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ORIGINAL PAPER

Tree effects on the chemical topsoil features of oak, beech and pine forests

Elena Marcos · Leonor Calvo · José Antonio Marcos · Ángela Taboada · Reyes Tárrega

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Abstract We aimed to study tree effects on the chemical properties of forest soils. We compared soil features of three types of forest ecosystems, each with four stands (replicates): beech forests (*Fagus sylvatica*), oak forests (dominated by *Quercus pyrenaica*) and pine plantations (*Pinus sylvestris*). Five samples from the top 10 cm of soil were taken per stand, from which pH, organic matter content (O.M.), total nitrogen (N) and available calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}) were determined. Litter layer depth was measured at each soil sampling point. We also measured tree density and crown diameters at each stand. Our results indicated that soil samples from the four pine plantation stands were more similar while oak and beech stands were characterised by great variability in terms of soil properties and leaf litter depth. Although the identity of the dominant tree species significantly influenced several topsoil chemical properties (increase in pH and available cations in oak forests and higher organic matter and total nitrogen in beech and pine ecosystems), there were other important factors affecting soil features that may be taken under consideration. Differences between soil properties of the three types of forest ecosystems were mainly related to the characteristics of the litter layer and less related to the tree layer structure. Finally, the establishment of pine plantations in naturally deciduous tree areas made the topsoil features more homogeneous.

Keywords Forest soils · Litter · pH · Tree density · *Fagus sylvatica* · *Quercus pyrenaica* · *Pinus sylvestris*

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E. Marcos (✉) · L. Calvo · J. A. Marcos · R. Tárrega
Área de Ecología,
Departamento de Biodiversidad y Gestión Ambiental,
Facultad de Ciencias Biológicas y Ambientales,
Universidad de León, 24071 León, Spain
e-mail: elena.marcos@unileon.es

Á. Taboada
Área de Zoología, Departamento de Biodiversidad y Gestión Ambiental, Facultad de Ciencias Biológicas y Ambientales,
Universidad de León, 24071 León, Spain

Introduction

The identity of the dominant tree species in a forest ecosystem affects soil properties through a variety of mechanisms (Ulery et al. 1995; Binkley and Giardina 1998; Augusto et al. 2002) such as: the quality [organic C, total N, acid detergent fibre (ADF), lignin and cellulose concentration and C:N and lignin:N ratios] of the litter layer that determines its decomposition rates (Sariyildiz et al. 2005), the amount of nutrient absorption by the plant's root system, the degree of interception of atmospheric depositions, and the interaction between the arboreal layer and the rainfall (Levia and Herwitz 2005). All these mechanisms can cause differences in the chemical properties of topsoils located under various tree species (Hägen-Thorn et al. 2004). The influence of the tree species on the edaphic characteristics has been extensively studied, mainly related to soil acidification processes (Hägen-Thorn et al. 2004). For instance, several studies found that conifer tree litter layer is more acidic than deciduous tree litter layer and consequently, soil acidification is stronger in the former case (Swift et al. 1979; Oulehle et al. 2007). On the other hand, the development of the arboreal structure as the forest matures can also affect soil properties through the creation of a specific microclimate. Indeed, Augusto et al. (2002) indicated that as the forest grows, decomposition processes slow down due to an increase in litter accumulation and higher soil acidification, together with the changing microclimate conditions. Likewise, the age of trees may also affect soil characteristics. Meanwhile young tree stages merely affect the chemical composition of the litter layer, tree influence on soil properties is more pronounced in the mature stages of the forest, when changes in the mineral soil have been detected at 40 to 50-year old stages related to the identity of the tree species (Hägen-Thorn et al. 2004). During the last century, reforestation strategies developed in Spain, similarly to other countries, have lead to a considerable increase in the areas occupied by conifer tree species often resulting in the replacement of native deciduous forests (Groome 1989). This matter has brought about a strong social debate regarding the possible negative impact of the establishment of non-indigenous conifer species on soil fertility (Barbier et al. 2007). Several authors have reported a higher C/N ratio, lower pH and lower nutrient soil content and increase the toxic Al^{3+} content of surface waters in coniferous stands compared with hardwood stands (Augusto et al. 2002; Hägen-Thorn et al. 2004; Barbier et al. 2007). Other studies pointed out that some coniferous species can modify water fluxes: have higher interception and lower deep seepage fluxes compared to hardwoods (Augusto et al. 2002). Moreover, coniferous stands present lower light transmittance, lower temperature and higher air humidity (Augusto et al. 2002). All these characteristics can limit the understory cover and richness, so it is generally considered that conifers are less favourable to understory diversity than deciduous trees (Barbier et al. 2007).

The objective of this study was to evaluate the influence of the arboreal layer, both the identity of the dominant tree species and the canopy layer structure, on the chemical properties of soils in three types of forest ecosystems: beech forests (*Fagus sylvatica*), oak forests (*Quercus pyrenaica*) and pine plantations (*Pinus sylvestris*). We also intended to determine if the establishment of non-native conifer tree species in areas where deciduous species are expected to grow naturally significantly affected soil features.

Methods

We selected three types of forest ecosystems: beech forests (*F. sylvatica*), oak forests (dominated by *Q. pyrenaica*, with presence of *Q. petraea* and their hybrids) and pine plantations (*P. sylvestris*); and four stands or replicates per forest type. Stands were located northeast of the León province, Spain (42° 36′–43° 4′ N, 4° 52′–5° 16′ W), at 1,000–1,400 m altitude and on siliceous substrate type. Climatic conditions are similar in all the stands, characterised by 900–1,200 mm of rainfall, mean temperatures between 8 and 11°C, with a mean minimum temperature of −3°C in the coldest month and a mean maximum of 25°C in the warmest month. The frost-free period lasts 4 months and there is a short summer dry period in July (Ministerio de Agricultura 1980). The type of soils is humic cambisol and ranker (Forteza et al. 1987). Beech stands were well-developed forests with similar environmental characteristics, and have suffered a variety of traditional management practices such as: cattle grazing, timber and firewood exploitation, which have been nowadays abandoned. Oak stands were also well-developed forests and have experienced the same type and intensity of management as beech forests (Tárrega et al. 2006). Pine plantation stands aged approximately between 40 and 80 years since planting (Marcos et al. 2007). Half of the pine plantation stands were located in areas where naturally-developing beech forests are potentially expected to grow and half were established in areas where *Q. pyrenaica* and *Q. petraea* forests represent the naturally-developing vegetation type. There are no detailed records on the specific management practices developed in these forest communities; probably only scarce and haphazard forestry practices have been applied (e.g. selective thinning). Neither there is information about the previous state of the pine plantations, probably there were broadleaved forest or grasslands. Sampling was carried out in summer 2003 and 2004. The forest stand characteristics are summarised in Table 1.

A systematic sampling method was used to characterise the tree layer structure. To determine both tree density and mean crown diameter, two perpendicular transects of about 40 m length were placed in the centre of each stand. Five

Table 1 Tree features in the studied plots

	Dominant tree height (m)		Trunk perimeter (m)		Density (tree/ha)
	Mean	SD	Mean	SD	
B1	15	1.9	1.37	0.45	345
B2	16	2.9	0.47	0.33	1,754
B3	17	2.1	0.62	0.37	2,336
B4	16	2.0	1.16	0.48	1,102
O1	15	1.9	0.65	0.56	1,315
O2	16	2.8	0.77	0.52	947
O3	13	2.5	0.65	0.56	2,439
O4	15	2.0	1.00	0.39	992
P1	16	2.3	0.77	0.23	851
P2	18	1.6	0.95	0.20	541
P3	17	1.7	0.91	0.14	482
P4	19	2.0	0.86	0.33	1,137

B Beech forests, *O* oak forests and *P* pine plantations points 8 m apart were selected in each transect. At each point we measured the distance to the closest tree in the four quadrants (40 measurements per stand), according to the point-centre-quarter method (Cottam and Curtis 1956) to estimate tree density based on the measurement of the mean tree distance [density = 1/(mean distance)^2]; and the mean crown diameter (i.e. average of the crown diameter measured along the two perpendicular transects on the same 40 tree individuals).

Five soil samples per stand, 8 m apart between them, were taken from the first 10 cm, using an auger, underneath the litter layer. Then were homogenised to obtain a uniform sample of the characteristics of each stand as a whole. Soil samples were air-dried and passed through a 2-mm mesh sieve for later analysis. Several chemical soil properties were determined in each stand sample: soil pH was determined potentiometrically in 1 g soil to 2.5 ml water slurries (M.A.P.A. 1994); organic matter by Walkley and Black (1934) method; total nitrogen by the Kjeldhal method (Bremmer and Mulvaney 1982); and available Ca^{2+}, K^+, Mg^{2+} and Na^+ were extracted with ammonium acetate 1 N pH = 7 (5 g soil to 50 ml $AcNH_4$) and determined by atomic absorption spectrophotometry (M.A.P.A. 1994). The depth of the litter layer was measured at each soil sampling point.

One-way analyses of variance (ANOVA) were carried out to determine whether there were significant differences in tree crown diameter and tree density, and soil variables among the different types of forests studied. In all cases, four replicates were considered. The Scheffe test was applied for post hoc comparisons when the ANOVA was significant ($p \leq 0.05$). Sample normality was checked beforehand using the Kolmogorov–Smirnov test and homogeneity of variances with the Cochran test. For the joint comparison of all the results we performed a principal component analysis (PCA) (using Statistica 6.0) considering eight soil variables: pH, organic matter, total nitrogen, available Ca^{2+}, K^+, Mg^{2+} and Na^+, and the litter layer depth. The correlation between soil and tree variables was analysed using the Pearson's coefficient.

Results

We found that beech forests were characterised by the highest tree crown diameter (Fig. 1) with a mean value of 5.6 m, followed by oak forests and pine plantations (mean value 4.6 and 4.2 m, respectively), although these differences were not statistically significant ($F = 1.83$; $p > 0.05$). Tree density was higher in oak and beech forests (1,423 and 1,384 trees/ha, respectively) than in pine plantations (752 trees/ha) (Fig. 1), although not significantly so ($F = 1.30$; $p > 0.05$).

The development of the litter layer was significantly higher in case of beech forests (mean litter layer depth = 8.6 cm) than in pine plantations and oak forests (Table 2). Lower pH values were found in beech forests and pine plantations (4.3 and 4.8, respectively), than in oak forests (5.4), differences being statistically significant (Table 2). Soil organic matter content was significantly higher in pine plantations (15.0%) than in oak forests, while beech forest values were intermediate (Table 2). The percentage of total nitrogen was significantly higher in beech (0.4%) than in oak (0.2%) forests (Table 2). We detected statistically significant differences in terms of available Na^+ concentration, with the lowest value in case of oak forests (Table 2), but no differences between forest types were found for available Ca^{2+}, K^+ and Mg^{2+}.

In the joint comparison of all variables by a principal component analysis, the first axis (explained variance 41%) ordered the forest stands according to the soil organic matter content, total nitrogen, available Na^+ and the highest litter layer depth (Fig. 2). As a result, beech forest and pine plantation stands were located at the positive part of axis I and were associated with high values of these variables. Meanwhile oak forest stands were located at the negative part of axis I, associated with low values of these variables. The second axis (explained variance 37%) differentiated the forest stands in relation to the high content of available Ca^{2+}, K^+ and Mg^{2+} and high values of pH. We also observed great variability among the stands of beech and oak forests, which were more heterogeneous in terms of

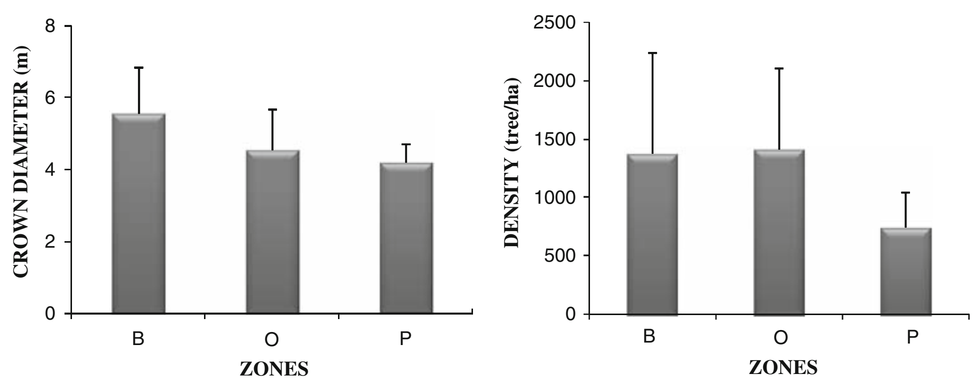

Fig. 1 Mean values and standard error of the crown diameter and tree density in the four replicates of the forest types studied (zones). *B* Beech forests, *O* oak forests and *P* pine plantations

Table 2 Mean values and standard error (SE) (four replicates in all cases) of the soil variables analysed

	Beech		Oak		Pine		*F* test	*p* value
	Mean	SE	Mean	SE	Mean	SE		
Litter layer depth (cm)	8.57a	1.82	3.78b	1.37	4.94b	1.35	10.67	0.004
pH	4.3b	0.5	5.4a	0.7	4.8ab	0.1	5.2	0.03
O.M.(%)	10.6ab	3.7	6.8b	2.5	15.0a	1.6	9.0	0.01
Total N(%)	0.43a	0.09	0.24b	0.10	0.39ab	0.05	4.98	0.035
Ca^{2+}(cmol/kg^{-1})	3.84a	4.35	5.01a	2.78	2.21a	0.66	0.87	0.450
Mg^{2+}(cmol/kg^{-1})	0.62a	0.39	1.12a	0.51	0.44a	0.13	3.48	0.078
K^{+}(cmol/kg^{-1})	0.48a	0.16	0.47a	0.24	0.41a	0.08	0.20	0.819
Na^{+}(cmol/kg^{-1})	0.05a	0.01	0.02b	0.01	0.06a	0.02	10.34	0.005

Results from the ANOVAs are included (*F* test and *p* value). Different letters in each line indicate significant differences ($p < 0.05$ by Scheffe test) between forest types

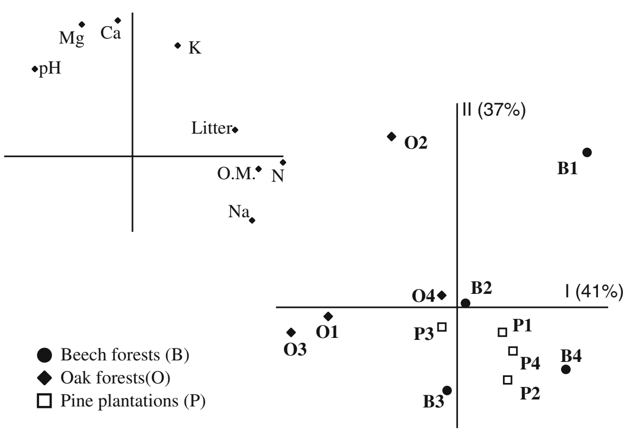

Fig. 2 Location of the forest stands and soil variables in the plane defined by the first two axes of the principal component analysis

Table 3 Pearson's correlation analysis between soil and tree characteristics

	Crown Diameter	Tree Density
Litter layer	0.63*	−0.20
pH	− 0.15	−0.11
Organic matter	0.24	−0.71*
Total nitrogen	0.61*	−0.56
Available Ca^{2+}	0.54	−0.29
Available Mg^{2+}	0.40	−0.20
Available K^{+}	0.57	−0.38
Available Na^{+}	0.06	−0.41

Marked correlations (*) are significant at $p < 0.05$

soil and litter layer characteristics. However, all the replicates of the pine plantations were quite similar. Three beech forest replicates were located next to the pine plantation stands, but the fourth beech stand was quite far apart, as it was associated to high values of available Ca^{2+}, K^{+} and Mg^{2+}, similarly to one of the oak forest stands.

The results of the Pearson's correlation analysis between soil variables and tree characteristics are shown in Table 3. The litter layer depth and total nitrogen content were positively and significantly related to the crown diameter. We also found that the tree density and the soil organic matter content were negatively and significantly correlated.

Discussion

Our results suggest that no significant differences between forest types in terms of the arboreal layer structure may be due to the great inter-stand variability that characterises each type of forest ecosystem studied. Among the three forest types studied, pine plantations were found to be the most homogeneous regarding tree characteristics, probably due to their even-aged structure and the absence of tree regeneration (Marcos et al. 2007). On the contrary, beech and oak forests were characterised by great heterogeneity in terms of tree size and by the highest values of tree density. Likely, this was caused by a certain degree of beech and oak vegetative regeneration after the abandonment of traditional management that results in great density of resprouts in the understory. According to Tárrega et al. (2006), the effect of resprouting on the structure of the arboreal layer is more pronounced in case of oak forests.

In this study there were only clear differences in soil pH between oak forests and the beech forest, although several studies have showed that soil pH and amount of exchangeable cations can be positively influenced by tree species composition (Finzi et al. 1998; Mohr et al. 2005). Indeed, the lowest pH values were found in beech forests and pine plantations, while the values for oak soil pH were higher, with more than 1 unit of difference between them. In case of beech forests, our results indicated that the lowest pH value was related to high levels of litter accumulation (Table 2). Previous studies indicated that leaf litter from oak and beech forests growing on poor soils closely resembles that of conifers (Neirynck et al. 2000), which is characterised by low decomposition rates, increased organic acid output and slowed down return of cations to the soil (Hägen-Thorn et al. 2004), favouring soil acidification. The low pH values and high litter accumulation found in the beech forests of this study are due to the poor soils and microclimatic conditions (high relative humidity and low temperature) they grow in. Higher soil acidity values in beech forests compared to other hardwood types of forests have also been found by other authors (Barbier et al. 2007). In case of pine plantations, it is well known that conifer litter is more acidic than deciduous leaf litter (Sariyildiz et al. 2005) and, consequently, soil acidification is higher. According to Binkley and Valentine (1991), the influence of the various tree species on soil pH is significantly relevant at the first 10 cm underneath the litter layer. On the other hand, there were no significant differences in the amount of exchangeable cations in the soil between forest types. The highest values for available Ca^{2+}, K^{+} and Mg^{2+} were found in the deciduous forest ecosystems, in accordance with previous studies (Augusto et al. 2002; Mohr et al. 2005), probably due to greater nutrient content in the leaf litter layer.

Oak forests were characterised by the smallest values of soil organic matter content and total nitrogen, probably associated to the lower degree of litter accumulation that distinguishes this type of forest ecosystem. Several authors have found that litter accumulation is related to the content of soil organic matter and total nitrogen, such as Mohr et al. (2005) when comparing oak forests and broom areas and Falkengren-Grerup et al. (2006) that related higher amounts of total nitrogen whit litter accumulation. Furthermore, Augusto et al. (2002) indicated that the amount of litter accumulation depends on the identity of the tree species and that regarding organic matter content *Pinus* stands allow higher values for this variable than hardwoods. However, other authors have found no clear relation between tree species and total nitrogen stocks in the soil, when comparing conifer and deciduous forest types (Klemmedson 1987; Raulund-Rasmussen and Vejre 1995).

When we analysed all the results as a whole, we clearly observed the influence of the tree species on the pH, organic matter and nutrients at the first cm of depth (Fig. 2). However, differences between topsoil characteristics under various tree species were more likely to be caused by differences in foliage properties, litter quality, litter decomposability and microbial activity (Hägen-Thorn et al. 2004; Barbier et al. 2007). In fact, oak forests were characterised by low litter accumulation and organic matter content, and were found to show higher amount of exchangeable cations and lower acidity than beech forests and pine plantations, which hold slowed down decomposition and mineralisation rates instead (Archibold 1995). Opposite to other studies, we did not find a strong influence of the arboreal structure on the edaphic characteristics. Although our results indicated that the crown diameter (meaning tree size) seemed to be related to a few soil variables studied, we cannot confirm that the arboreal layer structure strongly affects soil properties. It is very likely that the differences in mineral topsoil chemistry between forest types were mainly related to the characteristics of the litter layer and its decomposition rates and less related to the arboreal structure. For example, Sariyildiz and Anderson (2003) have reported that differences in the tree canopy structure caused differences in the litter layer and, consequently, in soil properties. Although we reported great variability in soil characteristics at the stands of beech and oak forests, this inter-stand heterogeneity was no related to differences in the arboreal structure.

Finally, the establishment of pine plantations in areas where beech and oak species are potentially expected to grow naturally has affected topsoil properties to a certain degree, as pine plantations were characterised by similar edaphic chemical features and less variability in soil properties compared to beech and oak stands. However, we did not find negative effects of pine plantations on soil characteristics in terms of higher acidity and nutrient loss, contrary to other authors (Augusto et al. 2002).

Conclusions

Even though our results indicated that the identity of the tree species affected several topsoil chemical properties (increase in pH and available cations in oak forests and higher organic matter and total nitrogen in beech and pine ecosystems), we cannot confirm that this was the only factor affecting soil chemistry as there may be other acting factors to take into account. Pine plantations clearly affected topsoil properties as the natural edaphic variability of these areas turned out to be reduced by the establishment of the non-native coniferous tree species. However, there was no general negative effect of pine plantations on the chemical properties of the soil.

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