burnt soils without (BS) and with straw mulching (BSM) were preincubated (3 and 6 months) in the laboratory before fire and mulching effects on gross N transformations were investigated with a paired ^{15}N-labelling experiment. The ammonium-to-nitrate (NH_4^+/NO_3^-) ratio of burnt soils decreased with preincubation time from 21 to 1.3, consistent with a shift of the N cycle towards net nitrification. After 3 months of preincubation, gross mineralisation (M_{SON}) and gross NH_4^+ immobilisation (I_{NH4}) in BS more than doubled compared to US, in the latter being M_{SON} 4.82 mg N kg^{-1} day^{-1} and I_{NH4} 3.01 mg N kg^{-1} day^{-1}. Mulching partly mitigated this stimulation in the mineralisation-immobilisation turnover (MIT). After 6 months, MIT differences among treatments disappeared and gross rates approached those in US after 3 months. After three months, autotrophic nitrification (NH_4^+ oxidation) in all treatments was 0.41–0.52 mg N kg^{-1} day^{-1}, while after 6 months it remained similar in US but increased 8-fold in burnt soils. Heterotrophic nitrification of organic N only occurred in burnt soils, and its importance was similar to autotrophic nitrification after 3 months, but around 4-fold lower after 6 months. To conclude, burning opened up the N cycle and NO_3^- accumulated, increasing the potential for ecosystem N losses. In the short term, straw mulching slightly mitigates the effects of fire on the N cycle.

1. Introduction

Most of the current large-scale and intense wildfires are caused by human activities and nowadays wildfires affect more land area than any other natural disturbance (Bento-Gonçalves et al., 2012; Caldararo, 2002; Pausas and Keeley, 2009). As a consequence of climate change and land use change, the number, extent and severity of wildfires is very likely to increase considerably (Bento-Gonçalves et al., 2012; Birot, 2009; Pereira et al., 2011). Moreover, there is evidence of a substantial positive feedback of wildfires on the climate system (Bowman et al., 2009). Elucidating the effects of wildfires on both the carbon (C) and nitrogen (N) cycles is crucial as these elements are fundamental to sustain primary production and some of their forms are among the main greenhouse gases. However, little is known about the impacts of fire and post-fire management activities on soil gross N dynamics (Bowman et al., 2009; Wang et al., 2014).

The main repercussions of wildfires on the soil N cycle are the significant removal of soil organic matter (SOM); the redistribution of the remaining soil organic N (SON), with an increase of recalcitrant forms and decrease of the most labile ones; the conversion of organic to inorganic N due to heating and combustion; considerable losses of N by leaching, erosion and volatilisation; as well as a marked alteration of both quantity and specific composition of microbial communities (Castro et al., 2006; Certini, 2005; Fisher and Binkley, 2000; Prieto-Fernandez et al., 2004). Both increased soil inorganic N concentrations and altered net N transformation rates after fires have been widely reported (see Wang et al. (2014) and references therein). Nevertheless, net N mineralisation is the outcome of the counteracting and simultaneous gross mineralisation and gross immobilisation processes (the so-called mineralisation-immobilisation turnover, MIT) and, similarly, net nitrification is the result of gross nitrification and gross NO_3^- immobilisation. Consequently, in order to gain a better understanding of the underlying mechanisms, we need to investigate gross N transformation rates together with the environmental variables controlling these fluxes (Koyama et al., 2010; Wang et al., 2014).

One of the emergency stabilization techniques most widely used after wildfires is straw mulching, which has shown an immediate effectiveness in increasing ground cover and thus reducing soil erosion

---

[*] Corresponding author.
E-mail addresses: mariafernandez@iiag.csic.es (M. Fernández-Fernández), tobias.rutting@gvc.gu.se (T. Rütting), serafin@iiag.csic.es (S. González-Prieto).

http://dx.doi.org/10.1016/j.geoderma.2017.06.023
Received 15 November 2016; Received in revised form 19 June 2017; Accepted 23 June 2017

during the first critical months after the fire (Bento-Gonçalves et al., 2012). Both the soil composition and soil processes might be altered by mulching, as it enhances vegetation recovery (and thus nutrient uptake by plants), decreases the runoff-infiltration ratio, reduces erosion and increases the topsoil C and N content. In Gómez-Rey et al. (2013) and Gómez-Rey and González-Prieto (2014) straw application after fire effectively reduced erosion but did not affect the soil nutrient concentrations. Mulching has been shown to affect gross N fluxes in unburnt soils (Cheng et al., 2012; Huang et al., 2008), but we are aware of only one experiment testing the effect of straw application on gross N rates in burnt soils (Gómez-Rey and González-Prieto, 2015). This study with a soil affected by a moderate to highly severe wildfire showed that mulching resulted in a short-lived stimulation of gross mineralisation and gross immobilisation of ammonium (NH_4^+). The aim of the present study was to investigate if this is also true for soils exposed to high severity fires, i.e., with even more extended consumption of surface organic matter, higher proportion of white/grey ashes and also with damage to soil structure (based on Parson et al. (2010) and Vega et al. (2013)).

In the reviews by Gómez-Rey and González-Prieto (2013) and Wang et al. (2014) no common response of gross N transformations to fires (wildfires and prescribed fires) was found, most probably due to the large number of influencing factors (e.g. forest and soil type, severity and recurrence of fire, climate, time between fire and sampling). In the present study, we investigated wildfire and post-fire mulching effects on gross N dynamics in a shrubland soil from NW Spain. We conducted a ^{15}N tracer experiment using the numerical ^{15}N tracing model *Ntrace* (Müller et al., 2007; Rütting and Müller, 2007) with a severely-burnt soil (with and without surface applied straw) and a control unburnt soil, previously preincubated for 3 and 6 months. Our hypotheses are: a) fire stimulates gross N transformations; b) mulching partially reverts the changes on N fluxes caused by a very high severity fire; and c) time after fire also affects N rates.

2. Material and methods

2.1. Site description

Soil samples for the laboratory experiments were collected in the Támega valley (42°4′45″ N, 7°28′36″ W, Galicia, NW Spain; 520 m asl). The area has a mesic and sub-humid climate with a mean annual temperature of 13–14 °C and a mean annual precipitation of 600–800 mm. The dominating vegetation is a shrubland of *Ulex europaeus* and *Erica arborea* with scattered *Pinus pinaster* trees. In this area fire recurrence is high and shrubland burns every 5–10 years. In August 2014 the area was affected by a high severity wildfire that burnt approximately 6 ha of shrubland. Within a distance of 25 m from the burnt place, an unburnt area with the same topography, orientation, vegetation cover and soil type was identified as control for the experiment. Burnt and unburnt soils were both characterized as Dystric Leptosol (IUSS Working Group, 2014).

2.2. Soil sampling

As the aim was to specifically study the effects of fire and post-fire mulching on the most severely affected area, the day after the fire and with the soil still warm, top soil (0–2 cm depth) was selectively sampled in 30 spots, of variable size (80–250 cm^2), burnt with high or very high severity (based on Parson et al. (2010) and Vega et al. (2013)) considering the following characteristics: a) almost all the pre-fire ground cover and surface organic matter (litter, duff, and fine roots) was consumed; b) the whole burnt surface was covered either with white (or grey) ashes or with bare greyish soil (with reddish spots) exposed; and c) topsoil structure damaged or destroyed. With this sampling strategy we collected relatively homogeneous sub-samples which were combined into a composite sample, and thus pseudoreplication can restrict the generalization of our results. For the unburnt control, ten sampling squares (15 × 15 cm) were selected at random and the litter layer (O horizon) and the mineral topsoil (0–2 cm) were separately sampled; soil subsamples were mixed into a composite sample and the same was done with the litter. In the laboratory the soils were sieved (< 2 mm), homogenised and stored at 4 °C for soil incubation purposes. For the mulching treatment, wheat straw (from an agricultural field nearby) was selected. Straw is widely used for this purpose in Galicia and elsewhere since a small dose (200–250 g m^{-2}) ensures the 60–70% of ground cover needed to effectively protect burnt soils against erosion (Gómez-Rey et al., 2013; Robichaud, 2009; Vega et al., 2013).

2.3. Soil, litter and straw characterization

Subsamples of each material were air-dried and finely ground (< 100 μm) in a planetary ball mill (Retsch PM100, Retsch GmbH, Haan, Germany, with cups and balls of zirconium oxide). The dry matter content of all samples was assessed by oven-drying sub-samples at 105 °C for 5 h and the water holding capacity (WHC) of fresh soils was determined in a Richards' membrane-plate extractor at a pressure of 10 kPa.

Soil pH was measured on air-dried samples with a pH meter (Metröhm, Switzerland) in KCl employing a 1:2.5 soil/solution ratio. Organic N and C of soils, litter and straw were measured on ground samples with an elemental analyser (Carlo Erba CNS 1508). The method for quantifying soil content of NH_4^+-N and nitrate NO_3^--N is described in the following section. All analyses were carried out in duplicate (if the coefficient of variation was higher than 5% the analyses were repeated) and the mean of both analyses for each replicate was used.

2.4. Soil incubation and gross N transformation rates

To assess the effect of burning and straw addition on gross N transformation rates on a temporal basis, an experiment with three treatments (unburnt soil, US; burnt soil, BS; and burnt soil with straw mulching, BSM) and two preincubation times (3 and 6 months) was set up. These preincubation times were chosen to cover the most critical period after the fire, i.e. the first months, with the soil mostly bare and exposed to N losses due to the high inorganic N levels and very low plant uptake. After treatment application, soils were preincubated in the laboratory instead of in the field because, as usual, fire severity was extremely heterogeneous throughout the burnt site (in the scale of decimeters) and, consequently, it would be impossible to find the areas burnt with high severity 3–6 months after applying the straw mulching without disturbing the whole burnt area. We are aware of the potential limitations of such an experimental design as it precludes some processes which play an important role in N cycling (physical mixing of soil and straw, plant growth, variable weather conditions). Nonetheless, short- or medium-term incubations are still considered an adequate method to get a picture of the potential capability of the different soils to transform N under optimal conditions (see Abadín et al. (2011) and references therein) and to test the effects of straw on soil N cycling. With the wetting system described in Gómez-Rey and González-Prieto (2013), which allows easily wetting highly hydrophobic soils, the soils were humidified to slightly below 70% of their WHC before starting the preincubation, so when soils received the labelled solution for the tracing experiment they were at 70% of their WHC. Approximately 2000 g of wet soil (corresponding to 1600 g of dry soil) were placed in six plastic trays (one per treatment and incubation time) of 20 × 20 × 2 cm. For the US and BSM treatments, a piece of nylon mesh (1 mm^2 mesh size) was placed on top of the soil to facilitate the separation of litter and straw from the soil. We added an amount of litter equivalent to 9.59 kg m^{-2} (as in the field) to the US soils, while the BSM received 250 g m^{-2} of straw, a frequently used dose that ensures a soil cover higher than 60% and, thus, effectively reduces erosion. The