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Soil dynamics in *Pinus halepensis* reforestation: Effect of microenvironments and previous land use

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ABSTRACT

Reforestation with *Pinus halepensis* has been the most frequently used method for restoring supposedly degraded lands in Mediterranean semiarid areas, a key objective of which is to improve soil conditions to trigger succession. In this paper we study the effect of a 30 year-old reforestation on lands formerly dedicated to two different uses: shrubland and barley fields. The study area is located in SE Spain in a semiarid area with an annual rainfall of 298 mm. We hypothesize that the previous land use will influence present day soil characteristics. In addition, reforestations have led to the formation of microenvironments associated to: (i) tree development, which generates a radial gradient of influence; (ii) disturbance by mechanical works with resulting microenvironments such as escarpments, showing a worse initial state and, therefore, slower dynamics. Ten plots were set up on former shrubland and ten on a former barley field. Each plot represented a set of related microenvironments that followed a gradient of tree influence/mechanical disturbance. The microenvironments on former shrubland were: under escarpment (ES), plantation line adjacent to *P. halepensis* stem (PL), beneath *P. halepensis* crown (BC), the upper bank where part of the material of the terrace was dumped (UB) and original unaltered hillslope taken as pseudocontrol of the original soil (PC). In the former barley field, only PL, BC and PC microenvironments were present as no terracing was carried out. Pine growth created a strong gradient of litter input in the sequence PL > BC > PC which, however, had no significant effect on soil organic carbon (SOC) or other soil variables (except light changes in extractable K and pH). The incorporation of organic matter into the soil was probably delayed by the quality of recalcitrant pine litter and the unfavorable semiarid climate. In addition, disturbance created by reforestation works seems to have been buffered by redistribution of fine particles through short-range erosion and sedimentation. In the external part of the terrace, the values of SOC and extractable Na were higher, accompanied by increased electrical conductivity and decreased pH. The most striking differences found were related to former land use. SOC was three times higher in former shrubland than in former barley field. Likewise, available P was higher in the former barley field and extractable Na was higher in the former shrubland, both apparently related to the pre-reforestation state. The results indicate that soil dynamics thirty years after the reforestation has hardly erased the differences attributable to former land use. Soil dynamics induced by the input of organic matter from trees is slower that expected when the reforestation was planned. We conclude that any future application of reforestation should take into account the slow soil dynamics observed in this study in order to be more effective.

1. Introduction

Reforestation has been the main method used to restore degraded lands and abandoned fields in the Mediterranean basin. In semiarid areas, *Pinus halepensis* Mill., was the most used species during the XXth century. It is supposed to reduce erosion, control runoff, improve soil conditions and trigger succession. However, the role of *P. halepensis* plantations in the restoration of degraded semiarid lands has been questioned (Maestre and Cortina, 2004) and it has not been proved that it is better at controlling runoff and soil erosion that the shrubland and grassland communities perceived as degraded where the trees are planted (e.g. Chirino et al., 2006).

Underlying reforestation there is a paradigm: the establishment of vegetation improves the physical and chemical properties of soil, which in turn, has a positive feedback effect on vegetation. However, there are few studies testing this paradigm in the medium and long term in semiarid ecosystems. Chaparro et al. (1994) found less organic matter and total nitrogen in terraced plantations than in the original shrubland. Goberna et al. (2007) found that the organic carbon

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content and microbiological activity is far lower on *P. halepensis* plantations than in natural maquis (shrubland) in semiarid ecosystems. Moreover, when a natural pine forest with maquis is compared with a pine plantation set in formerly cultivated land, the microbiological activity of the soil profile is markedly different (Goberna et al., 2006), indicating that the restoration goal is far from being achieved.

In order to study soil dynamics, we have to consider the original soil conditions and the inherent alteration produced by reforestation works and the subsequent growth of planted vegetation. The original soil conditions are the result of soil forming factors (lithology, climate, vegetation, etc.) and anthropic disturbance (ploughing, overgrazing, etc.). Therefore, the soil status prior to reforestation is well related to land use. The soil conditions under these uses may differ substantially when reforestation is undertaken and it could influence later soil evolution (Paul et al., 2002). In the Mediterranean, abandoned agricultural fields and grasslands and shrublands are the lands most likely to be reforested.

In the 1950s and 1960s the reforestation techniques in the Mediterranean changed from being manual to mechanical. However, mechanical terracing has been a very controversial issue because of its ecological, aesthetic and social effects (García Pérez, 1999). Detrimental effects of terracing on the physicochemical properties of soils have been found (Ortigosa, 1991; Chaparro et al., 1994). Mechanical disruption mobilizes considerable volumes of soil, which especially affects top horizons (Williams et al., 1995), triggering surface runoff (De Witt and Brouwer, 1998) and erosive processes (Chaparro and Esteve-Selma, 1995; Ternan et al., 1996). Managers assumed that such detrimental effects would be transitory, but there is evidence that they last a long time (e.g. Chaparro and Esteve-Selma, 1995). In other words, alteration of the soil by mechanical means may hamper the achievement of soil improvement, which was the goal of the reforestation.

Mechanical works create a set of different microenvironments (bank, terrace, etc.). The growth of trees planted in regular arrangements also produces a radial differentiation of the soil depending on the distance from the trunk (Zinke, 1962; Amiotti et al., 2000). Both factors, may influence soil dynamics.

The aim of this paper was to study the changes induced in the soil 30 years after typical reforestation using *P. halepensis* in a semiarid ecosystem of SE Spain. We tested two hypotheses:

1. Soil dynamics is affected by microenvironment differentiation induced by (i) mechanical works, being delayed on more disturbed microenvironments and (ii) the development of pines, which accelerates soil dynamics near the trunk.
2. Current soil characteristics depend on the former land use.

A succinct summary of the effects of microenvironments on soil differentiation in only one land use is contained in Navarro-Cano et al. (2009) within the framework of seedling emergence experiments.

2. Area description and methods

2.1. Study site

Field work was carried out in the catchment of the Rambla de Cárcavo (Murcia) in the semiarid SE of the Iberian Peninsula (38°12′ N, 1° 31′ W). The catchment covers 2713 ha and it is a depression filled by Miocene marls surrounded by ranges of Jurassic dolomites and limestones to the north, east and west and Keuper marls to south. The altitudinal range is 250–950 m. The dominant soils are Margalic Regosols in the central depression and Lithosols and Calcic Xerosols in the surrounding ranges (Alías Pérez, 1986a,b).

The climate is semiarid Mediterranean, with average rainfall of 298 mm and an average temperature of 16.5 °C (Observatory of Almadenes, State Agency of Meteorology of Spain). Potential evapotranspiration calculated by Thornthwaite's method is 876 mm. Potential vegetation is a maquis of *Quercus coccifera* L., *Rhamnus lycioides* L., *Juniperus oxycedrus* L., *Pistacia lentiscus* L. and *Daphne gnidium* L. Flat areas in the marl depression are cultivated (olive, almond, vineyards, peach) or has been reforested with *P. halepensis*. *Stipa tenacissima* L. perennial grassland is dominant on the colluvia of the footslope. Most of these colluvia are also reforested.

2.2. Experimental setting and field sampling

The experimental area was set up in the Miocene marls in the center of the basin. A hill with 20% slope with NNE aspect, and its corresponding footslope (5% slope) were chosen. On the hillslope the former land use was shrubland/grassland dominated by the legume *Anthyllis cytisoides* L., *Rosmarinus officinalis* L. and *S. tenacissima*, while the flat footslope was formerly cultivated with barley. Reforestation was carried out in 1975 by mechanical terracing using a bulldozer on the hillslope, while on the footslope subsoiling was applied. The original stocking rate was >1000 trees ha^{-1}. The median height of trees at the sampling time was 3.5 m on the footslope and <2.5 m on the hillslope.

Mechanical works produce microenvironments that represent different intensities of alteration. On the other hand, as the trees develop, gradients of soil alteration will result, input of organic matter decreases from the stem to the inter-crown areas. The areas not mechanically altered and located in inter-crown areas could be considered pseudocontrols, since they represent the most similar conditions to the state prior to reforestation. Because of the high degree of environmental variation within the basin (especially in marl areas with very variable sedimentation facies) the choice of an unaltered area far from the reforested plot to act as a control may be misleading.

In each former land use ten plots of 2×5 m were set up. In the hillslope (formerly shrubland) five microenvironments per plot were identified (Fig. 1a): the terrace sector under the escarpment of the bank/upper terrace system (ES); the central terrace within a 50-cm radius around the *P. halepensis* stem in the plantation line (PL); the terrace sector below the crown cover, approximately midway between stem and border of crown (BC); the outer part of the terrace and the upper part of the bank where the terrace materials were dumped (UB); the lower part of the bank where the original slope and soil was not altered by reforestation works and was not influenced by planted trees was

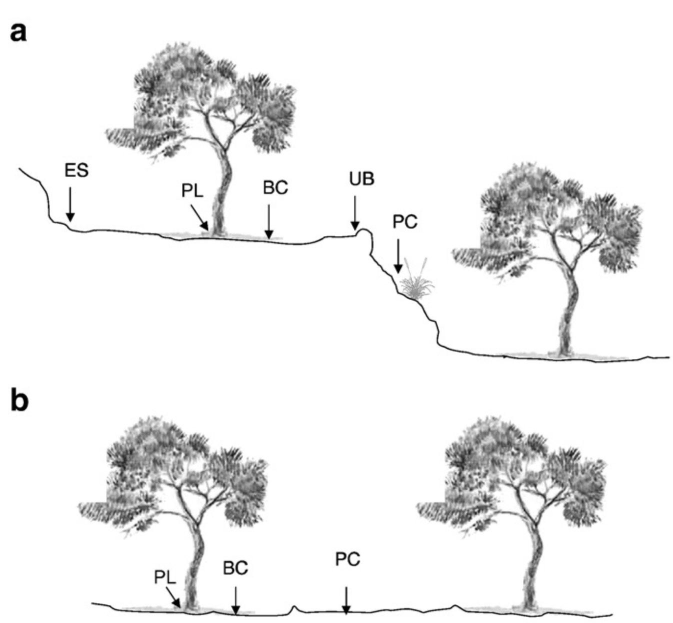

Fig. 1. Sampling scheme on terraced former shrubland (a) and subsoiled former barley field (b). a. ES, under the escarpment in the transition bank/terrace; PL, adjacent to stem of pines planted on the terrace; BC, beneath crown cover; UB, external border of the terrace and upper rim of bank; PC, pseudocontrol, remaining hillslope and vegetation unaltered by mechanical works. b. PL, BC and PC as in a.