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Cation export by overland flow in a recently burnt forest area in north-central Portugal

A.I. Machado [a], D. Serpa [a,*], R.V. Ferreira [a], M.L. Rodríguez-Blanco [b], R. Pinto [a], M.I. Nunes [a], M.A. Cerqueira [a], J.J. Keizer [a]

[a] CESAM & Department of Environment and Planning, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal
[b] Faculty of Sciences, University of A Coruña, A Zapateira, 15071 A Coruña, Spain

HIGHLIGHTS

- Post-fire base cation export was evaluated in a Mediterranean forest.
- Burnt slopes showed an intense cation export in the two months after fire.
- Higher cation exports were found at eucalypt than pine sites.
- The influence of parent material on cation export varied with spatial scale.
- Higher cation exports were found at micro-plot than hill slope scale.

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ABSTRACT

The current fire regime in the Mediterranean Basin constitutes a serious threat to natural ecosystems because it drastically enhances surface runoff and soil erosion in the affected areas. Besides soil particles themselves, soil cations can be lost by fire-enhanced overland flow, increasing the risk of fertility loss of the typically shallow and nutrient poor Mediterranean soils. Although the importance of cations for land-use sustainability is widely recognized, cation losses by post-fire runoff have received little research attention. The present study aimed to address this research gap by assessing total exports of Na^+, K^+, Ca^{2+} and Mg^{2+} in a recently burnt forest area in north-central Portugal. These exports were compared for two types of planted forest (eucalypt vs. maritime pine plantations), two types of parent materials (schist vs. granite) and for two spatial scales (micro-plot vs. hill slope). The study sites were a eucalypt plantation on granite (BEG), a eucalypt plantation on schist (BES) and a maritime pine plantation on schist (BPS). Overland flow samples were collected during the first six months after the wildfire. Cation losses differed strikingly between the two forest types on schist, being higher at the eucalypt than pine site. This difference was evident at both spatial scales, and probably due to the extensive cover of a needle cast from the scorched pine crowns. The role of parent material in cation export was less straightforward as it varied with spatial scale. Cation losses were higher for the eucalypt plantation on schist than for that on granite at the micro-plot scale, whereas the reverse was observed at the hill slope scale. Finally, cation yields were higher at the micro-plot than slope scale, in agreement with the general notion of scaling-effect in runoff generation.

1. Introduction

In Portugal, like in other Mediterranean countries, wildfires are now widely accepted to be a natural phenomenon. However, fire frequency and intensity are considered to have increased dramatically since the 1960s (Pereira et al., 2006; Shakesby, 2011). As principal causes of this intensified fire regime have been appointed a combination of socio-economic factors, in particular the large-scale planting of fire-prone tree species such as eucalypt and pine, and the extensive abandonment of traditional land-use practices (Moreira et al., 2009; Shakesby, 2011).

The increase in fire occurrence is a matter of concern for the (semi-)natural ecosystems in the Mediterranean Basin because it exerts both immediate and lasting environmental and ecological impacts (Certini, 2005; Shakesby, 2011). Most of these impacts are directly or indirectly related to changes in the physical, chemical and biological properties of soils, which affect biogeochemical cycles, and may therefore increase the risk of soil degradation (Certini, 2005; Knoepp et al., 2005; Shakesby, 2011; Soto et al., 1997; Thomas et al., 2000a,b).

* Corresponding author.
E-mail address: dalila.serpa@ua.pt (D. Serpa).

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During fires, macro-nutrients (N and P) and base cations (Na, K, Ca and Mg) contained in plant biomass and in the litter and soil organic layers may be lost through volatilization, convection (of ash and smoke), or particulate transport (Knoepp et al., 2005; Neary et al., 1999; Soto et al., 1997; Wanthongchai et al., 2008). After a fire, the elements deposited as ash or mineralized from burnt organic matter on the soil surface are often leached into the soil or lost by wind and water erosion (Caon et al., 2014; Knoepp et al., 2005; Neary et al., 1999; Soto et al., 1997; Wanthongchai et al., 2008).

Cation losses by hydrological processes are strongly affected by fire-induced changes in soil cover due to the (partial) combustion of vegetation and litter layer (Certini, 2005; Ferreira et al., 2005; Granged et al., 2011; Kutiel and Shaviv, 1992; Shakesby, 2011; Zavala et al., 2010). The increase in bare soil, which is known to enhance the erosive potential of rain drops (Certini, 2005; Fernandez-Raga et al., 2010), and the removal of vegetation and litter, promotes overland flow and the associated sediment losses (Ferreira et al., 2005, 2008; Granged et al., 2011; Prats et al., 2014; Shakesby and Doerr, 2006). Fire-induced changes in topsoil properties such as, infiltration capacity (Badía et al., 2014; Moody et al., 2013; Shakesby, 2011; Shakesby and Doerr, 2006), porosity (Granged et al., 2011), soil water repellency (Doerr et al., 2006; Keizer et al., 2008; Malvar et al., 2011), organic matter (Badía et al., 2014; Knoepp et al., 2005) and aggregate stability (Varela et al., 2010), can further enhance overland flow and losses in soil and soil fertility. The first rainfall events after a wildfire are often of major importance in terms of cation depletion (Badía et al., 2014; Knoepp et al., 2005; Shakesby, 2011).

The magnitude of post-fire cation losses is extremely variable, depending on a complex interplay of factors such as type and growth stage of the vegetation, fire behavior and severity, local fire history, antecedent weather conditions, and site characteristics (Brais et al., 2000; Caon et al., 2014; Certini, 2005; Knoepp et al., 2005; Neary et al., 1999; Shakesby and Doerr, 2006). The temperature reached in soils during burning is particularly important for the direct fire effects on soil fertility (Caon et al., 2014; Certini, 2005). Low-intensity wildfires are usually associated with an increase, albeit ephemeral, in soil cation availability (Brais et al., 2000; Scharenbroch et al., 2012) whereas moderate- and high-intensity fires generally produce base cation losses (Certini, 2005; Shakesby, 2011).

The effects of fire on soil nutrient dynamics in forest areas have been addressed by various studies (Caon et al., 2014; Fernández et al., 2011; Johnson et al., 2007; Kutiel and Shaviv, 1992; Trabaud, 1994; Wanthongchai et al., 2008; Yildiz et al., 2010). However, post-fire export of base cations by overland flow has received little research attention; in spite of the few-existing studies which clearly suggested its relevance for soil productivity (Cancelo-González et al., 2013; Ferreira et al., 2005; Thomas et al., 1999, 2000b). Especially in the fire-prone regions of the Mediterranean Basin with their typically shallow and nutrient poor soils, fire-enhanced cation exports are particularly relevant for land-use sustainability (Ferreira et al., 2005, 2008; Shakesby, 2011).

In Portugal, post-fire cation export by runoff was studied by Thomas et al. (1999, 2000b) and Ferreira et al. (2005). These three studies assessed the losses for the two principal forest types in the study region – plantations of eucalypt (*Eucalyptus globulus* Labill.) and maritime pine (*Pinus pinaster* Ait.) – at different spatial scales ranging from micro-plot to catchment. However, Thomas et al. (1999, 2000b) and Ferreira et al. (2005) measured the losses of dissolved or exchangeable cations rather than the total losses, and, thus, most likely underestimated the full impacts of wildfires on soil fertility.

To address this research gap, the present study aimed at providing further insights into total cation exports by post-fire overland flow in recently burnt Mediterranean forests. To this end, total losses of Na^{+}, K^{+}, Ca^{2+} and Mg^{2+} in post-fire runoff were quantified: i) for two contrasting spatial scales, i.e. micro-plot and hill slope; ii) for two contrasting forest types, i.e. the eucalypt and maritime pine plantations that are now dominating the north-central Portuguese mountains; and iii) for two contrasting bedrock types, i.e. schist and granite that are both widespread in north-central Portugal. These base cation losses by overland flow were furthermore compared with the stocks in the ash and uppermost soil layers, both immediately after the wildfire and at the end of this study as well as with the losses under long-unburnt conditions, albeit only at the slope scale and just for a eucalypt plantation. As post-fire hydrological and geomorphological activity in the study region is particularly intense during the early stages of the so-called "window of disturbance" (Ferreira et al., 2005, 2008; Malvar et al., 2011; Martins et al., 2013; Prats et al., 2014; Shakesby, 2011; Shakesby and Doerr, 2006), base cation losses were monitored during the first six months after a wildfire. Plans to continue the monitoring scheme had to be abandoned as the recently burnt study sites were terraced in preparation for a new eucalypt plantation.

2. Materials and methods

2.1. Study area and study sites

The study area was located within the Vouga River basin, near the Ermida village in the Sever do Vouga municipality, Aveiro District, north-central Portugal (Fig. 1). At the end of July 2010, a wildfire ravaged the area for two days and consumed almost 295 ha of forest lands (DUDF, 2011). The "Ermida" burnt area was predominantly covered by eucalypt plantations but also included a few, small maritime pine stands. The fire severity was, on overall, moderate, since the litter layer and undergrowth vegetation of herbs and shrubs were mostly completely consumed, whereas the tree crowns were typically only partially combusted (Shakesby and Doerr, 2006). Within the burnt area, three hill slopes were selected for this study for their moderate fire severity and, at the same time, contrasting forest types as well as parent materials (Table 1). The BEG study site concerned an eucalypt plantation on granite, the BES site an eucalypt plantation on schist and the BPS site a maritime pine slope on schist (Fig. 1). In addition, a long-unburnt (more than 20 years) eucalypt plantation on schist (UES) was selected just outside the burnt area, while a long-unburnt maritime pine site could not be located within reasonable distance (Fig. 1).

The climate of the study area can be classified as humid meso-thermal, with moderate but prolonged warm dry summers (Köppen: Csb; DRA-Centro, 2002). Mean annual temperature at the nearest climate station (Castelo Burgães: 40°51′10″N, 8°22′44″W at 306 m a.s.l.) was 14.9 °C (SNIRH, 2011: 1991–2011). Annual rainfall at the nearest rainfall station (Ribeiradio: 40°73′65″N, 8°30′08″W at 228 m a.s.l.) was, on average, 1609 mm but varied markedly between 960 and 2530 mm (SNIRH, 2011: 1991–2011). The study area is part of the Hesperic Massif, one of the region's major physiographic units. This unit mainly consists of pre-Ordovician schists and greywackes but includes Hercynian granites at several locations (Ferreira, 1978). According to the existing soil map (1: 1 000 000; Cardoso et al., 1973), the soils in the study area are predominantly Humic Cambisols. However, the soils of the four study sites were also described in the field, and ranged from Humic Leptosols to Humic Cambisols at the BEG and BES sites; Lithic Leptosols to Humic Leptosols at the BPS site; and Umbric Leptosols at the UES site (IUSS, 2006). During the description of soil profiles, topsoil (0–2 cm depth) samples were collected at five equally-spaced points along a transect immediately after the wildfire, and later analyzed in the laboratory to determine bulk density [using the core method as described by Porta et al. (2003)], granulometric composition [following the international method of mechanical analysis as defined by Guítian and Carballas (1976)] and organic matter content [determined by loss on ignition at 550 °C for 4 h as described by Botelho da Costa (2004)]. The uppermost 2 cm of the soils at the study sites were rather coarse, with a loam to sandy-clay loam texture, and very rich in organic matter, ranging from 16 to 29% (Table 1).