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EDITORIAL

ADVANCES TOWARDS AN INTEGRATED ASSESSMENT OF FIRE EFFECTS ON SOILS, VEGETATION AND GEOMORPHOLOGICAL PROCESSES

Q3

PREFACE

Background

It is now generally accepted that fire is a natural disturbance agent (Naveh, 1975; Scott, 2010) and has been an important evolutionary driver of vascular plant species in fire-prone areas as evidenced by, for example, the numerous resprouter and seeder species in the Mediterranean Basin (Pausas *et al*., 2004; Pausas & Verdú, 2005). At the same time, there has been a growing awareness of and an increasing concern about an intensification of fire regimes across the world during the past decades (Adam, 2013; Attiwill & Binkley, 2013; Moritz *et al*., 2014; Pausas *et al*., 2008). In the EU Mediterranean region, the annual number of wildfires have roughly ranged from 20 000 to 70 000 between 1980 and 2010, and the annual burnt area from 0·2 to 1 Mha (San-Miguel-Ayanz *et al*., 2013). Globally, 301 to 377 Mha burned each year between 1997 and 2011, averaging 348 Mha per year (Giglio *et al*., 2013).

Societal and political concerns regarding the present-day fire regime have largely focussed on the efforts and costs of suppressing wildfires as well as on the wildfires' direct impacts in terms of losses of human lives and livestock, losses of and damages to property, and health problems due to air pollution. Recently, a considerable body of scientific evidence has emerged that shows that fire can also have noticeable and, typically, undesirable effects on air, water, soil and other living organisms and their communities. In the case of soils—the focus of this special issue [reflecting its origin at an European Geosciences Union (EGU) session of the Soil System Sciences division]—this body of evidence appears to be growing rapidly, as, for example, suggested by the number of papers reviewing fire effects on soils that have been published in peer-reviewed journals over the past five years (2011–2015) as compared with the preceding five years (2006–2010), that is 12 versus 5 (e.g. Shakesby & Doerr, 2006; Pausas *et al*., 2008; Keeley, 2009; Peppin *et al*., 2010; Shakesby, 2011; Wang *et al*., 2012; Moody *et al*., 2013; Bodí *et al*., 2014; Vieira *et al*., 2015). There is also a growing number of abstract submissions related to the fire issue to the EGU and American Geophysical Union, as well as to other international well-know meetings such as Eurosoil, the International Soil Science Society or the Soil Science Society of America (Figure 1). F1 Q4

Increasing recognition of the diverse-direct and indirect effects of fires on soils and soil processes reinforces the need for furthering the current knowledge. The range of these effects reflects, in part, differences between fires themselves in terms of intensity, timing and spatial extent. In the case of soil water repellency (SWR), a main topic of four of the papers in this special issue (Aznar *et al*., 2016; Jiménez-Morillo *et al*., 2016; Lozano *et al*., 2016; Malvar *et al*., 2016a), it is now clear that fire does not necessarily induce or enhance SWR, as had become widely accepted since the 1960s following the work by DeBano and colleagues (e.g. Debano, 1981). Fire can also reduce or eliminate SWR, or have no noticeable short-term or long-term impacts on it. Likewise and contrary to generally established understandings (Moody & Martin, 2009; Scott *et al*., 2009), fire does not necessarily enhance soil erosion, the main topic of six of the papers in this special issue (Estrany *et al*., 2016; Inbar *et al*., 2016; Malvar *et al*., 2016b; Martínez-Murillo *et al*., 2016; Prats *et al*., 2016a, 2016b). In response to these emerging understandings of these complex responses to fire effects on soils, Shakesby (Shakesby, 2011) and Moody *et al*. (2013) recently argued in favour of a region specific rather than unified perspective towards fire-induced erosion response. A second argument for continued research is that aspects of fire-induced changes to soils and soil processes have been overlooked or otherwise received comparatively little research attention. Examples addressed in this special issue include the role of fire regime and, in particular, fire recurrence (Tessler *et al*., 2016), the long-term effects of fire on soil organic carbon (Mora *et al*., 2016) and the effectiveness of post-fire soil conservation measures (Guénon & Gros, 2016; Inbar *et al*., 2016; Prats *et al*., 2016a, 2016b).

In view of the marked complexity of the environmental and ecological effects of fire and the resulting necessity of studying them in an integrated manner, we convened a session at the 2014 assembly of the EGU to share recent findings and exchange ideas about other approaches and methods and/or working across geographical realms. As an important outcome of this session, this special issue entitled 'Advances towards an integrated assessment of fire effects on soils, vegetation and geomorphological processes' comprises 16 manuscripts based on oral and poster presentations from the EGU session. We believe that the papers in this special issue clearly demonstrate that the need for 'ideal' studies, as outlined by Doerr & Cerdà (2005), has become even more urgent given the likely future increase in climate-driven fire danger due to increasing temperatures and decreasing rainfall (Mitchell *et al*., 2014; Moritz *et al*.,

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Figure 1. High severity fires deeply impact vegetation and soil properties and functions and ecosystem response. Shrub vegetation was almost completely consumed, and topsoil properties visibly affected by a wildfire on La Palma (Spain).

Figure 2. Vegetation recovery and hillslope stabilization treatments are key factors for soil conservation and ecosystem regeneration. Log debris barriers and forest recovery 1 year after a wildfire in Canary Islands (Spain).

2014; San-Miguel-Ayanz *et al*., 2013). In addition, stakeholder involvement is becoming increasingly recognized as a key element in any integrated assessment of the impacts of fire regimes on soil ecosystem services and, ultimately, of the policies affecting fire regimes. This is well illustrated by the paper by Pereira *et al*. (2016b) in this special issue.

ADDITIONAL INSIGHTS

In addition to addressing SWR and soil erosion, papers in this issue provide new insights into vegetation recovery, soil biochemistry and erosion mitigation.

Advances in post-fire vegetation recovery

Tessler *et al*. (2016, this issue) evaluate the impact of fire recurrence on the recovery of Mediterranean vegetation. They study vegetation cover and plant species richness in areas affected by fires of different recurrence and recovery intervals. Results suggest that the impact of fire on vegetation response depends on the time elapsed from the previous fire and that the species composition depends on the number of fire events. According to their results, high-fire frequency may delay or even suppress vegetation recovery, whereas regeneration may accelerate following long-fire intervals (Figure 2).

Pereira *et al*. (2016, this issue) clarify the factors affecting the rapid vegetation recovery after a grassland fire. The authors evaluate the effect of aspect and slope position on fire severity and, therefore, on vegetation recovery by measuring soil cover at different time intervals because of the fire. They suggest that aspect and slope angle influence fire severity and vegetation recovery, increasing the former and reducing the later. The occurrence of ash and soil accumulation and of rainfall events are also factors affecting the fast vegetation recovery of the studied area.

Advances in soils affected by fire

Aznar *et al*. (2016, this issue) evaluate to what soil depth-key physical and chemical soil properties are affected by fire-induced heating. A laboratory approach with undisturbed blocks of soil is used to mimic field and control burning conditions. The authors show the effect of moderate severity fires on topsoil properties and also emphasize its limited impact on deeper horizons. Additionally, the results link soil organic matter (SOM) reduction and chemical alteration to changes in other key soil properties such as SWR.

Long-term effects of fire on soils of two volcanic ecosystems, a fire-adapted pine forest and a laurel forest not prone to fire, are studied by Mora *et al*. (2016, this issue). Topsoil physical–chemical properties are evaluated in a chronosequence in order to determine the persistence of fire impacts on their soil fertility. The authors suggest substantial differences in the nature and persistence of fire-induced impacts on the topsoil of the ecosystems evaluated and therefore in their vulnerability and management.

The assessment of spatial and temporal dynamics of SWR in recently burned eucalypt plantations was the main objective of Malvar *et al*. (2016, this issue). The authors carried out a 1- to 2-year SWR monitoring at different scenarios of fire occurrence and pre-fire management practices. The high spatial and temporal variability found, not totally explained by the occurrence of moderate severity fires, management operations or by the precedent rainfall and soil moisture content, suggest major implications for management of hydrological processes.

The interactions between SOM and SWR were studied in an old-fired affected area by Jiménez-Morillo *et al*. (2016, this issue). The authors analysed SWR under different plant species and for different fractions in order to determine the effect of SOM content and organic molecular assemblage on this property. One important finding is that SOM content explains the response of SWR for finer fractions, whereas the degree of evolution of SOM is the main factor affecting SWR values for coarser fractions.

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Lozano *et al*. (2016, this issue) evaluate glomalin-related soil protein (GRSP) as a proxy for fire severity. They used a laboratory approach to study the response of GRSP to heating and the soil properties affecting this response. The results show that GPSR content is highly susceptible to temperature increases and that its response to heating depends on soil texture, structure and soil organic carbon. The use of GRSP is proposed to evaluate temperature reached during the fire and thereby fire severity when other indicators are not available, or together with them for a more accurate assessment.

The potential use of compost to restore nutrient cycling of fire-affected areas is studied by Guénon & Gros (2016, this issue). Microbial activity involved in the main nutrient cycles was evaluated after the addition of composts of different qualities to a chronosequence of fire-affected Mediterranean areas. The authors highlight the influence of compost quality and time because the fire on the acceleration of nutrient cycling and suggest that the selection of the appropriate compost to restore burned areas should be based on both factors.

Fernández *et al*. (2016, this issue) propose a cartographic technique to map organic carbon and to explore the stability of the organic compounds in fire-affected areas. The authors use hyperspectral images combined with near-infrared spectroscopy to model carbon stocks in the post-fire period. High accuracy is obtained using partial least-square regressions in the upper 5 cm of soils. The authors conclude that this method can be applied to areas where the vegetation cover reduces the ability of the sensors to monitor SOM.

Advances in post-fire water erosion studies and mitigation strategies

After wildfires, soils are partially or totally exposed to erosion by water, depending on the fire severity and the removal of vegetation and ash. The methods to study these processes are mainly based on field techniques. Other studies combine field data with laboratory observations and results from experimental fires. Some research addresses mitigation practices to minimize post-fire erosion and to enhance vegetation recovery. Some new findings from such studies are included in this special issue.

Estrany *et al*. (2016, this issue) study the 137Cs and 210Pbex contents in soils affected by fire concluding that these isotopes help assess the impacts of wildfire on fluvial environments downstream of burned areas. Both tracers are used to quantify the proportional contributions of fine sediment from hillslope surface and channel bank sources to suspended sediment and channel bed deposits following wildfire. Martínez-Murillo *et al*. (2016, this issue) present results from monitoring overland flow and soil loss to assess the short-term response to experimental fires. The most erosive events were delayed by 1·5 years after the protective cover of ash and rock fragments were naturally removed.

Regarding some new advances in the application of mitigation techniques to post-fire environments, Lado *et al*. (2016, this issue) present a laboratory investigation into the effectiveness of granular polyacrylamide (PAM) to reduce erosion in soils exposed to different fire conditions (unburned, low-moderate severity fire and prolonged heating under moderate temperature). Granular PAM effectively reduced post-fire erosion. However, especially in soils with high structural stability, the applied dosage needs to be selected properly in order to find the right balance between its stabilising effect on soil structure, and the effect PAM exerts to increase run-off during the first storm (Figure 3). Q6 F3

Prats *et al*. (2016a, 2016b, this issue) present two investigations about the efficacy of the application of mulch (forest residues: straw, needles and wood-based material) to mitigate post-fire run-off and soil losses on a logged and burnt eucalypt hillslope. Their results indicate forest residue mulching is an effective post-fire treatment for enhancing vegetation regrowth and reducing run-off rates. Authors emphasize the importance of the scaling-up process in this type of studies.

Finally, this special issue also include investigations about the combined effect and pre-existent ploughing operations from the post-fire run-off and erosion point of view (Malvar *et al*., 2016b; this issue) and the application of modelling techniques to simulate rainfall-run-off response, under soil-water-repellent conditions and different stages of vegetation recovery (van Eck *et al*., 2016). The former indicates that using rainfall simulations the sediment losses were significantly higher on the unploughed than on the pre-fire ploughed site during the first year and especially during the second year after the fire. It was remarkable that half of the eroded sediments consisted of organic matter. The latter shows the applied model performed better for individual hydrographs, especially under wet conditions, giving a close to equal model performance with the Leaf Area Index and therefore can be considered a suitable substitute for ground-based measurements in post-fire run-off predictions.

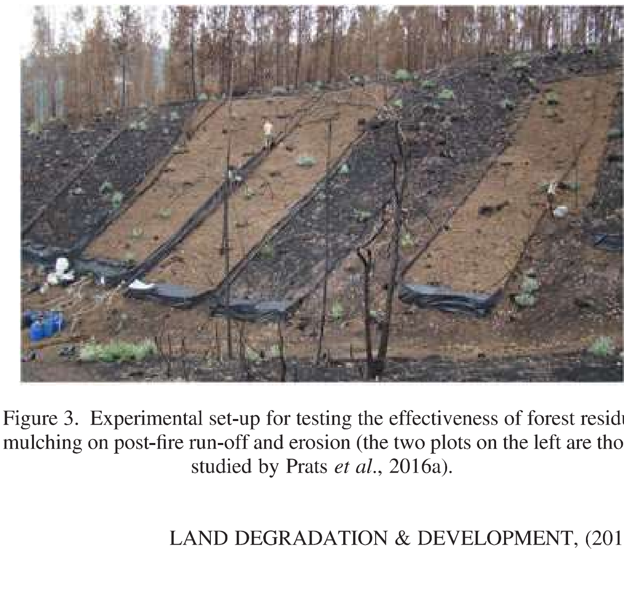

Figure 3. Experimental set-up for testing the effectiveness of forest residue mulching on post-fire run-off and erosion (the two plots on the left are those studied by Prats *et al*., 2016a).

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