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Mulch application as post-fire rehabilitation treatment does not affect vegetation recovery in ecosystems dominated by obligate seeders

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ABSTRACT

Mulching treatments have been successfully tested for reducing soil erosion in the first years after fire. However, little is known about their possible negative effect on vegetation regeneration. The aim of this work is to assess the effect of mulch application (woody chips) on the regeneration of Mediterranean Basin ecosystems dominated by obligate seeders. For this purpose, two different mulch ratios (1 and 2 kg m^{-2}) were applied immediately after fire as a post-fire rehabilitation treatment. Soil micro-environmental modifications were tested by monitoring soil temperature and moisture. Vegetation regeneration was assessed by monitoring seedling emergence, seedling establishment, species richness and plant cover during the following three years. Mulch application modified micro-environmental conditions as soil temperature lowered and soil moisture increased. However, no significant effects were found in the final establishment of individuals, plant cover and species richness. In addition, application ratios of 2 kg m^{-2} increased the seedling survival of obligate seeders species. Mulch application reduced only seedling emergence in one species (*Cistus albidus*) in the 2 kg m^{-2} treatment, but did not affect final establishment. The lack of negative effects on vegetation regeneration is of paramount importance in the ecosystems studied as all plant individuals die and the root system protecting the soil must be completely restored by new individuals. Rapid vegetation establishment and growth will help reduce the “window of disturbance” for soil erosion, which occurs until vegetation is recovered. In conclusion, woody chip applications may be a suitable post-fire rehabilitation treatment as they have no negative effects on vegetation regeneration.

1. Introduction

Wild fire is a major agent of land degradation in the Mediterranean Basin (Shakesby, 2011). Apart from destroying vegetation cover and producing heat-induced changes in soil properties (e.g., soil water repellence, aggregate stability, organic matter losses; Certini, 2005), wild fire is characterised by a drastic increase of runoff and soil erosion (Shakesby and Doerr, 2006; Varela et al., 2010). Removal of the protective litter and vegetation layers from the soil surface by fire produces a ‘window of disturbance’, which allows sediment transportations in later rainfall (Prosser and Williams, 1998). This erosion normally peaks during the first rainstorms and declines over time as vegetation regenerates (Mayor et al., 2007). In the last few decades, socio-economical and climatic causes have led to a significant increase in the number of fires and areas burned in the Mediterranean Basin (Pausas and Fernández-Muñoz, 2012). Consequently, there is growing concern about the possible triggering of soil degradation processes after wild fires (Pausas et al., 2008), especially if we consider that wild fires in the Mediterranean Basin occur mainly in summer and that these areas are affected yearly by torrential rainfall in late summer and autumn (de Luís et al., 2005; Peñarrocha et al., 2002).

The application of mulch as a rehabilitation treatment against runoff and soil erosion after fires has been widely tested in Mediterranean areas in recent years (Calvo et al., 2012). This treatment consists in spreading organic material (e.g., wheat straw or wood chips) over soil immediately after a fire and just before the first autumn rainfall. Generally, this application has obtained satisfactory results, including significant reductions in runoff and soil

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erosion (Badia and Marti, 2000; Bautista et al., 1996; Fernández et al., 2011; Groen and Woods, 2008; Wagenbrenner et al., 2006), although highly variable reductions can be obtained depending on the mulch type and the application ratio (Fernández et al., 2011; Prats et al., 2012). Nevertheless, studies about mulching effects on vegetation regeneration are still scarce and remain controversial (Dodson and Peterson, 2010). Mulch application can modify the micro-environmental conditions of treated sites and influence plant regeneration. For example, mulch can benefit plant establishment and growth at water-stressed sites by reducing soil temperatures and retaining soil moisture (Badia and Marti, 2000; Bautista et al., 1996; Robichaud et al., 2000). In contrast, this treatment can act as a physical barrier for plant establishment, especially when accumulated in deep piles (Dodson and Peterson, 2010; Izhaki et al., 2000). Moreover, some studies have found no effects on seedling growth, vegetation cover or species richness (Dodson and Peterson, 2010; Kruse et al., 2004). Hence it is necessary to disentangle the possible effects of mulch application on vegetation regeneration, especially if we consider that this recovery is a key factor for reducing the 'window of disturbance' after fire.

The socio-economic changes and the associated abandonment of agricultural lands that have occurred in the Mediterranean Basin in the last few decades have led to an increasing number of ecosystems in early succession stages (Pausas and Fernández-Muñoz, 2012). These ecosystems are dominated mainly by shrub species that accumulate large amounts of standing dead fine fuels which increase the probability of fire occurrence and land degradation (Baeza et al., 2011; Saura-Mas et al., 2010). These shrubs are mostly obligate seeders with hard coated seeds which base their regeneration on persistent soil seed banks (Verdú, 2000). These obligate seeders are normally characterised by a pulse of germination and establishment in the autumn following the fire (Santana et al., 2012). Initially, it was assumed that this pulse was produced by the breakage of seeds physical dormancy as a result of fire heat. However, it has been recently observed that soil temperature fluctuations occur immediately after fire in summer may also play a determining role in breaking seed dormancy, being more important than fire temperatures in some cases (Baeza and Roy, 2008; Santana et al., 2013). The mulch application effect on micro-environmental conditions can buffer soil temperatures thus diminishing obligate seeders recovery by reducing seed germination. A good understanding of the possibility that vegetation recovery is lacking in this kind of ecosystems is of vital importance to reduce soil degradation processes. It should be taken into account that after a wild fire, all obligate seeder individuals die and the root system protecting the soil must be completely restored by new established individuals. This contrasts, for example, with the communities dominated by resprouter species where root systems are practically unaffected (Pausas et al., 2008).

In this paper, we attempt to address these issues by testing the effect of different mulch ratios (1 and 2 kg m^{-2}) after wild fire on the regenerative capacity of three main obligate seeders species in the Mediterranean Basin ecosystems: *Cistus albidus*, *Ulex parviflorus* and *Rosmarinus officinalis*. These issues may be of vital importance in improving mulching application methods to reduce soil erosion, while favouring species regeneration. The experiment was performed at three different sites burned experimentally in 2006 by measuring the mulch effects on seedling emergence and seedling establishment over a 3-year period. Total vegetation cover and species richness were also assessed. Here we hypothesise that mulch application: (1) will reduce the recovery of obligate seeders by reducing temperature fluctuations on the soil surface, thus limiting obligate seeders emergence; (2) in contrast, mulch application will increase the survival of obligate seeders of emerged seedlings by increasing soil moisture content; and finally (3) mulch application will modify plant cover and species richness by affecting the micro-environmental conditions in the establishment phase.

2. Material and methods

2.1. Study area

The study was carried out inland in the Valencian Community (southeast Spain) at three sites: Onil (38°39′N–0°39′W), Pardines (38°40′N–0°39′W) and Ayora (39°07′N–0°57′W). In all cases, the study sites were old-field terraces that had been abandoned ca. 50–60 years ago and had a well-documented history of exploitation and fire occurrence (Santana et al., 2010). Their altitudes range between 900 and 1050 m.a.s.l., and their climate is typically Mediterranean. Mean annual rainfall ranges between 466 mm (Onil) to 537 mm (Ayora). Summer drought is pronounced from June to August, with no more than 65 mm of rain at any site. The mean annual temperature is approximately 14 °C, and the mean maximum temperature for the hottest month (July) is 30 °C. To minimise environmental variability between sites, all the sites were oriented north, located on marls and their soils were *Calcaric cambisols* (Anon, 1988). At the time of our study, vegetation was a shrub-land dominated by several obligate-seeding species. The woody stratum was composed mainly of the shrubs *C. albidus* (*Cistus* hereafter), *U. parviflorus* (*Ulex* hereafter) and *R. officinalis* (*Rosmarinus* hereafter), whereas the herbaceous stratum consisted of perennial resprouting species, mainly the grass *Brachypodium retusum*. There were a few isolated individuals of woody resprouting species like *Quercus coccifera* and *Juniperus oxycedrus*.

2.2. Experimental fires and mulching treatments

At each site (Onil, Pardines and Ayora), an experimental plot of 30 × 20 m was selected in spring 2006. All three sites were burned by an experimental fire in June 2006, and only a 1-week separation was left between each fire (see Santana et al., 2011 for more details of experimental burnings). In order to test the effect of mulching on vegetation response, a 10 × 10 m square subplot was laid out within each experimental plot at each site, and 15 points within this subplot were chosen randomly from a 1 × 1 m grid (five points for each mulch treatment per site; see below). At each point, we set a permanent 0.5 × 0.5 m quadrat where mulch was manually applied. Mulch treatments were applied as follows: (i) control with no mulch application (Control hereafter), (ii) mulch at the 1 kg m^{-2} rate (1 kg hereafter); (iii) mulch at the 2 kg m^{-2} rate (2 kg hereafter). The mulch applied at each site consisted in woody chip particles produced from the slash of *Pinus halepensis* stems. Mulch particles were no bigger than 2 cm and 0.5 cm thick, and were applied by considering their moisture (Mean: 7.9%, SD: 0.4, n = 8). Treatments were applied approximately 1 week after fire and resulted in soil cover values of ca. 60% (1 kg) and 95% (2 kg). Mulch depths did not exceed 1 cm. Treatments were in accordance with the typical application ratios of woody chips in Mediterranean areas (e.g., 0.4 kg m^{-2} in Fernández et al., 2011; 0.87–1.75 kg m^{-2} in Prats et al., 2012).

2.3. Micro-environment monitoring

After mulch applications, we monitored soil temperature and soil moisture to check the effect of mulching on changing soil micro-environmental conditions. First, the continuous soil temperature in the absence of treatments (Control) was recorded at a 1-cm depth over a 2-month period in summer 2006 (from July 21 to September 21). At each site, temperature was recorded hourly