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Effects of secondary succession and afforestation practices on soil properties after cropland abandonment in humid Mediterranean mountain areas

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ABSTRACT

Cropland abandonment and subsequent revegetation processes (due to secondary succession and afforestation practices) are global issues with important implications in Mediterranean mountain areas. Several publications have reviewed the impact of cropland abandonment and revegetation on the soil properties dynamics but, so far, limited attention has been paid to Mediterranean humid mountain areas. This paper examines six neighbouring land covers, in the Central Spanish Pyrenees to determine the effects of land covers, cropland abandonment and consequently secondary succession and afforestation practices on soil properties. For this purpose, a total of 85 samples from 6 land covers and from two soil depths were analysed. We observed that changes in soil properties after cropland abandonment were limited, even if afforestation practices were carried out, and no differences were observed between natural succession and afforestation. Land cover and depth had a significant effect on the physical and chemical variables, being larger in the uppermost 0–10 cm depth. The organic and inorganic carbon and N concentration, SOC and TN stocks, CN ratio, organic matter, and bulk density showed significant differences. Afforestation improved soil properties, aggregate stability and carbon concentration and stocks when compared to neighbouring bare soils. A soil quality index –based on statistical analysis- suggested that natural forests and *Pinus nigra* areas developed a higher soil quality rating. Our general results also demonstrated that the impact of disturbance by afforestation techniques (microsites) is difficult to discern. The differences found with respect to the native forest appear to indicate that the afforested soils have not yet reached their maximum soil quality and maximum potential as soil organic carbon sink. As there was no difference found between the soil improvement by natural succession in comparison to afforestation, these results put the question forward which type of forest and landscape management is most appropriate to decide for the best practices after cropland abandonment for soil recovery and erosion control.

1. Introduction

Most Mediterranean mountain areas have been subjected to significant human pressure through deforestation, cultivation of steep slopes, fires and overgrazing (Roberts, 2014). During the 20th century the mountainous areas of the northern rim of the Mediterranean region were affected by rapid population migration and abandonment of cultivated fields (MacDonald et al., 2000; Keenleyside and Tucker, 2010). Cropland abandonment is one of the main changes in land cover in Mediterranean countries leading to the expansion of forest and scrublands (Tasser et al., 2007; Sluis et al., 2014). These abandoned areas can be left to undergo secondary succession (passive restoration) or be subjected to active restoration that mostly consists of tree (i.e. conifers) and shrub planting (i.e. *Quercus coccifera*, *Atriplex halimus*) (afforestation), resulting in a mosaic of regenerated vegetation and afforestations.

Abandoned Mediterranean cropland under secondary succession is initially colonized by herbaceous vegetation which persist for a long time before woody vegetation establishes (Bonet and Pausas, 2004). Molinillo et al. (1997); Nadal-Romero et al. (2013)

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identified different succession stages: (i) during the first years an invasion by herbaceous plants occurs; (ii) between 10 and 60 years of abandonment generalized cover by woody shrubs is observed; (iii) around 60 years of abandonment the entry of young trees in field is common; and (iv) more than 100 years are necessary to observe a forest stage (Lasanta et al., 2005). In that sense, Errea et al. (2015) corroborated that only 10.6% of abandoned lands in the Aísa Valley (Central Pyrenees) had already reached a forest stage after more than 50 years of abandonment.

Due to the slow process of secondary succession, and with productive (to achieve self-sufficiency in the supply of pulp and paper) and environmental objectives (to control hydrological and geomorphic processes in order to reduce flood frequency and magnitude and soil erosion), extensive afforestation programs were conducted by national forest services all over the Mediterranean region (Ortigosa et al., 1990; Yaşar Korkanç, 2014). Afforestation is defined as establishment of forests on lands which historically have not contained forests (Houghton et al., 1996) or alternatively as lands which have been without forest for a period of several decades and have previously been under a different land use (Watson et al., 2000). The case of Spain is a good example: modern afforestation policies were introduced in 1940 by the Forest Administration in the Pyrenees, Galicia, the Alicante Region, Iberian Range, Baetics Range and the northwest of the Murcia Region (Calvo-Iglesias et al., 2009; Symeonakis et al., 2007). Afforestation has been based mainly on conifers because they are fast-growing species, and also because it was believed that this would lead to rapid restoration of soil hydrological processes, to control soil erosion, to regenerate forest ecosystem services and the formation of protective vegetation cover (Ortigosa et al., 1990). In the case of the Pyrenees, large areas were afforested with *Pinus nigra* and *Pinus sylvestris* (Ortigosa et al., 1990). Both processes, secondary succession and afforestation, resulted in the expansion of shrublands and forests, and as a result of both processes, the fraction of forest cover in the EU-Mediterranean countries is increasing.

Cropland abandonment and the revegetation process have been extensively examined from a hydro-geomorphological (García-Ruiz and Lana-Renault, 2011), landscape and management point of view (Lasanta et al., 2015). However, despite the extensive cropland abandonment and the consequent revegetation process, and the time occurred after the first afforestation plans, few investigations have studied the consequences of secondary succession and afforestation in Mediterranean humid mountain environments related to soil properties. In recent years, some work has been published, analyzing the effects of land cover change, land abandonment and afforestation on soil properties (Pardini and Gispert, 2012; de Baets et al., 2013) on other Mediterranean subclimate types. In particular, there is evidence that secondary succession and afforestation leads to a significant change in the physical and chemical properties and biochemical soil cycles, but, there is no clear common pattern in the change observed. An overview of the main experimental studies investigating the effects of afforestations in soil properties in Mediterranean areas indicates that most of them were carried out in degraded/disturbed semi-arid areas (Cuesta et al., 2012; Laudicina et al., 2012) (the full dataset is included as online supplementary material). These studies had diverse objectives, mainly focused on the impact on physical and chemical soil properties after afforestation, and a few were also addressing C and N cycles.

A high variety of species were used, in the studies included in the dataset. It is important to note that conifers were the most common species. *Pinus halepensis* was often used, and it was one of the most important forest species in the Mediterranean basin (covering more than 25,000 km^2) applied for afforestation (Maestre and Cortina, 2004). This species was selected due to

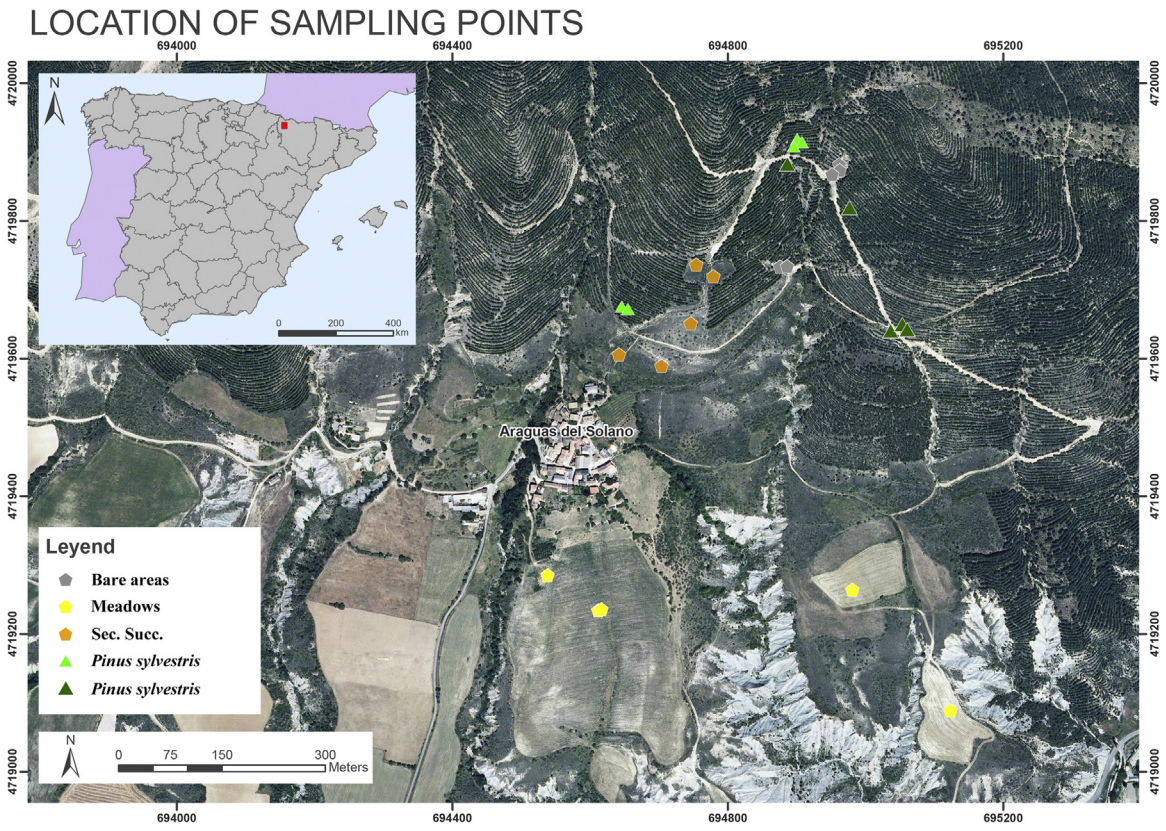

Fig. 1. Location of sampling points in the Araguás catchment. Location of the native natural forest is not shown in the Figure.