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Grassland fire effect on soil organic carbon reservoirs in a semiarid environment

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Abstract. The aim of this work was to investigate the effect of an experimental fire used for grassland management on soil organic carbon (SOC) stocks. The study was carried out on *Hyparrhenia hirta (L.)* Stapf (*Hh*) grassland and *Ampelodesmos mauritanicus* (Desf.) T. Durand & Schinz (*Am*) grasslands located in the north of Sicily. Soil samples were collected at 0–5 cm before and after the experimental fire, and SOC was measured. During the grassland fire, soil surface temperature was monitored. Biomass of both grasses was analysed in order to determine dry weight and its chemical composition. The results showed that SOC varied significantly with vegetation type, while it is not affected in the short term by grassland fire. *Am* grassland stored more SOC compared with *Hh* grassland thanks to lower content in the biomass of the labile carbon pool. No significant difference was observed in SOC before and after fire, which could be caused by several factors: first, in both grassland types the measured soil temperature during fire was low due to thin litter layers; second, in a semiarid environment, a higher mineralization rate results in a lower soil carbon labile pool; and third, the SOC stored in the finest soil fractions, physically protected, is not affected by fire.

1 Introduction

Grasslands play an important role in geomorphological processes (controlling runoff and sediment dynamics) and ecosystem stability (Kocyigita and Demirc, 2012; Mukhopadhyay and Maiti, 2013; Yu et al., 2013; Kukal and Bawa, 2013). Fire is part of the Earth system and has for millennia been a tool for many societies (Pyne, 2001), and this is well-known in grasslands (Dickie and Parson, 2012).

Fire is regarded as an active ecological agent able to mobilize nutrients and restore soil fertility (Snyman, 2003), but also as a primary cause of soil degradation due to nutrient loss for volatilization, leaching and erosion, especially in severe wildfires. It is, in fact, considered a major disturbance in many ecosystems which leads to important shifts in soil properties and vegetation (Certini, 2005; Granged et al., 2011a). One of the most common effects of fire is the alteration in the composition and amount of soil organic matter (Knicker, 2007; Terefe et al., 2008). Several studies recorded a decrease (Fernández et al., 1997; Novara et al., 2011) in soil organic carbon (SOC) after fire, while results of other studies showed no significant change or even an increase in previous SOC content (Kavdir et al., 2005). These discrepancies occur due to the large amount of controlling factors, and therefore the effect of fire is highly variable in space and time. Among these factors, fire intensity, fire severity, fire regimen, type of burned vegetation, connectivity, distribution of fuel on the soil surface, type of ash produced and dispersion, topography, soil properties, aspect, regional climate and meteorological conditions in the immediate period after the fire play a key role in determining SOC alteration and accumulation in soils (Certini, 2005; Pereira et al., 2010, 2013).

In semiarid areas fire is one of the common management tools used by shepherds to enhance pasture regrowth, and this is found in many other grass-covered soils on the Earth, at any latitude (Wang et al., 2005; Li et al., 2012; Busso et al., 2012). In fact, the recovery of vegetation canopy after fire in the Mediterranean area can be quite rapid due to adaptation of plant communities to the disturbances caused by fire, as observed in several studies (Trabaud, 1981; Oba, 1990; Woube, 1998; Barberis et al., 2003; Pausas and Verdú 2005). It is known, moreover, that fire is considered an important factor for arid and semiarid grasslands because it avoids invasion of trees and shrubs, with implications for soil carbon storage (Briggs et al., 2005). Despite the importance of fire for grassland ecosystems (Bond et al., 2005), its impact on SOC is not well understood in the immediate period after the fire in the Mediterranean grasslands (Snyman, 2003). The aim of this work is to quantify SOC stock change as a result of an experimental fire to two of the most widespread types of Mediterranean grassland (Brullo et al., 2010; Díez-Garretas and Asensi, 1999) and, therefore, to establish if this practice could be used as a sustainable management tool for grazing recovery (Álvarez-Martínez et al., 2013).

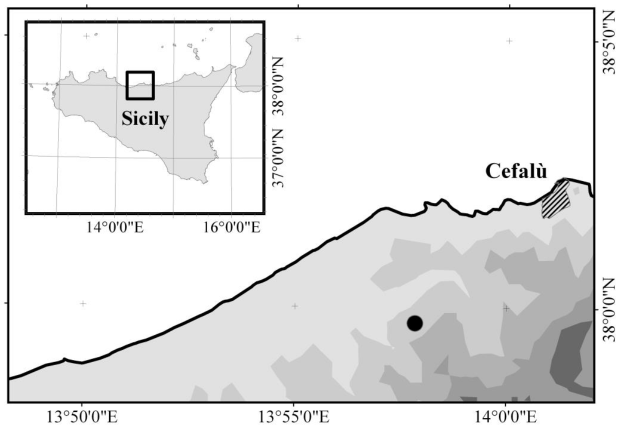

Fig. 1. Localization of the study area (black point) in Sicily (rectangle in inset) and with respect to the next urban settlement Cefalù. Grey scale represents altitudinal gradient (1 shade of grey = 200 m).

2 Materials and methods

The field studies were carried out in the province of Palermo, Sicily (Italy, 350 m a.s.l.; Fig. 1). The local soil type is a *Eutric Cambisol* according to WRB (WRB, 2006), with sand and clay contents of 18 % and 46 %, respectively. The climate is Mediterranean, with mean annual rainfall of 580 mm and yearly average temperature of 16 °C.

An experimental fire was conducted in July and September 2009 on five (replica) delimited square areas (50 × 50 cm) in two different grassland types, dominated by *Hyparrhenia hirta (L.)* Stapf (Hh) and *Ampelodesmos mauritanicus (Desf.)* T. Durand & Schinz (Am). Each sampling square was about 2 m distant from the neighbouring square. In order to simulate a natural wildfire, burning was allowed to take its natural course until it extinguished itself. The fire was generated with a match, starting from leeward in each plot. Soil surface temperature during the burning was measured using a thermocouple system (type K Inconel 600 insulated). In each selected area three soil samples were collected at 0–5 cm depth before and immediately after the fire. On three one-metre squares in both grasslands (dominated by *Hyparrhenia hirta* or *Ampelodesmos mauritanicus*) all plants were cut, oven-dried for 3–4 days at 60–65 °C, and weighted. SOC content was measured using a CHN elemental analyzer. For the δ^{13}C analysis, EA-IRMS (elemental analyzer isotope ratio mass spectrometry) was used. The International Atomic Energy Agency (IAEA), Vienna, distributes IAEA-CH-6 as standard reference material. The results of the isotope analysis are expressed as a δ value (‰) relative to the international Pee Dee Belemnite standard as follows:

$$\delta(‰) = \frac{R_\mathrm{s} - R_\mathrm{st}}{R_\mathrm{st}} \times 1000, \quad (1)$$

where $\delta = \delta^{13}$C, $R = {}^{13}\mathrm{C}/{}^{12}\mathrm{C}$, s = sample and st = standard.

Dry biomass weight and its chemical composition (ADF acid detergent fibre, NDF neutral detergent fibre, cellulose, hemicellulose, lignin, ash) were determined on three 0.5 m^2 square area subsamples for each grassland type.

Data analysis was conducted using the SAS statistical package (SAS Inst., 2002). Normal distribution of data was verified previously to statistical data comparisons, and analysis of variance (ANOVA) was conducted. Significant differences were considered at $p < 0.05$.

3 Results and discussion

SOC ranged from 20.3 to 37.0 g kg^{-1} and from 15.4 to 32.5 g kg^{-1} before and after experimental fire, respectively, in soil covered by *Hh*, and from 32.5 to 38.2 g kg^{-1} and from 38.3 to 49.1 g kg^{-1} before and after experimental fire, respectively, in soil covered by *Am*. The experimental fire did not have significant differences in SOC in both grassland types (Fig. 2). Similar to SOC results, δ^{13}C was not affected significantly by fire. The average by time of δ^{13}C values measured in *Hh* grassland was -25.418 ± 0.25 ‰ and -25.161 ± 0.40 ‰ in soil sampled before and after fire, respectively, while in *Am* grassland it was -26.873 ± 0.16 ‰ and -26.98 ± 0.31 ‰ before and after fire, respectively. Our results are in agreement with similar observations reported by other authors (Granged et al., 2011b) who found no change in SOC content before and after prescribed fire. The experimental fire has a moderate fire severity, similar to prescribed fire described by Granged et al. (2011b). The time of combustion was 12 ± 2 min and 7 ± 1 min for *Hh* and *Am*, respectively (Fig. 3). The maximum temperature measured at soil surface was around 480 °C in both grasslands. Temperatures over 200 °C persisted for 5 and 3 min for *Hh* and *Am*, respectively. The burning time and intensity were low due to low amounts of fuel in both grasslands. Mediterranean environmental conditions involve high organic matter mineralization rates, and thus negligible amounts of litter biomass

Table 1. Biomass composition (% of dry biomass) of *Hyparrhenia hirta* (Hh) and *Ampelodesmos mauritanicus* (Am). Values in parenthesis are standard deviations. Abbreviations: ADF = acid detergent fibre, NDF = neutral detergent fibre.

Grassland	ADF	Cellulose	NDF	Hemicellulose	Ash	Aboveground biomass ($Mg\,ha^{-1}$)	C Biomass ($g\,kg^{-1}$)
Am	6.91 (0.58)	37.72 (1.58)	73.03 (2.65)	23.99 (1.32)	4.02 (1.10)	4.76	43.8
Hh	5.98 (0.68)	34.00 (1.20)	72.01 (1.53)	28.26 (1.76)	4.34 (1.49)	11.60	45.8

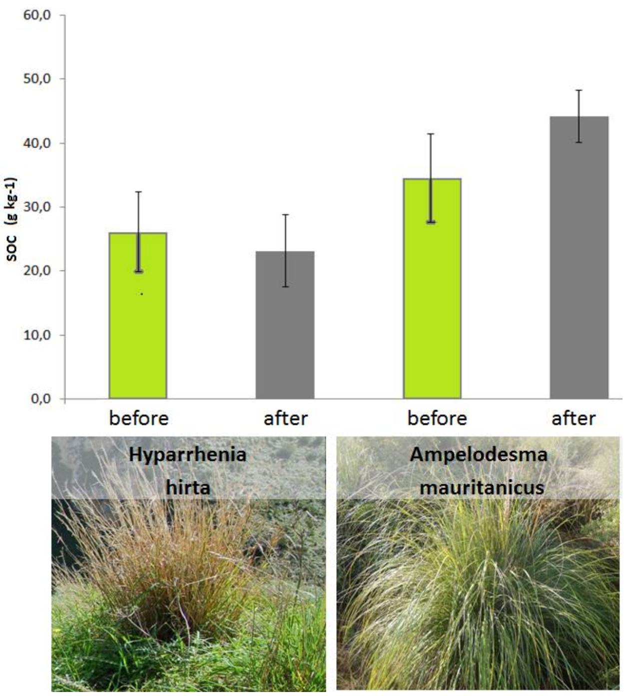

Fig. 2. Soil organic carbon before and after fire in *Hyparrhenia hirta* (Hh) and *Ampelodesmos mauritanicus* (Am) grassland.

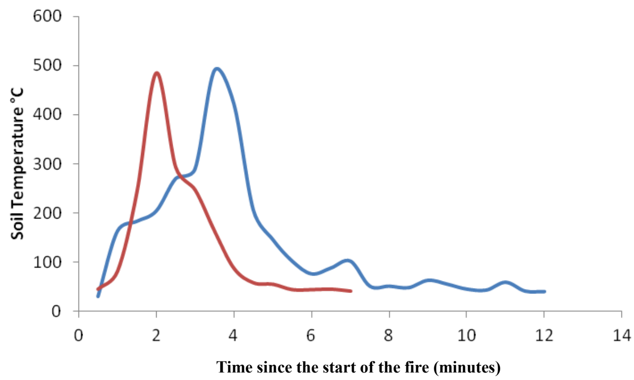

Fig. 3. Soil temperature during fire under *Hyparrhenia hirta* (Hh) (blue line) and *Ampelodesmos mauritanicus* (Am) (red line) grassland.

stock. The low temperatures registered during low severity fires does not have important effects on SOC stock (Úbeda et al., 2005). The loss of organic carbon by burning can occur even at relatively low temperatures such as 200 °C, but total combustion is only observed at high temperatures 450–500 °C (De Bano et al., 1998). When comparing the two grasslands, the SOC amount and the effect of fire on SOC stock was contrasted. The lower SOC content was measured under *Hh* grassland, which also recorded the lower biomass yield. The above-ground biomass estimated is 4.76 $Mg\,ha^{-1}$ and 11.60 $Mg\,ha^{-1}$ of dry matter for *Hh* and *Am* grassland, respectively.

Even if the SOC change before and after fire was not statistically significant, after fire SOC content decreased by 11.5 % in *Hh* and increased by 27.9 % in *Am* grassland. The increase in SOC after fire could occur due to external inputs of charred material and ash, as is commonly observed in low severity fires due to incomplete combustion of fuel and organic matter. In particular, the burned material returns to soil as particles smaller than 2 mm in the form of ash, which are mixed in the top horizon, and which cause a net increase in SOC content (González-Pérez et al., 2004). The reason for the slight SOC increase after fire only in *Am* grassland may depend on different characteristics of the two considered grasses. Firstly, *Am* biomass contains more lignin and cellulose than *Hh* biomass (Table 1), and thus more recalcitrant compounds that under low temperature do not completely volatilize. Secondly, *Am* has a densely caespitose habit: this feature impedes complete burning and favours the retention of incompletely burnt plant residues. The ash of *Hh* is, instead, lighter and quickly eroded by wind (Cerdà and Doerr, 2007). This is clear evidence that *Hh* grassland burned at higher severity, despite the similar temperatures observed. Previous studies observed that fire severity is different according to the burned species (Pereira et al., 2011). Thirdly, biomass of *Am* contains siliceous compounds that obstruct burning.

4 Conclusions

Data reported here confirm that the use of experimental fire to favour plant recovery in *Hh* and *Am* grassland does not affect SOC stock, even if these grasslands have not burned for many years. Therefore it is possible to adopt the system of controlled burning to maintain grassland formations.

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