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Short and medium-term effects of a wildfire and two emergency stabilization treatments on the availability of macronutrients and trace elements in topsoil

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HIGHLIGHTS

- Effects on topsoil of fire and BAER treatments (seeding, mulching) were evaluated.
- Topsoil concentrations of NH_4^+–N, NO_3^-–N, P, Ca and Mn increased after the fire.
- One year after the fire, NH_4–N and extractable Mn were still higher in burned soil.
- The emergency stabilization treatments did not affect topsoil nutrient contents.

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ABSTRACT

In NW Spain, a European region with very high fire incidence and erosion risks, the effects on soils of a medium-to-high severity wildfire and two emergency stabilization techniques were studied. In burned plots (control, BS; seeded with cereal, BSS; straw mulched, BSM) and adjacent unburned plots (US), the topsoil (0–2 cm) pH and thirteen NH_4Ac–DTPA extractable elements were evaluated at t = 0, 4, 8 and 12 months after the fire. Compared to US, fire increased by 0.3–0.5 units the soil pH which decrease slowly over time, but remaining significantly higher at t = 12 (BS, BSM, BSS > US). Ammonium nitrogen (N) levels were higher ($p < 0.05$) in burned plots than in US, difference decreasing progressively from 48-fold (t = 0) to 25-fold (t = 12). Although no significant effect of fire was immediately observed, the extractable sodium (Na) and potassium (K) were higher ($p < 0.05$) in burned plots than in US at t = 4 and t = 8, probably due to cation leaching from the overlying ash. Fire did not modify the extractable magnesium (Mg), but at t = 0 the extractable calcium (Ca) and phosphorous (P) were transiently and significantly higher in burned plots than in US. Extractable aluminum (Al), iron (Fe), copper (Cu), cobalt (Co) and zinc (Zn) were lower and manganese (Mn) was higher in burned plots than in US. Neither seeding nor mulching significantly modified the topsoil concentrations of the elements considered. The PCA revealed that BS, BSM and BSS became more similar to US over the study period due to a rapid decrease in extractable Ca and Mg and a slow decrease in extractable Mn and NH_4^+–N. At t = 12, the most notable differences between burned plots and US were in the concentrations of extractable Al and Zn. Data suggest that at least another 4–8 months will be required for full recovery of the burned plots to unburned conditions.

1. Introduction

Although fire is a natural driving force in the evolution of the terrestrial flora and fauna, humans have largely modified the fire regimes (Pausas and Keeley, 2009) and the actual large-scale intense forest fires are considered a relatively recent artifact of human intervention in forest ecology, especially by the reduction of herbivores (Caldararo, 2002). Due to their increasing frequency and extent during the last half a century, anthropogenic wildfires are a global concern as a worldwide factor of forests destruction and soil degradation (Chandler et al., 1983; Certini, 2005). Climate change will very likely increase the length and severity of the fire season, as well as the extension of areas of risk, and recurrent droughts and reduced precipitation are likely to imperil ecosystem regeneration after fire (Birot, 2009). Moreover, the shift in land use as a consequence of rural exodus and socio-economic factors will also contribute to increase the number of wildfires and the burned area (Pereira et al., 2011). Despite its situation in a temperate-humid zone, the region of Galicia (NW Spain; surface 29,574 km^2) is one of the areas of Europe with the highest incidence of fire (Birot, 2009):

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more than 175,000 wildfires burned a total area of 5100 km^2 between 1991 and 2010 (Ministerio de Agricultura y Medio Ambiente, 2012). The cause is a complex mixture of traditional use of fire as an agro–sylvo-pastoral tool, deep economic and demographic changes in rural areas and incendiarism as protest (Gómez-Rey et al., 2013a,b).

The effects of fire on soil organic matter (SOM) and available macronutrients have been widely studied during the last 30 years. Although depending on the fire severity SOM can increase, decrease or remain unchanged, most studies have reported short-term SOM losses (Carballas, 1997; Fisher and Binkley, 2000; Simard et al., 2001; Certini, 2005; Couto-Vázquez and González-Prieto, 2006; Certini et al., 2011), although a meta-analysis showed a significant increase 10 years after the fire (Johnson and Curtis, 2001). Usually, the concentration of available basic cations and inorganic phosphorous (P) increased transiently after the fire (Debano and Conrad, 1978; Trabaud, 1983; Carballas, 1997; Certini, 2005; Couto-Vázquez and González-Prieto, 2006; Gómez-Rey et al., 2013a), due to the accumulation of ashes rich in oxides and carbonates of basic ions (Chandler et al., 1983; Kutiel et al., 1990; Carballas, 1997; Pereira et al., 2011) and the heat-induced mineralization of the extractable organic P (Saá et al., 1993; Serrasolsas and Khanna, 1995). Until recently, the post-fire effects on soil trace elements were not well known; however, in the last decade more research has been devoted to this topic. Most studies indicate a post-fire increase in soil extractable manganese (Mn) and zinc (Zn) (García-Marco and González-Prieto, 2008; Close et al., 2011; Stankov-Jovanovic et al., 2011; Gómez-Rey et al., 2013a), although inconsistent results (Ponder et al., 2009) have also been reported for these nutrients, that can even decrease in the ash layer (Pereira et al., 2011). Conversely, a reduction of available iron (Fe) was usually found (García-Marco and González-Prieto, 2008; Ponder et al., 2009; Pivello et al., 2010; Pereira et al., 2011). Most results pointed to a post-fire increase of extractable copper (Cu) (Close et al., 2011; Stankov-Jovanovic et al., 2011; Gómez-Rey et al., 2013a), but García-Marco and González-Prieto (2008) did not find significant changes and Pivello et al. (2010) reported a diminution, probably due to differences in fire severity, soil type, vegetation cover, climate conditions and sampling strategy. The scarce published information shows an increment of extractable boron (B) (Ponder et al., 2009; Gómez-Rey et al., 2013a) and suggests the lack of a clear tendency for the extractable cobalt (Co) (García-Marco and González-Prieto, 2008; Aref et al., 2011).

Wildfire can lead to an increased runoff and erosion, especially when the soil is bare, intense rainfall events are frequent and topography is dominated by steep slopes (Díaz-Fierros et al., 1987; Robichaud and Brown, 1999; Cerdà and Lasanta, 2005; Vega et al., 2005). In these circumstances, the burned area emergency response (BAER) must assess the need for, and to implement, emergency post-fire stabilization treatments "that provide essential and demonstrated protection at minimum cost while meeting emergency stabilization objectives" (Robichaud et al., 2010), i.e. that reduce the threat to life and property, loss of soil and onsite productivity, loss of control of water, and deterioration of water quality (Robichaud, 2009). Widely used BAER techniques include herbaceous seeding, to accelerate re-vegetation of the soil, and straw mulching, to provide immediate ground cover — as occurs naturally with needles or leaves from unburned canopy (Vega et al., 2005; Groen and Woods, 2008; Robichaud, 2009; Fernández et al., 2011). A literature search has shown that, although the effectiveness of BAER in reducing soil erosion has been evaluated, very few studies have demonstrated the effectiveness of the treatments involved. The highest effectivity have been reported for straw mulching, which can reduce soil erosion by 66–95% (Wagenbrenner et al., 2006; Groen and Woods, 2008; Fernández et al., 2011; Díaz-Raviña et al., 2012), while mean sediment yields in wood-chip mulch and erosion barrier treatments were similar to rates in the untreated plots (Fernández et al., 2011). Although in some cases grass seeding can reduce erosion losses by up to 34–42% (Díaz-Raviña et al., 2012), this treatment is often ineffective because of the limited increment in ground cover that it produces (Wagenbrenner et al., 2006; Groen and Woods, 2008). For the contour felling treatment, Wagenbrenner et al. (2006) found that it can be able to store much of the sediment generated in an average year, but will not reduce sediment yields from larger storms. The available information about the effects of BAERs treatments on the quality and fertility of burned soil is still very scarce. After an experimental fire of low severity, neither straw mulching nor grass seeding had effects on chemical properties of soils and sediments (Gómez-Rey et al., 2013a,b, 2014), and on biomass, activity and diversity of soil microorganisms (Fontúrbel et al., 2012). After a wildfire, Díaz-Raviña et al. (2012) reported no short-term changes in soil physical, chemical and microbiological properties due to the application of mulching and seeding BAER treatments. However, as far as we know, there is no published information about the effects of BAERs treatments on nutrient availability in soils affected by medium or high severity wildfires, i.e., the scenarios in which BAERs treatments are more likely to be applied.

Consequently, the objective of present work is to fill this gap of knowledge by studying, during the first year after a medium-to-high severity wildfire, the effects of two widely used BAERs stabilization techniques (cereal seeding and straw mulching) on the topsoil pH and extractable NH_4^+–N, NO_3^-–N, Na, K, Mg, Ca, P, Al, Fe, Mn, Zn, Cu and Co.

2. Material and methods

1. Site description

The experimental site is located close to the Montes do Invernadeiro Natural Park (UTM 29 T PG34168-71422, 1566 m a.s.l.) in Galicia (NW Spain). The climate of the area is temperate (mean annual temperature: 6–8 °C) and rainy (1600–1800 mm y^{-1}). Due the high altitude of the site, the soil (especially the bare areas) is subjected to freezing and thawing cycles of variable length and intensity during the winter. For example, in the nearest meteorological station (Cabeza de Manzaneda, located 10 km NE at 1758 m a.s.l.; Meteogalicia, 2014) the mean soil temperature at a 10 cm depth during the winter season of the studied period varied as follows: 0.5 ± 0.1 °C (December 16th to 31st, 2010), 1.9 ± 0.6 °C (January 1st to 21st, 2011), −0.1 ± 0.1 °C (January 22nd to February 15th, 2011) and 0.2 ± 0.1 °C (February 16th to March 25th, 2011).

The entire study area was very homogeneous in terms of: a) orientation (245–250° WSW); b) slope (26–30%); c) soil type, a silty loam Entisol (IUSS Working Group, 2006) developed over metamorphic rocks (phyllites); and d) vegetation cover, dominated by a 7-year-old *Pinus sylvestris* L. plantation (1.0–1.6 m height) and by shrubs (0.9–1.3 m height) such as *Erica* spp., *Vaccinium myrtillus* L., *Pterospartum tridentatum* Willk. and *Cistus* spp., with 100% ground cover. Considering the results of Vega et al. (2006) for scrublands from the same region with similar height, cover and species composition, the estimated pre-fire fuel load was 24–45 Mg ha^{-1}.

In the first four days of September 2010, the area was affected by a moderate to highly severe wildfire (1700 ha), as identified by taking the following into account: a) complete consumption of the shrubs' stems and scorching of pine seedlings' trunks; b) almost complete consumption of the continuous litter layer (4–8 cm thick); c) high percentage of bare soil (42%); d) 0–1 cm layer of white and black ash and charred plant debris that covered 58% of soil; and e) 25% reduction in the organic matter content (C and N) in the 0–2 cm soil layer (for further details, see Gómez-Rey and Gonzalez-Prieto, 2013). We selected a hillside site for carrying out the study and took advantage of some unusual characteristics in relation to wildfires, i.e. the availability of a fully comparable unburned control in close proximity to a soil affected by a fire of medium–high severity. In the burned area an experimental zone of 3000 m^2 (100 m along the contour line, 30 m downslope) was delimited and nine experimental plots (three treatments × three replicates distributed alternately) of dimensions 4 × 20 m (each separated by 3 m) were established between planting rows with the longest dimension