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Isolated cork oak trees affect soil properties and biodiversity in a Mediterranean wooded grassland

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A B S T R A C T

Mediterranean wooded grasslands are multipurpose systems that support high plant and animal diversity levels and are habitats of European importance (i.e., 6310 – Dehesas with evergreen *Quercus* spp.). Moreover, these systems offer a number of agro-ecosystem services such as forage production, soil carbon sequestration, nutrient recycling and soil protection. The scattered trees enhance the ecological complexity of grassland influencing the soil properties, the herbaceous layer diversity and composition and the soil communities. Understanding how isolated trees influence the other components of the system is essential to comprehend their role supporting high levels of above and below ground biodiversity and ecosystem services.

In the present study, we present a hypothetical framework of the effects of isolated trees on soil properties, plant and soil fauna assemblages, the latter here represented by the class Collembola. The floor litter and the associated input of organic matter to the soil was a key factor linking the components of the tree-soil-biodiversity system in a Mediterranean cork oak wooded grassland.

Topsoil C increased by +50% under the tree canopy in comparison with the areas beyond the tree canopy. Plant diversity was lower under tree canopy, but contributed to enhance the total species richness of the grassland. Collembolan diversity was higher under the peculiar conditions beneath the tree canopy. Relationships between plant and collembolan species emerged.

The findings of this study suggest that isolated trees have direct and indirect effects on soil properties, plant and collembolan assemblages, hence they can influence the ecological processes of wooded grasslands, with implications for food webs, nutrient cycling and productivity of the agro-ecosystem.

1. Introduction

In Mediterranean countries, agricultural landscapes are often dominated by scattered trees with different tree densities, commonly referred as agro-silvo-pastoral systems (Moreno and Pulido, 2012). These landscapes have evolved through millennia in the Mediterranean Basin as a response to the environmental conditions and are associated with a long history of deforestation, periodical fires and grazing as strategies to maximize production of multiple goods and ecosystem services (Chirino et al., 2006; Pulido et al., 2010; Zapata and Robledano, 2014). Similar complex landscapes can be found also in semi-arid pastoral and savannah-type ecosystems worldwide, e.g., where woody encroachment was and is still occurring (Asner et al., 2004; Tape et al., 2006; Liu et al., 2011).

Among the Mediterranean agro-silvo-pastoral systems, wooded grasslands are the most widespread (Tárrega et al., 2009; Moreno et al., 2007; Eichhorn et al., 2006). In these systems, cereal/fodder crops or semi-natural grass–herbs communities are mixed with a tree layer mostly dominated by oak trees

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(Pinto-Correia, 1993; Joffre et al., 1999; Carreiras et al., 2006; Costa et al., 2008). These landscapes are common in Spain and Portugal, where they are respectively named Dehesa and Montado, but are also spread in other areas such as Sardinia in Italy, where they cover about 113.000 ha (4.7% of the regional surface and 9.8% of the total agricultural land) (RAS, 2013; ISPRA, 2014) (Fig. 2a). Sardinian wooded grasslands, often tilled and sown every two to eight years to grow annual mixtures for grazing and/or hay production, are mainly dominated by cork oak, with tree densities ranging from 7 to 250 ha^{-1} and are generally concentrated in the hilly areas of the North and the center. Grazing animals are principally sheep and cattle (Eichhorn et al., 2006; Caballero et al., 2009; Rossetti and Bagella, 2014).

Mediterranean wooded grasslands are primarily productive systems, however their relevance is not only associated to their economic importance: those with evergreen oaks are also habitats of European importance (i.e., 6310 – Dehesas with evergreen *Quercus* spp.) supporting high plant and animal diversity levels and serving as habitat for a number of threatened species of the European fauna (Biondi et al., 2013). These multipurpose systems offer a number of agro-ecosystem services such as forage production, soil carbon sequestration, nutrient recycling and soil protection, and contribute to the esthetical value of landscapes (Palma et al., 2007).

A key component of the most prominent features of wooded grasslands is represented by the scattered trees. The presence of trees in a farming system enhances its ecological complexity.

The relationships between trees and understorey vegetation and soil properties have been widely investigated in temperate and Mediterranean wooded pastures, forests and savannas (Maltez-Mouro et al., 2005; Treydte et al., 2007; Perez-Ramos et al., 2008; Abdallah and Chaieb, 2010; Canteiro et al., 2011; Abdallah et al., 2012; Xu et al., 2012). Interception of solar radiation, root competition, litter humification and mineralization, cations and water retrieval from deep soil layers may positively or negatively influence the herbaceous communities under the tree canopy (Marañón et al., 2009). An increasing body of knowledge is recently emerging on the role of trees in agroforestry systems on C sequestration and on processes controlling C cycling in soils (e.g., Haile et al., 2008; Takimoto et al., 2009; Nair et al., 2010; Pérez-Cruzado et al., 2012; Lai et al., 2014). However, very few studies explored at small scale the effect of trees on the surrounding biotic and abiotic environment (e.g., Fernández-Moya et al., 2010; Howlett et al., 2011), and a small number are focused on the effects on soil fauna. For instance some groups of pedofauna, like Collembola, are known as excellent bio-indicators of soil ecological conditions. Not only they are an important element of the biodiversity in the soil system, but they also respond to a variety of environmental and ecological factors, like changes in soil chemistry, microhabitat configuration, and forestry and agricultural practices (Hopkin, 1997; Sousa et al., 2006). Sousa et al. (2004) found changes in species composition of collembolan communities along a gradient of soil-use intensification in a Mediterranean landscape dominated by cork oak. Nevertheless, to our knowledge, there is a lack of studies on the impact of isolated oak trees on these bio-indicators for Mediterranean semi-arid wooded grasslands.

In this study we examined the effect of isolated trees on soil properties, plant assemblages and biotic soil components, the latter represented here by the Class Collembola.

We hypothesized that the effects of an isolated tree on soil properties, plant and collembolan assemblages can be direct and indirect (see Fig. 1). We considered as direct effects those derived from floor litter accumulation, interception of solar radiation, soil moisture and temperature, root competition, root exudation and the animal gathering (Haile et al., 2008; Marañón et al., 2009; Takimoto et al., 2009; Nair et al., 2010; Pérez-Cruzado et al., 2012).

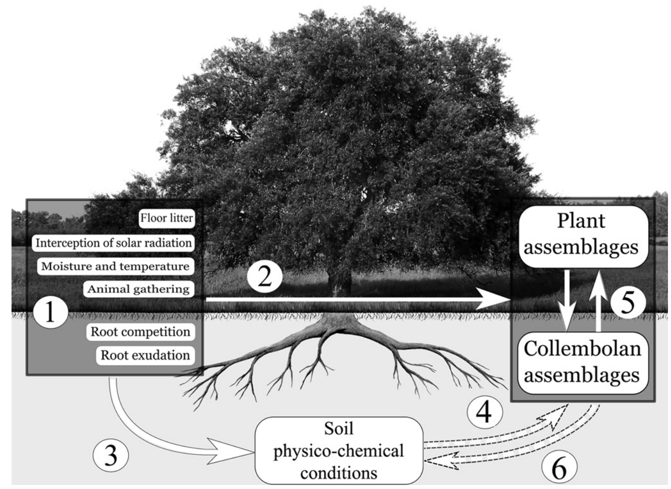

Fig. 1. Scheme of the hypothesized direct and indirect effects of the tree on soil properties, plant and collembolan assemblages. Solid and dashed arrows represent, respectively, direct and indirect effects of the tree on soil properties, plant and collembolan communities. (1) Factors that exert a direct effect on soil properties, plant and collembolan assemblages; (2) direct effects on plant and collembolan assemblages; (3) direct effects on soil properties; (4) indirect effects of soil properties on plant and collembolan assemblages; (5) reciprocal influence between plant and collembolan assemblages; (6) influence of plant and collembolan assemblages on soil properties.

We considered as indirect effects of trees on plant and collembolan assemblages the soil properties that are directly influenced by the trees via litter humification and mineralization. In turn, plant and collembolan assemblages influence soil properties via organic matter accumulation/decomposition, root exudation, nitrification and other complex mechanisms involving soil food webs (De Deyn et al., 2003; Van der Heijden et al., 2008; Sabais et al., 2012; Krab et al., 2013a; Hodson et al., 2014).

Because the role of interception of solar radiation, soil moisture and temperature on above and below ground communities is well known (Moreno, 2008; Marañón et al., 2009; Fernández-Moya et al., 2010), we focused our attention on floor litter as one of the most prominent factors by which the tree exerts its direct and indirect effects on soil properties and plant/collembolan assemblages. In our hypothesis we considered the floor litter and the derived input of organic matter as the key factor linking the components of the tree-soil-biodiversity system in Mediterranean wooded grasslands. The floor litter has direct consequences on the input of organic matter on the soil and on the plant and collembolan assemblages. In a medium and long term, the floor litter, affecting soil properties, indirectly influences plant and collembolan assemblages through complex interactions and feedback processes (Six et al., 2004; Krab et al., 2013a). Moreover, the plant composition, by influencing litter quality, can have an impact on abundance, diversity and diet choices of Collembola (Krab et al., 2013a). On the other hand, Collembola can alter the soil organic matter decomposition patterns and, thus, plant nutrient acquisition and performances that may modify plant competition and shape plant assemblages (De Deyn et al., 2003; Sabais et al., 2012).

The objectives of this study were to assess in a Mediterranean wooded grassland (i) the influence of isolated trees on soil properties, plant and collembolan assemblage diversity and composition; (ii) the indirect effect of trees on plant and collembolan assemblage composition via soil properties and (iii) the relationships between plant and collembolan assemblage patterns.