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The role of wildfire on soil quality in abandoned terraces of three Mediterranean micro-catchments

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ABSTRACT

Wildfire in abandoned terraces represents a challenge of land management and soil protection in the Mediterranean region due to afforestation of former agricultural land is a major driving force in changing fire regimes and hence land degradation. The effects on physicochemical and biological parameters caused by wildfires on abandoned terraces and non-terraced soils were investigated in three Mediterranean micro-catchments. The study areas were set up as follows: (i) unburned and non-terraced, (ii) unburned and terraced, (iii) once burned and non-terraced, (iv) once burned and terraced, (v) twice burned and non-terraced and (vi) twice burned and terraced. In each of these areas, six composite soil samples 0–15 cm depth were collected from representative plots (25 m^2). The results revealed that the best soil quality related with microbiological activity occurred in the unburned and non-terraced plots. However, burned terraced sites, whether burned once or twice, showed significantly higher values of C/N ratio than unburned and non-terraced plots. The nutrient content (magnesium, sodium and potassium) was not affected by wildfire whereas terracing significantly altered the base cation content. Soil enzyme activity correlated positively with the basal soil respiration (REB) rates and carbon content (correlation coefficients ranged from 0.80 to 0.85), but correlated negatively with the C/N ratio (correlation coefficients ranged from −0.37 to −0.47). Even a long time after abandonment (> 50 years), soils in terraced plots did not reach the soil quality status of non-terraced and unburned plots. These data suggest significant soil degradation generated by wildfires frequency in abandoned terraces.

1. Introduction

Mediterranean soils are very fragile and sensitive to anthropogenic and natural disturbances (Hooke, 2006; Woodward, 2009). Since the mid-twentieth century, major socio-economic changes have led to a gradual abandonment of farmland, starting a process of afforestation in marginal areas. As a result, the fire regime in many Mediterranean landscapes has changed due to increased fuel availability and decreased landscape heterogeneity (MacDonald et al., 2000; Moreira et al., 2009, 2011). Wildfires affecting forest ecosystems are an intrinsic phenomenon in the ecology of Mediterranean climate regions (Cochrane et al., 1999). They are one of the most important agents of soil degradation, mainly because they promote soil erosion, runoff generation and associated transport of soil nutrient (Shakesby, 2011). They also cause other indirect effects such as changes in plant species composition (i.e. promoting those species adapted to wildfire) and vegetation cover (Cerdà and Doerr, 2008; Fernández et al., 2011). Intrinsically, fire severity and recurrence are important factors causing negative effects on soil quality and plant biodiversity (González-De Vega et al., 2016). The more severe a fire, greater is the amount of fuel consumed, ash deposited and nutrients and soil organic matter released, and more susceptible the site is to soil erosion and runoff, which may well affect soil quality (Neary et al., 1999; Hedo et al., 2015a; González-De Vega et al., 2016). As Mayor et al. (2016) reported, recurrent fires might lengthen

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the post-fire window of disturbance (sensu Prosser and Williams, 1998), increasing sensitivity to soil loss and degradation.

The use of land for intensive agriculture is another main cause of soil damage (Trasar-Cepeda et al., 2008). Terracing is one of the most common practices in agricultural landscapes (Tarolli et al., 2014), as it is a very effective measure for soil conservation (Wheaton and Monke, 2001; Arnáez et al., 2015). However, terraces require a significant investment in terms of building and maintenance, whilst terrace abandonment may generate important land degradation processes (Lesschen et al., 2008; Calsamiglia et al., 2017a). Moreover, soil organic matter and microbiological parameters may be lower in terraced areas than in forests caused by the same tillage (Garcia et al., 1997). At the same time, the gradual abandonment of terraced areas may lead to significant increases in microbial biomass and richness and to shifts in the microbial community structure, probably due to cessation of tillage (Zornoza et al., 2009). Thus, soil ecosystems under terracing conditions might become fragile systems after the abandonment of terraces and more research is needed for generating new management strategies (Calsamiglia et al., 2017a).

The soil pH and C/N ratio are predominant factors when determining the composition of the microbial community (Högberg et al., 2007). Microbial communities are essential to crucial processes in soil quality and function, such as organic matter dynamics, decomposition processes and nutrient cycling (García et al., 1994). Higher soil organic matter content or soil enzyme activities and soil respiration rates have usually been related to higher soil quality in Mediterranean ecosystems (Lucas-Borja et al., 2012a; Hedo et al., 2015a). Physicochemical soil properties (i.e. organic matter, pH or C/N ratio), general indicators of microbial activity (i.e. soil respiration or soil microbial biomass) and specific indicators of microbial activity closely related to varied nutrient cycling (i.e. urease, β-glucosidase and phosphatase enzyme activities) have all been used as indicators of soil quality (Aon et al., 2001; Armas et al., 2007).

Considering that wildfire frequency in abandoned terraces represent a challenge in terms of land management and soil protection (Shakesby, 2011), further research is needed because no previous studies investigated how increased soil erosion and wildfire occurrence interferes with soil quality recovery following terrace abandonment to properly understand land degradation processes in Mediterranean landscapes. Land degradation reduces ecosystem's resilience with significant consequences on their biophysical status at the catchment scale; e.g., concentration of chemicals, trophic status, biota status, buffering capacity, salinity, suspended matter and sediment, water level, morphology and pedology (Négrel et al., 2014). The assessment of these global change patterns in Mediterranean regions can assist soil quality preservation through the application of land management strategies. The present study focuses on physicochemical, biochemical and microbiological parameters as indicators for soil quality and subsequent post-fire vegetation recovery. Correlation and multivariate analysis explored the interactions and relationships of these combined factors with soil properties, examining how abandoned terrace soils and non-terraced soils affect soil quality.

2. Material and methods

2.1. Study area

Sa Font de la Vila catchment is located in the south-western part of the Tramuntana Range on the island of Mallorca, Spain (Fig. 1a, b and c). This small catchment (4.8 km^2) is a paradigmatic case of cultural Mediterranean landscape with important interactions between natural dynamics and historical human activities. Over the centuries it has been shaped by intensive agricultural activity, resulting in a massive presence of terraces (37% of the catchment surface area; Calsamiglia et al., 2017a). The catchment's morphology is complex, with height ranging between 63 and 517 m.a.s.l. and a mean gradient slope of 38%. Currently, agricultural activities are restricted to the valley bottoms, where slope is less pronounced (< 10%), and lithology consists mainly of Upper Triassic (Keuper) clays and loams. In the upper parts, where Rhaetian dolomite and Lias limestone predominate, slope gradients are steeper than 30%. Under the Soil Taxonomy System (Soil Survey Staff, 1999, 2006), soils can be classified as Entisols at the catchment headwaters and Alfisols in the lower parts.

The climate is Mediterranean sub-humid and ranges between temperate and warm on the Emberger climate classification (Guijarro, 1986). The mean annual temperature is 16.5 °C and the mean annual precipitation is 532 mm $year^{-1}$ with an inter-annual coefficient of variation of 23% (1970–2010, data provided by the Spanish Meteorological Agency, AEMET). High-intensity rainstorms with a recurrence period of 10 years may reach 85 mm in 24 h.

Since the mid-twentieth century, important socio-economic changes have caused the gradual abandonment of farmland in marginal areas, leading to gradual tree and shrub encroachment as a natural process. In the early 1990s, forest areas had expanded to 77% of the entire catchment and only 15% remained as an agricultural area. The increased availability of biomass, together with the lack of management, favoured the occurrence of two large wildfires in 1994 and 2013. In 1994, the first wildfire affected 25% of the catchment's surface area and reduced the forest cover to 52%. In July 2013, a second large wildfire affected 71%, with 30% of this overlapping with the area burned in 1994.

At the headwaters of the Sa Font de la Vila catchment, three afforested micro-catchments were selected (Fig. 1d and f) under the following criteria: (a) similar area and comparable characteristics in terms of altitude, slope gradient, soil type and lithology (see Table 1), (b) representative presence of abandoned terraces, (c) distinct fire occurrence. Over the past 60 years, microcatchment 1 (MC1) was completely burned at two occasions, in 1994 and 2013, whilst microcatchment 2 (MC2) was completely burned in 2013 and partially (40%) by the 1994 fire. However, this MC2 was classified as once burned because the plots were located in areas not affected by the 1994 fire. Microcatchment 3 (MC3) was selected as the control, since it has not been affected by fire for at least 60 years, based on oral sources and official records (http://xarxaforestal.caib.es).

Information on species composition (tree, shrub and herbaceous species), tree diameter and height and vegetation cover is given in Table 2, emphasizing differences in vegetation patterns between microcatchments. Plant cover and species composition at each plot were obtained from previous studies carried out by the authors (Estrany et al., 2014). In relation to tree species, a mixed forest stand of holm oak (*Quercus ilex* L.) and Aleppo pine (*Pinus halepensis* M.) species was observed in the unburned plots (U and UT), whereas only Aleppo pine (*Pinus halepensis* M.) was present in burned plots (1B, 2B, 1BT, and 2BT). Tree diameter and height were also higher in unburned (U and UT) than in burned (1B, 2B, 1BT, and 2BT) plots. Table 2 also shows how the shrub and herbaceous vegetation cover was higher in unburned plots, with 60% and 70% plant cover in U and UT, respectively; whilst the cover values were 40–50% in the 1BT and 22–44% in the 2BT plots. The shrub and herbaceous composition differed between all plots, as can be seen in Table 2.

2.2. Experimental design and sampling

For each selected microcatchment affected in different ways by wildfires, 12 plots (5 m × 5 m each) were established: six on terraced areas and six on non-terraced areas (Fig. 1e and f). Samples (one per plot) were collected in January 2016 (i.e. 2.5 $year^{-1}$ after the last wildfire in 2013) following the same procedure used in previous studies (Lucas-Borja et al., 2010). After manual exclusion of litter, samples were taken from the top 15 cm of soil at each plot. Differences associated to vegetation cover (through leaf fall) should be stronger in the first top soil cm than in deeper horizons (Garcia et al., 1997; Bastida