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Thinning and recovery effects on soil properties in two sites of a Mediterranean forest, in Cuenca Mountain (South-eastern of Spain)

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A B S T R A C T

Thinning effects on soil microbial activity and biomass in two sites of a Mediterranean forest, in Cuenca Mountain (South-eastern of Spain), were compared 2–6 years following treatments. In order to study changes in these properties, five plots were established; three plots in mature natural site dominated by *Pinus pinaster* and *Quercus ilex* and two plots post-wildfire natural regeneration site dominated by *Quercus ilex*. In each site, a silviculture treatment of thinning had been previously carried out, while the other was left as a forest control. Soil samples were taken during the dry season (July 2010) and after the first autumn rains (October 2010). The experiment consisted on a nested factorial design with two factors: the site (two levels: mature natural and regenerated) and thinning treatment nested within site effect (three levels in mature natural site: control, thinned in 2002 and thinned in 2004, and two levels within regenerated site: control and thinned in 2008).Several sensitive variables related to the soil microbial activity such as soil respiration and biomass carbon and some enzyme activities (urease, phosphatase, β-glucosidase and dehydrogenase) were evaluated. Physical and chemical soil variables (organic matter, total nitrogen, phosphorus, pH, conductivity and carbonates) were also measured. These variables of forest soil in autumn were highest that in summer. Also the results showed that thinning have a significant effect on soil microbiological variables and soil enzymatic activities. Thinning operations tended to alter soil variables and highly reduced the organic matter content. A significant correlation was also found between microbiological and biochemical variables and physic chemical variables, organic matter and total nitrogen. Adaptative management forest plans should consider these results in order to achieve sustainable forest management, especially in the context of soil quality and Mediterranean forest subjected to wildfire disturbances.

1. Introduction

Mediterranean forests are usually subjected to shrub-clearing practices (Montoya, 1988). This silvicultural practice consists of the removal by slashing of the woody understory vegetation with two main objectives: to improve productivity by decreasing the competition by shrubs for soil nutrients, and to reduce the risk of summer fires by avoiding the accumulation of fuel biomass. However, these silvicultural practices may have detrimental side-effects on the forest soils. Removal of the above ground vegetation cover biomass may affect the forest soil properties, especially the biological and biochemical ones, since shrub-clearing modifies the microclimatic conditions at ground level, and the amount and quality of the potential organic inputs to soil (Grady and Hart, 2006). The microbiota and soil composition are necessary to determine the optimal management strategies although these factors have received little attention (Mabuhay et al., 2003). The long-term effects of forest management practices and forest fires on soil biological activity are not well understood and it is needed to study, specially the Mediterranean forest management context.

The recovery capacity and speed of community basically depends on the regeneration strategy of the species present. *Q. ilex* is a typical resprouter, regenerating from shoots on the rhizome or the stem of subterranean roots (Pausas and Vallejo, 1999). However, their germination capacity in the field is low. In the other type of community, *P. pinaster* is an obligate seeder (Martínez-Sánchez et al., 1995). The advantage of germination is that it increases

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the genetic variability and stability of the populations (Baskin and Baskin, 1998). However, obligate seeders in general are at a disadvantage in comparison with species that can sprout vegetatively so occupy the area more quickly (Pausas, 2004b). It has also been demonstrated that silvicultural treatments improve nutrient availability in old forest stands and in young stands naturally regenerated after wildfire (López-Serrano et al.,2006).

Soil quality depends on a large number of physical, chemical, biological, microbiological and biochemical properties, the last two being the most sensitive since they respond rapidly to changes (Dick and Tabatabai, 1993; Trasar-Cepeda et al., 1998; Ros et al., 2003; Bastida et al., 2008). Among the variables related to the biochemical and microbiological state of the soil, particularly important are the indicators of the soil microbial activity, principally different enzymatic activities, both specifically related to the cycles of N, P, and C (urease, phosphatase, and β-glucosidase, respectively) and of a more general nature, such as dehydrogenase and respiration. These soil variables are sensitive indicators of soil quality (Bastida et al., 2008) and could have implications for the establishment of native plant communities and cover (Vance and Entry, 2000).

The main objectives in this study were: (1) to measure biochemical, microbiological and physical–chemical soil properties in Mediterranean forests soils, during conditions of two contrasting seasons (summer and autumn); (2) to study the relations between these properties and (3) to evaluate the potential impact of the thinning treatments management practice on biochemical, microbiological and physical–chemical soils properties of two sites. We hypothesized that the effects of thinning in microbiological and biochemical properties of soil; (i) are highest in stands that had intense thinning and disturbance, and (ii) depend on the sites type and the season.

2. Material and methods

2.1. Study area

The study area is located in the Cuenca mountain range (Region of Castilla-La Mancha, central-eastern Spain), in a continuous homogeneous Mediterranean maritime pine forest of about 70 years old, which is called "Dehesa de Abajo" forest (996 m above sea level, 39°40′N, 1°55′W), number 166 in the Public Utility Catalogue of the province of Cuenca. This forest ecosystem is naturally distributed in more than 3000 ha across the study area. It can be considered a mountain plain, where the slopes do not exceed a 3% gradient. The climatic data of this area was obtained with MTCLIM (MounTain microCLIMate simulation model), presented by Running et al. (1987). MTCLIM is a model which generates daily weather data for a target area extrapolating daily data from a reference weather station (Lo et al., 2011). The study area has a Mediterranean climate with an average annual temperature for the simulated period (1992–2010) of 15.5 °C. Mean air temperatures usually reach 8.5 °C in winter, 16.8 °C in spring, 25.7 °C in summer and 12.6 °C in autumn. The average annual rainfall is 510 mm, with 123.3 mm falling in winter, 161.9 mm in spring, 69.7 mm in summer and 157.0 mm in autumn. During the sampling work, in 2010, the average air temperatures in summer and autumn were 23.9 and 12.1 °C, respectively. Also, the summer and autumn rainfall were 67.9 mm and 73.5 mm, respectively. According to the Soil Atlas of Europe (2005), the typical soil of the study area is *Leptosol,* a very shallow soil over calcareous hard rock. Soil texture analysis showed sandy loam texture (60% sand, 16% silt and 24% clay).

The forest is a natural Mediterranean maritime pine forest with two canopy layers comprising different species (*Pinus pinaster* Ait. subsp. *mesogeensis* and *Quercus ilex* L. subsp. *rotundifolia*). Subdominant tree species include *Quercus coccifera* L. and *Quercus faginea* Lam. Shrub species composition include *Rosmarinus officinalis* L., *Thymus vulgaris* L., *Lavandula latifolia* L. and *Genista scorpius* L. In July 2001, nearly 70 ha of this Maritime pine-Holm oak mixed forest were naturally burned. A very high density of Holm oak standards appears one or 2 years after the wildfire. Six years after the wildfire (July 2007), the natural vegetation of the burned area was composed by a very high density of Holm oak standards (11,600 shoots ha^{-1}) and some Maritime pine saplings (350 trees ha^{-1}) (Table 1). In the study area, two different experimental sites were established: (i) a natural mature site and (ii) a natural regenerated site. In the first site, three plots were thinned in different dates: (i) one plot of 5 ha where thinning operations were carried out in winter 2002, (ii) a second plot of 15 ha thinned in winter 2004 and (iii) a third plot of 15 ha without thinning treatments since 30 years ago. Simultaneously, two plots were established in the natural regenerated site: (i) a control plot (unmanaged forest after the wildfire) and (ii) a plot of about 1.25 ha thinned to a final density of 3500 Holm oak shoots ha^{-1} in winter 2008.

2.2. Experimental design and sampling process

The experimental work was based on a nested factorial design with two factors: the site (two levels: mature natural and regenerated) and thinning treatment nested within site effect (three levels in mature natural site: control, thinned in 2002 and thinned in 2004, and two levels within regenerated site: control and thinning in 2008). Plots in mature natural site were denoted as: NC (mature natural control plot, unmanaged), NT04 (thinned in 2004) and NT02 (thinned in 2002). Plots in regenerated site were denoted as: RC (regenerate control plot, unmanaged since forest wildfire in 2001) and RT08 (thinned in 2008). Moreover, the five selected plots were characterised using a systematic sampling design with 8–12 subplots of 70,686 m^2. The forest plots characteristics can be observed in Table 1.

Soil sampling was carried out in two different seasons: during the dry season (end of July 2010), and in autumn, just after the first rains (October 2010). Summer and autumn were two contrasting

Table 1
Tree and standard density (trees ha^{-1}; standards ha^{-1}) (mean ± standard error) of each plot before and after thinning treatments (n = n° sub-plots).

Treatment[a]	Stand Age (years)	n	Maritime pine			Holm oak		
			N_B (trees ha^{-1})	N_R (trees ha^{-1})	N_A (trees ha^{-1})	N_B (standards ha^{-1})	N_R (standards ha^{-1})	N_A (standards ha^{-1})
NC	70	8	440 ± 40	0 ± 0	440 ± 40	440 ± 30	0 ± 0	440 ± 30
NT04	70	12	440 ± 40	51 ± 9	389 ± 40	434 ± 24	84 ± 9	350 ± 22
NT02	70	10	448 ± 22	116 ± 23	332 ± 23	154 ± 9	57 ± 5	97 ± 9
RC	9	10	330 ± 30	0 ± 0	330 ± 30	9100 ± 1700	0 ± 0	9100 ± 1700
RT08	9	9	350 ± 30	0 ± 0	350 ± 30	11600 ± 1800	8100 ± 1000	3500 ± 0

[a] NC: mature natural control plot, unmanaged, NT04: mature natural plot, thinning in 2004, NT02: mature natural plot, thinning in 2002, RC: regenerated control plot, unmanaged, RT08: regenerated plot, thinning in 2008, N_B: number of trees (for pines) or standards (for quercus) before thinning, N_R: number of removed trees or standards by thinning, N_A: Remaining trees or standards after thinning treatments.