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Soil properties and understory herbaceous biomass in forests of three species of *Quercus* Northeast Portugal

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Abstract

Aim of study: This paper aims to characterize some soil properties within the first 25 cm of the soil profile and the herbaceous biomass in *Quercus* forests, and the possible relationships between soil properties and understory standing biomass.

Area of study: Three monoespecific *Quercus* forests (*Q. suber* L., *Q. ilex subsp. rotundifolia* Lam. and *Q. pyrenaica* Willd) in NE Portugal.

Material and methods: During 1999 and 2000 soil properties (pH-KCl, total soil nitrogen (N), soil organic carbon (SOC), C/N ratio, available phosphorus (P), and available potassium (K)) and herbaceous biomass production of three forest types: *Quercus suber* L., *Quercus ilex subsp. rotundifolia* Lam. and *Quercus pyrenaica* Willd were studied.

Main results: The results showed a different pattern of soil fertility (N, SOC, P, K) in *Quercus* forests in NE of Portugal. The C/N ratio and the herbaceous biomass confirmed this pattern.

Research highlights: There is a pattern of *Quercus* sp. distribution that correlates with different soil characteristics by soil characteristics in NE Portugal. *Q. pyrenaica* ecosystems were found in more favoured areas (mesic conditions); *Q. rotundifolia* developed in nutrient-poor soils (oligotrophic conditions); and *Q. suber* were found in intermediate zones.

Key words: fertility; biomass; C/N ratio; cork oak; holm oak; pyrenean oak.

Introduction

The Iberian Peninsula is one of the main centres of diversity of the genus *Quercus* in Eurasia, with more than nine native species forming extensive forests and woodlands (Ruiz de la Torre, 2002). In the Northeast of Portugal, where the present study was carried out, forestland use occupies an approximate area of 156,000 ha (24% of the territory) (IFN, 2005). In this area, the most abundant species of the *Quercus* genus are *Q. suber* L., *Q. pyrenaica* Will and *Q. ilex subsp. rotundifolia* Lam occupying 12.5%, 11.5% and 9.4% of the forestland, respectively. *Q. pyrenaica* is a deciduous transitional Mediterranean oak, which is restricted to Southwest Europe (west-northwest Spain, southwest France and Northeast Portugal) and some isolated sites in northern Morocco.

Q. pyrenaica occurs where there is a transition between typical Mediterranean sclerophyllous and temperate deciduous forests (Tarrega *et al.,* 2006). It occurs in regions with an annual precipitation above 740-800 mm and a mean temperature around 12°C, on acid soils (Castro, 2008). The species is well adapted to survive summer water deficits while maintaining photosynthetic production (Rico *et al.,* 1996). Therefore, it often occupies transitional areas from sub-humid to semi-arid conditions. *Q. suber* is an evergreen Mediterranean tree relatively abundant in the western parts of the Iberian Peninsula, as well as in western Italy, the large islands between Italy and Spain, and in North Africa (Morocco, Algeria and Tunisia) (Tutin, 1964). In the Iberian Peninsula, most *Q. suber* occur on acidic soils in the centre and western half of the Peninsula. *Q. suber* grows in non-carbonated soils such as acidic soils on granite, schist or sandy substrate and occasionally on neutral soils over dolomitic bedrocks (Pausas *et al.,* 2006). It occurs in regions with an annual precipitation normally above 600 mm and a mean temperature around 15°C (Blanco *et al.,* 1997). *Quercus ilex* is a sclerophyllous evergreen tree very abundant in a western Mediterranean region. It is occurs in the driest conditions, follo-

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wed by *Q. suber*. For instance, *Q. suber* dominates in coastal areas where the oceanic influence is stronger, while *Q. ilex* is characteristic of the driest areas on calcareous and even acid soils.

Quercus species are long-life trees and are frequently more than 100 years old (Plieninger *et al.,* 2003). Over such an extended period, trees can significantly affect the fertility of the soil, mostly by recycling via leaf litter and root turnover of nutrients that were pumped from deep layers (Moreno *et al.,* 2007). On the other hand, in the Mediterranean climate, nutrient availability is largely dependent on favourable combinations of warm temperatures, high soil moisture, and particularly of the quality and quantity of soil organic matter (Gallardo *et al.,* 2000). Carbon accumulation in soil is strongly influenced by biological factors, such as vegetation (Vesterdal *et al.,* 2008), microbial communities that decompose inputs (Ekschmitt *et al.,* 2008), and by abiotic factors (Homann *et al.,* 2007; Zinn *et al.,* 2007). Nitrogen (N) is the most limiting nutrient in ecosystems (Whitehead, 1995) and the quantity of N in soils is intimately associated with organic matter levels, thus with soil quality. Assuming relatively low atmospheric inputs (EEA, 2011) and low losses via leaching or denitrification, soil N concentration basically depends on the balance between the N mineralisation rate and the N uptake by roots and soil microorganisms. Phosphorous (P) presents a mineral concentration that is quantitatively as important as the organic one, and forms part of soil minerals and rocks. Although P is required in lower amounts than other major nutrients (approximately 10 times less than for N and potassium) is another essential element for plants. P is unique among the anions in that it has low mobility and availability in soils. Potassium (K) is required by plants in approximately the same or slightly larger amounts as N. K does not form a part of any organic molecule, but plants usually amass large quantities of K in their tissues. K is mainly cycled through mineral weathering, but also by biological pumping through leaf litter decomposition (Lucas, 2001). Unlike N and P, K is easily leached from leaves and plant tissues (Aber & Melillo, 2001).

On the other hand, different processes such as weathering dissolution, atmospheric deposition, leaching, and biological mechanisms (immobilisation by plants and microbes) contribute to the vertical distribution of soil nutrients. It is known that leaching moves nutrients downward, while, biological mechanisms generally moves nutrients upwards. Previous studies showed that the most limiting nutrients for plants (N, P, K) were relatively more abundant in surface soil horizons than in deeper horizons (Gallardo, 2003; Jobbágy & Jackson, 2001).

The effect of tree species on forest soils is not fully understood and has been discussed for more than a century (Binkley, 1995). Also, tree species are often associated with specific soil types (Kristensen *et al.,* 2004). For instance, at the landscape scale, it is known that broadleaved forests are mainly located on nutrient-rich soils whereas coniferous forests are found in poor soils. Furthermore, several authors (cited by Zas & Alonso, 2002) argued that the relationships between vegetation and soil characteristics could be used as an important tool to assess sites. It has been recently reported that tree species is the most important explanatory variable for the C/N ratio in soils of European forests (Cools *et al*., 2014). Thus, it would be expected that the ecological functioning of the *Quercus* sp. studied could be expressed in different soil properties. In this study, we aimed to i) study soil properties and herbaceous biomass production on three different *Quercus* ecosystems located in the Northeast of Portugal; ii) study whether soil properties varied along depth in the three ecosystems; iii) associate these soil properties with herbaceous biomass production by each ecosystem.

Material and methods

Study area and experimental design

The study area was located in Trâs -os-Montes (NE Portugal), between the coordinates

41° 23' N, 1° 56' W and 41° 50' N, 7° 02' W (Fig. 1). This region is characterized by high climatic and landscape diversity. Due to its internal situation, it has few maritime influence, yet its diversified geomorphology results in a wide variation of rainfall, this being the order of 1,500 mm in inner mountain areas in the north and, 400 mm in areas of the Upper Douro valley embedded. Among the native forests in the region, were chosen in this study, the three most representative species of *Quercus: Quercus pyrenaica* Will, *Quercus ilex subsp. rotundifolia* Lam (henceforth *Q. rotundifolia*) and *Quercus suber* L. Four experimental sites in *Q. pyrenaica and Q. suber* and three sites in *Q. rotundifolia* forest were selected (Fig. 1). Each site was representative of each species forest type and was selected

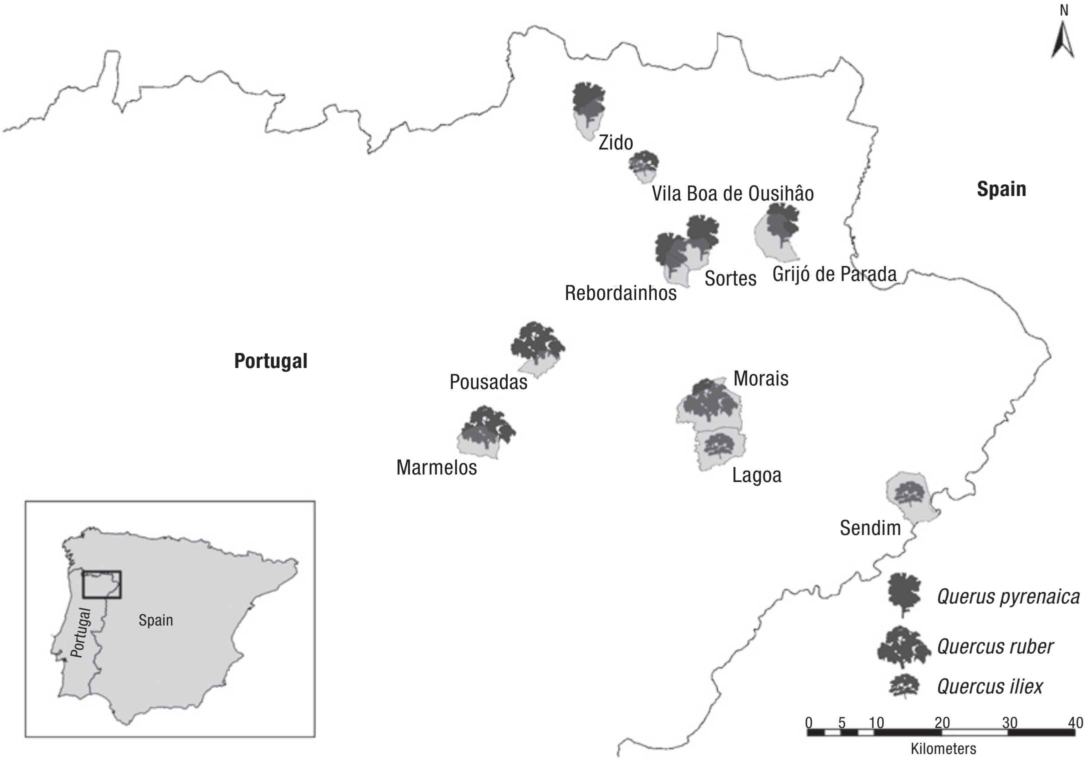

Figure 1. Location of the ecosystems studied.

randomly across the distribution area. A total of 68 plots were sampled: 44 plots in *Q. pyrenaica* (11 plots per site); 12 plots in *Q. rotundifolia* (4 plots per site); and 12 plots in *Q. suber* (4 plots per site). Selected forests showed physiographic and ecological dendrometer measurements that were very different from each other (Table 1). The study area is characterized by a Mediterranean climate with an annual rainfall between 520-1386 mm and annual average temperature between 11.9-14.2°C (INMG, 1991). The average altitude of the study areas was between 380-980 m a.s.l. Density varied considerably among the different ecosystems; ecosystems of *Q. rotundifolia* had higher plant densities, while *Q. suber* ecosystems were more dispersed (Teixeira *et al.*, 2001).

During 1999 and 2000 we proceeded to study the characteristics of the soil and herbaceous biomass of three forest types: *Q. suber*, *Q. rotundifolia* and *Q. pyrenaica*.

Sample collection and analysis

A total of 204 soil samples were randomly collected using a soil corer: 132 soil samples were collected under *Q. pyrenaica* (11 samples at each sites × 4 sites × 3 depths), 36 samples under *Q. suber* (4 samples at each site × 3 sites × 3 depths) and 36 samples under *Q. rotundifolia* (4 samples at each site × 3 sites × 3 depths). Litter was removed from the surface before sampling. Upon collection, samples were taken to the laboratory to be dried to constant weight (40°C) and sieved through a 2-mm sieve. The < 2-mm fraction was used to determine the main soil properties: pH-KCl was determined by the potentiometric method (Santos, 1965); Total soil nitrogen (N) by the Kjeldahl method (Bremner, 1996), and soil organic carbon (SOC) by the Walkley-Black method described by Schulte (1980). Available P and K (mg kg^{-1}) were extracted with an ammonium acetate-lactate A-L solution (pH 3.7; ratio 1:20). Available P and K were determined by spectrophotometry and flame photometry, respectively by the Egner-Riehm-Domingo method (Egner-Riehm and Domingo, 1960).

Herbaceous biomass was evaluated by the method of cutting and weighing in square 0.25 m^2. A total of 68 samples were cut: 44 samples in *Q. pyrenaica* (11 samples at each site × 4 sites), 12 samples in *Q. suber* (4 samples at each site × 3 sites), and 12 samples in *Q. rotundifolia* (4 samples at each site × 3 sites) in the late spring of 2,000. Herbaceous biomass was cut at a height of

Table 1. Description of the study areas

Specie	Coord	N (tree ha^{-1})	n (tree)	D (cm)	BA (m^2 ha^{-1})	R (mm)	T (°C)	Alt (m)	SLO (%)	OR	Parent rock
Q. pyrenaica											
Site											
Zido	41° 50' 19" N, 7° 2' 28" W	368	28	30.41	26.71	1,075.1	11.9	850	25	SW	Umbric Leptosols of basic rocks
Rebordaínhos	41° 40' 2" N, 6° 51' 10" W	1,069	93	13.57	15.75	1,385.8	11.9	980	25	NE	Umbric Leptosol of granites
Sortes	41° 40' 2" N, 6º 51' 10" W	1,017	61	12.79	13.00	741.1	11.9	750	3	NE	Dystric Leptosols of schists
Freixedelo	41° 41' 48" N, 6° 51' 50" W	1,850	86	9.39	12.90	741.1	11.9	720	27	N	Dystric Leptosols of schists
Q. suber											
Site											
Morais	41° 29' 20" N, 2° 21' 28" W	58	6	59.19	10.00	636.2	14.2	500	0	—	Eutric Leptosols and Cambric
Pousadas	41° 32' 12" N, 2° 01' 00" W	98	23	43.20	14.29	520.1	14.2	400	2	NW	Dystric Leptosols of schists or Eutric
Marmelos	41° 25' 49" N, 1° 56' 36" W	62	6	5.07	5.9	520.1	14.2	380	12	SW	Dystric Leptosols of schists or Eutric
Q. rotundifolia											
Site											
Sendim	41° 23' 3" N, 2° 42' 19.6" W	1,330	63	8.06	6.75	554.7	12	600	25	SW	Dystric Leptosols of schists
Lagoa	41° 26' 39.7" N, 2° 22' 12" W	—	—	—	—	636.2	14.2	440	30	NW	Eutric Leptosols and Cambric
Vila Boa	41° 48' 15" N, 2° 21' 28.4" W	2,800	148	5.76	7.20	1,075.1	11.9	823	12	N	Eutric Leptosols of ultramafic rocks

Coord: coordinates. n: tree sample size. N: number of trees per hectare. D: average diameter. BA: stand basal area. R: annual average rainfall. T: annual average temperature. Alt: altitude. SLO: slope.OR: orientation.

2.5 cm. Subsequently, each sample was dried (48 at 65°C) and we proceeded to determine the dry matter yields.

In the winter of 1999, a different number of trees (n) were measurement in each plot (Table 1). All the trees in each sample plot were labelled with a number. Cross diameters at breast height (D: 1.3 m above ground level) were measured with callipers, and the arithmetic mean was calculated. The following stand variables were calculated for each plot: number of trees per hectare (N); average diameter (D); and stand basal area (BA).

Statistical analysis

The variables studied were: pH-KCl, total soil nitrogen (N); soil organic carbon (SOC); available P; available K; C/N ratio; and herbaceous biomass. For soil variables, data were analyzed via Repeated Measures ANOVA, using Mauchly's Criterion to test sphericity. If the sphericity assumption was met, univariate approach output was used; if not, multivariate output (Wilks' Lambda test) was used. The LSD (Least Significant Difference) test was used to make subsequent pairwise comparisons after a normalization test ($\alpha = 0.05$), but only when factors were significant according to the results of the ANOVA analyses. The statistical software package SAS (2001) was used for all analyses. A Pearson correlation test was used to evaluate possible correlations between soil variables and biomass.

Principal component analysis (PCA) with the topsoil variables measured and biomass was carried out in the CANOCO 4.5 program (ter Braak & Smilauer, 2002). To improve the interpretability of principal components we used the orthogonal varimax rotation that results in uncorrelated principal components. Results of the multivariate analysis were visualized in the form of a bi-plot ordination diagram created with CanoDraw© software.

Results

The herbaceous biomass production obtained was significantly lower (F: 14.69, dg: 2, $p < 0.001$) in the ecosystems of *Q. rotundifolia* compared with *Q. suber* and *Q. pyrenaica* ecosystems (Fig. 2).

The interaction *ecosystem* × *depth* was significant for pH-KCl, total soil N, available P, available K and SOC (Table 2). *Q. pyrenaica* and *Q. suber* ecosystems showed lower pH-KCl values than *Q. rotundifolia* ecosystems. The difference between *Q. rotundifolia* and the other two ecosystems studied was about 0.5 pH-KCl units (Fig. 3) Soil pH-KCl was significantly reduced at 15-25 and 5-15 cm compared with the top 5 cm soil layer in *Q. rotundifolia* and *Q. pyrenaica ecosystems*, respectively (Fig. 3). No differences between depths were found under *Q. suber* ecosystems. On the other hand, concentration of macronutrients and SOC consistently decreased with depth in the three studied ecosystems (Fig. 4). In the three ecosystems, more than 50% of SOC was stored in the topsoil while, the lower amounts were found in the 5-15 cm (26%) and 15-25 cm layer (20%). When analysing the influence of ecosystems, the highest SOC values were observed under *Q. pyrenaica* at 0-15 cm and under *Q. pyrenaica* and *Q. rotundifolia* in the 15-25 cm layer. In general, *Q. suber* ecosystems showed lower SOC values along the soil profile compared with the other two ecosystems studied, with the exception of the top 5 cm layer where no differences between *Q. suber* and *Q. rotundifolia* ecosystems were found.

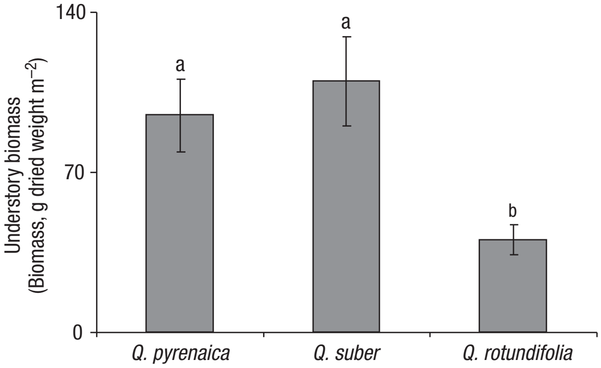

Figure 2. Understory herbaceous biomass in the three *Quercus ecosystems* (*Q. pyrenaica, Q. suber* and *Q. rotundifolia*) in Northern Portugal. Different letters indicate significant differences between ecosystems. Vertical lines indicate mean standard error.

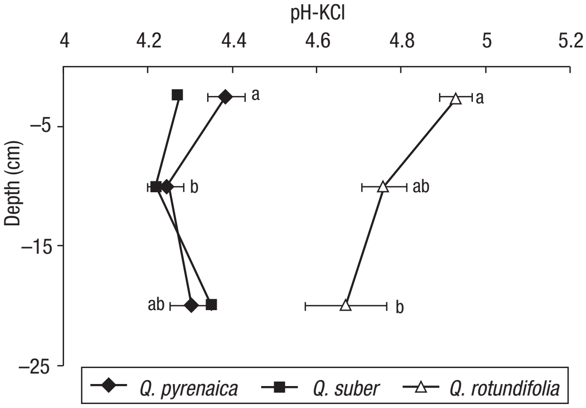

Figure 3. pH-KCl in the three ecosystems (*Q. pyrenaica, Q. suber* and *Q. rotundifolia*) and in the three soil depths studied (0-5, 5-15 and 15-25 cm). Different letters indicate significant differences between depths in the same ecosystem. Vertical lines indicate mean standard error.

Q. rotundifolia ecosystems showed higher C/N ratio at 15-25 cm compared with the top 5 cm soil layer (Fig. 5), while the results showed that in *Q. pyrenaica* ecosystems, the C/N ratio was significantly increased at 5-15 cm compared with 15-25 and the top 5 cm soil layer. No effects of depth on the C/N ratio were found in *Q. suber* ecosystems. On the other hand, *Q. rotundifolia* showed a higher C/N ratio than *Q. suber* and *Q. pyrenaica* ecosystems along the soil profile.

The interaction *ecosystem x site* was significant for pH-KCl, total soil N, available P, available K, SOC and C/N (Table 2). The results showed that pH-KCL was significant higher under Q. rotundifolia sites (Lagoa, Sendim and Vila Boa) compared with Q. pyrenaica and Q. suber sites (Table 3). In general, the higher total soil N and available K levels were found in *Q. pyrenaica* sites along the soil profile. Rebordainhos was the site with the higher available P at the top 5 cm compared with *Q. suber* and Q. *rotundifolia* sites (except Lagoa). On the other hand, SOC was significant higher in the four *Q. pyrenaica* sites studied compared with *Q. suber* and *Q. rotundifolia* sites at the top 5 cm. Vila Boa (under *Q. rotundifolia*) showed the higher C/N ratio at 0-5 and 15-25 cm compared with the other sites studied while, Zido (under *Q. pyrenaica*) was the site with the higher C/N ratio at 15-25 cm.

Table 2. Results of repeated-measures ANOVA on soil variables

	Total soil nitrogen (mg g^{-1})	**Available soil phosphorous (mg kg^{-1})**	**Available soil potassium (mg kg^{-1})**	**Soil organic carbon (g kg^{-1})**	**C/N**	**pH-KCl**
Ecosystem						
DF	2	2	2	2	2	2
F-value	24.42	10.10	29.13	23.33	9.84	31.01
P-value	<0.0001	0.0008	<0.0001	<0.0001	0.0009	<0.0001
Site						
DF	3	3	3	3	3	3
F-value	24.63	5.36	10.19	22.76	5.52	10.20
P-value	<0.0001	0.0063	0.0002	<0.0001	0.0056	0.0002
Plot (site)						
DF	40	40	40	40	40	40
F-value	1.10	0.31	0.52	0.90	0.38	1.04
P-value	0.4199	0.3030	0.9651	0.6273	0.9961	0.4752
Error						
DF	22	22	22	22	22	22
Depth						
DF	2	2	2	2	2	2
F-value	13.32	81.21	45.38	17.12	3.65	5.03
P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.032	0.0108
Depth ecosystem						
DF	4	4	4	4	4	4
F-value	11.11	13.57	6.23	19.26	2.21	3.02
P-value	<0.0001	<0.0001	0.0005	<0.0001	0.0434	0.0275
Depth site						
DF	6	6	6	6	6	6
F-value	9.47	35.88	6.96	8.39	5.90	4.30
P-value	<.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0017
Depth plot(site)						
DF	80	80	80	80	80	80
F-value	1.37	16.40	0.87	1.15	0.90	1.42
P-value	0.1287	0.5501	0.7130	0.3132	0.6661	0.1275
Error						
DF	44	44	44	44	44	44

Table 4 shows the results of the Pearson correlation test used to evaluate possible correlations between soil variables and biomass in the surface layer (5 cm). The highest correlations were found between N and SOC (r = 0.909), and N and P (r = 0.710), followed by SOC and P (r = 0.634). On the other hand, available K was positively correlated with N (r = 0.554), SOC (r = 0.588), and P (r = 0.448). Moreover, a moderate negative correlation was found between N and C/N (r = –0.447) and herbaceous biomass and C/N ratio (r = –0.367). As with the surface layer, a positive correlation between N and SOC (r = 0.847), K and N (r = 0.659), K and P (r = 0.659), K and SOC (r = 0.503), and N and P (r = 0.515) was found in the deeper layer (Table 5).

PCA was significant ($p < 0.000$) in the explanation of dependent variables (Fig. 6). PCA showed that 92% of the total variance of the data could be explained using only two principal components. The first axis,

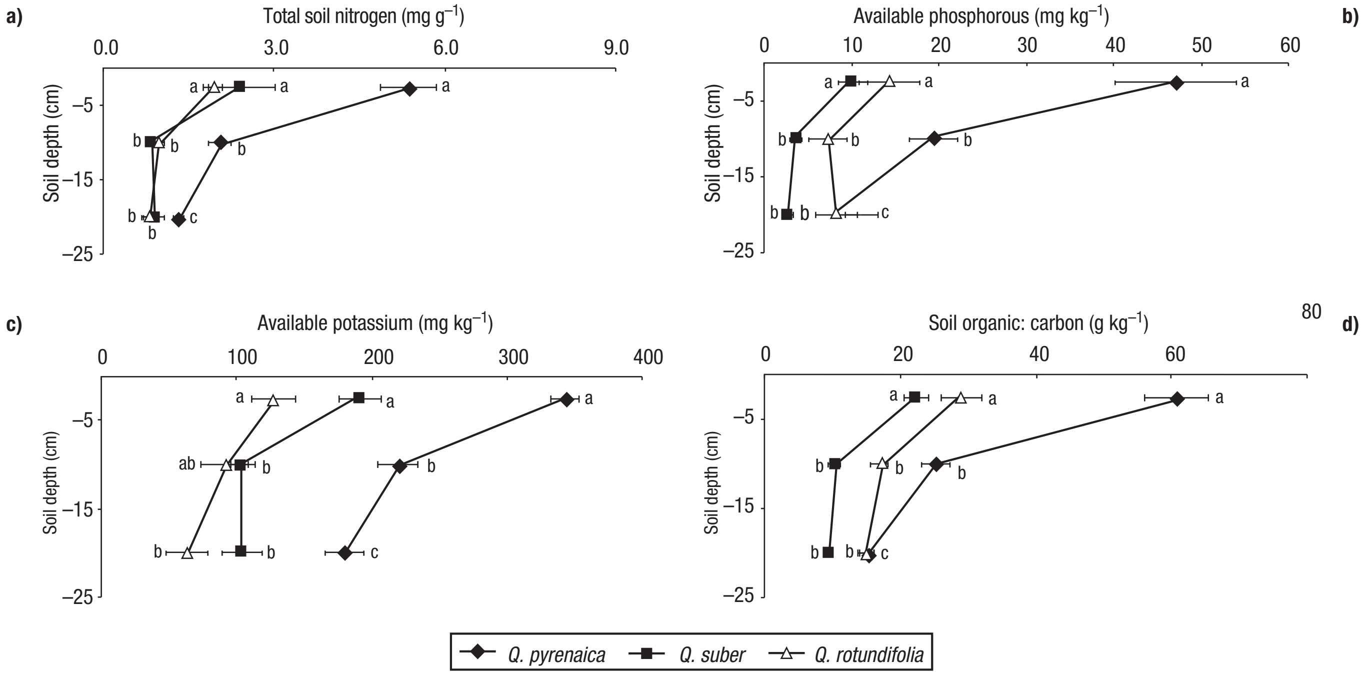

Figure 4. a) Total soil N (mg g^{-1}), b) available P (mg kg^{-1}), c) available K (mg kg^{-1}) and d) soil organic carbon (SOC) (g $^{-1}$) in the three ecosystems (*Q. pyrenaica, Q. suber* and *Q. rotundifolia*) and in the three soil depths studied (0-5, 5-15 and 15-25 cm). Different letters indicate significant differences between depths in the same ecosystem. Vertical lines indicate mean standard error.

PC1 was positively related to total soil N, SOC, P, K and negatively related to C/N ratio, indicating the existence of a fertility gradient. On the other hand, the positive contributions of herbaceous biomass and the negative contributions of the C/N ratio suggested the existence of a gradient of productivity associated with soil C/N ratio. Moreover, PC1 separated N, SOC, P, K, which were concentrated on the positive side of axis 1, reflecting that these parameters reached higher values in the case of *Q. pyrenaica* ecosystems and lower values in the case of *Q. rotundifolia* ecosystems. The second axis, PC2, was positively correlated with biomass and negatively with the C/N ratio.

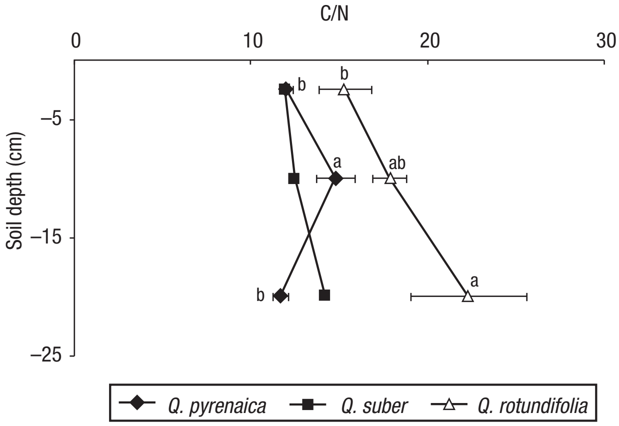

Figure 5. C/N ratio in the three ecosystems (*Q. pyrenaica, Q. suber* and *Q. rotundifolia*) and in the three soil depths studied (0-5, 5-15 and 15-25 cm). Different letters indicate significant differences between soil depths in the same ecosystem. Vertical lines indicate mean standard error between soil depths in the same ecosystem.

Discussion

It is known that Mediterranean soils often suffer from nutrient deficiencies, especially of N and P (Sardans *et al.,* 2004). In our study, the soils of the three ecosystems are defined as acidic, which could affect the availability of N, P, K and the decomposition rate of the organic matter, and therefore the accumulation of SOC (Ulrich & Summer, 1991). In the three ecosystems studied, nutrient scarcity manifested as low N content along soil profile. With the exception of the top 5-cm layer of *Q. pyrenaica* ecosystems, all soil layers showed amounts below 0.27 mg g^{-1}, far lower than the worldwide mean N value for the first 30 cm of soil proposed by Batjes (1996) that was settled to 4.2 mg g^{-1} for Leptosols, or 4.9 mg g^{-1} for Litosols and humid Cambisols in Spain (Zas & Alonso, 2002).

Table 3. pH-KCl, total soil N (mg g^{-1}), available P (mg kg^{-1}), available K (mg kg^{-1}), soil organic carbon (SOC) (g kg^{-1}), and C/N ratio in the each site studied (*Q. pyrenaica*- 4 site, *Q. suber*- 3 sites and *Q. rotundifolia*- 3 sites) and in the three soil depths studied (0-5, 5-15 and 15-25 cm)

	Soil depth (cm)	*Q. pyrenaica*				*Q. suber*			*Q. rotundifolia*		
		Freixedelo	Rebordaínhos	Sortes	Zido	Marmelos	Morais	Pousadas	Lagoa	Sendim	Vila Boa
pH-KCl	0-5	4.53^{b}	4.46^{b}	4.10^{c}	4.45^{b}	4.28^{bc}	4.45^{b}	4.10^{c}	4.98^{a}	4.90^{a}	4.93^{a}
	5-15	4.53^{bc}	4.05^{e}	4.08^{de}	4.32^{cd}	4.30^{cd}	4.33^{cd}	4.05^{e}	4.70^{ab}	4.68^{b}	4.93^{a}
	15-25	4.60^{b}	4.16^{cde}	4.14^{de}	4.31^{bcde}	4.48^{bc}	4.45^{bc}	4.13^{e}	4.63^{b}	4.45^{bc}	4.95^{a}
Total soil Nitrogen (mg g^{-1})	0-5	5.65^{b}	8.80^{a}	4.74^{bc}	2.31^{cd}	3.44^{bcd}	1.46^{d}	2.14^{d}	2.56^{cd}	1.51^{d}	1.70^{d}
	5-15	2.89^{a}	3.15^{a}	1.60^{b}	0.56^{c}	0.79^{c}	0.70^{c}	1.12^{bc}	1.24^{bc}	0.86^{bc}	0.86^{bc}
	15-25	1.64^{ab}	1.87^{a}	1.03^{cd}	0.71^{cd}	1.11^{bc}	0.53^{d}	1.01^{cd}	0.92^{cd}	0.88^{cd}	0.61^{cd}
Available Phosphorus (mg kg^{1})	0-5	53.30^{ab}	68.31^{a}	30.72^{abc}	35.94^{abc}	10.48^{bc}	4.70^{c}	15.28^{bc}	25.83^{abc}	11.55^{bc}	5.45^{c}
	5-15	33.87^{a}	14.48^{b}	13.16^{b}	16.10^{b}	3.18^{b}	2.08^{b}	5.80^{b}	14.98^{b}	6.55^{b}	0.33^{b}
	15-25	18.01^{a}	8.49^{ab}	7.11^{ab}	10.70^{ab}	2.40^{b}	1.75^{b}	4.15^{b}	16.80^{a}	8.05^{ab}	0.00^{b}
Available Potassium (mg kg^{-1})	0-5	391.23^{a}	370.40^{a}	338.70^{a}	269.42^{b}	137.80^{ef}	198.83^{cd}	237.00^{bc}	92.35^{f}	172.45^{de}	117.68^{ef}
	5-15	327.38^{a}	257.19^{a}	142.86^{bcd}	150.12^{bc}	73.65^{de}	111.05^{bcde}	121.63^{bcd}	81.13^{cde}	154.83^{b}	45.65^{e}
	15-25	291.61^{a}	207.15^{b}	96.21^{c}	122.70^{c}	62.90^{cd}	126.80^{c}	122.45^{c}	76.18^{cd}	90.68^{c}	24.08^{d}
Soil Organic carbon (g kg^{-1})	0-5	54.53^{bc}	97.32^{a}	58.82^{b}	32.17^{d}	18.62^{d}	20.71^{d}	27.72^{d}	34.02^{cd}	16.50^{d}	36.63^{cd}
	5-15	26.02^{b}	42.19^{a}	21.46^{bd}	11.67^{de}	8.41^{e}	11.05^{de}	11.80^{de}	19.79^{bc}	14.21^{cde}	16.95^{cd}
	15-25	15.15^{bcd}	25.02^{a}	13.52^{bcd}	6.72^{e}	7.99^{e}	10.15^{de}	10.35^{cde}	15.24^{bc}	14.08^{bcd}	16.36^{b}
C/N	0-5	9.81^{de}	11.71^{bcd}	12.48^{bc}	14.05^{b}	8.80^{e}	14.25^{b}	12.93^{bc}	13.53^{bc}	10.93^{cde}	21.53^{a}
	5-15	9.21	13.76^{cdef}	13.57^{ef}	22.78^{a}	11.45^{def}	15.88^{bcde}	10.30^{ef}	16.68^{bcd}	17.20^{abc}	19.68^{ab}
	15-25	9.34^{c}	13.36^{bc}	13.20^{bc}	10.86^{c}	13.30^{bc}	19.18^{b}	10.33^{c}	17.88^{b}	18.18^{b}	29.98^{a}

It is known that N contents reaches higher values in soils developed over schist than over granites (Turrión *et al*., 2009). This could explain the fact that the total soil N found in this study was higher than the levels reported by Silla & Escudero (2006) and Turrión *et al*. (2009) in *Q. pyrenaica* forests developed over granites. In the case of *Q. rotundifolia* and *Q. suber*, total soil N contents were between the range obtained by Canadell and Vilá (1992) for *Q. ilex* forests studied in Spain & Otieno *et al*. (2011) for *Q. suber* forests in Southern Portugal. Furthermore, our results showed similar available P contents than those reported by Rapp *et al*. (1999) in *Q. pyrenaica* forests developed over schist; and higher levels compared with those obtained by Andivia *et al*. (2010) for *Q. suber* forests developed over a sandy soil with low cation exchange capacity which could have favoured cation leaching. Regarding K, the results showed higher K than P levels in the three ecosystems and along the soil profile. This could be explained because, in all ranges of soil pH, phosphate ions tend to react with other cations to form less soluble compounds; therefore, P availabi-

Table 4. Pearson correlation coefficient matrix among each pair of variables considered in the study for the surface layer (5 cm) (n = 68)

	N (mg g^{-1})	SOC (g kg^{-1})	pH-KCl	C/N	P (mg kg^{-1})	K (mg kg^{-1})	Biomass (gm^{-2})
N (mg g^{-1})	1.000						
SOC (g kg^{-1})	0.909***	1.000					
pH-KCl	–0.080	–0.076	1.000				
C/N	–0.447***	–0.131	0.209	1.000			
P (mg kg^{-1})	0.710***	0.634***	0.087	–0.245	1.000		
K (mg kg^{-1})	0.554***	0.588***	–0.319	–0.300	0.448***	1.000	
Biomass (g m^{-2})	0.118	–0.032	–0.106	–0.367*	0.198	0.288	1.000

*,*** Significance at $p < 0.05$ and $p < 0.001$, respectively.

Table 5. Pearson correlation coefficient matrix among each pair of variables considered in the study for deeper layer (5-25 cm) (n = 136)

	N ($mg\ g^{-1}$)	SOC ($g\ kg^{-1}$)	pH-KCl	C/N	P ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)
N ($mg\ g^{-1}$)	1.000					
SOC ($g\ kg^{-1}$)	0.847***	1.000				
pH–KCl	–0.103	–0.190	1.000			
C/N	–0.408***	–0.028	0.148	1.000		
P ($mg\ kg^{-1}$)	0.514***	0.358***	0.153	–0.149	1.000	
K ($mg\ kg^{-1}$)	0.659***	0.503***	–0.018	–0.355***	0.633***	1.000

*** Significance at $p < 0.001$.

lity could be reduce (Turrión *et al.*, 2008). However, this reactions can be very pronounced in acidic soil because, in this case, Al is the dominant ion that will react with phosphate, as well as some Fe and Ca phosphates, which will result in very insoluble compounds of phosphate that are generally not available to plants.

On the other hand, unlike P, the enhancement of K availability in soils is easily achieved, because this nutrient remains stored in soil cation exchange sites (Bortoluzzi *et al.,* 2005). Generally, K adsorption in soils is sufficiently strong to avoid the leaching process and sufficiently weak to supply this nutrient to the soil solution.

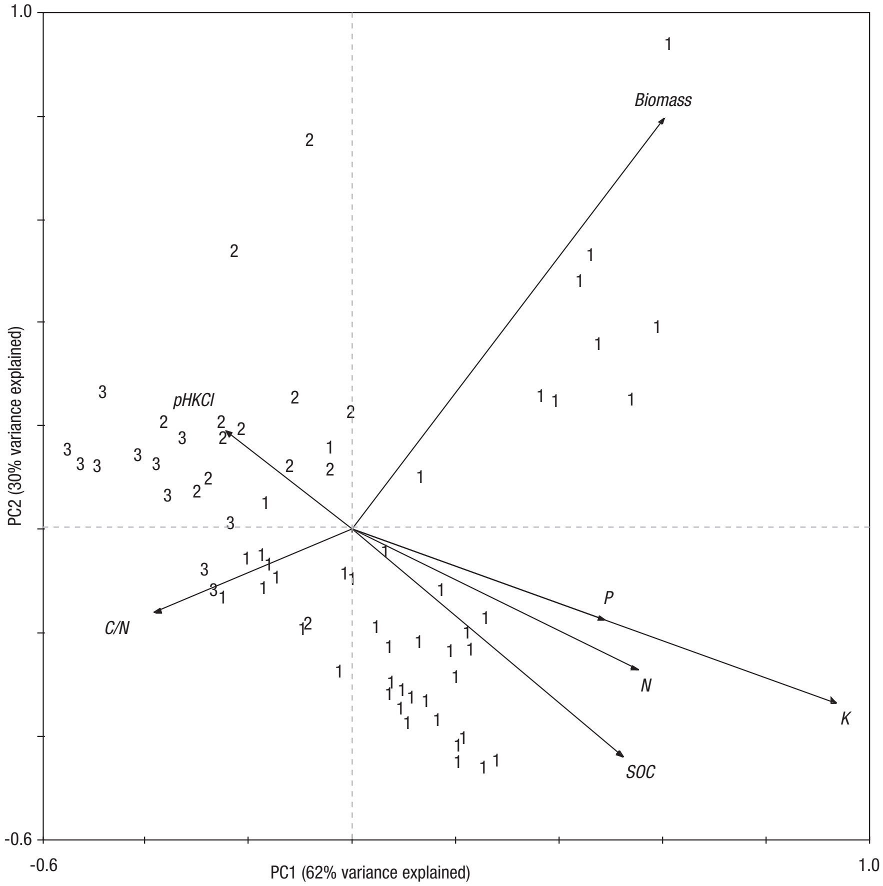

Figure 6. PCA biplot (varimax rotation) for the different soil variables studied (0-5 cm) and herbaceous biomass. Where: 1: *Q. pyrenaica;* 2: *Q. suber;* 3: *Q. rotundifolia;* C/N = relation C/N. SOC: soil organic carbon. P: available soil phosphorus. K: available soil potassium. N: total soil nitrogen. pH: pH-KCl. Biomass: herbaceous biomass.

Regarding to vertical distribution of macronutrients for plants (N, P and K), concentrations were higher in the top 5-cm soil layer and decreased down the soil profile in the three ecosystems studied. These results support the prediction that the most limiting nutrients for plants would have the shallowest distributions (Jobbágy & Jackson, 2001). In the case of vertical distribution of SOC content, it is known that soil-buffering capacity may reduce the effects of environmental variables (*e.g.* temperature and moisture) on SOC content in deep soil layers. Authors such as Jobbágy & Jackson (2000), who analysed more than 2,700 worldwide distributed soil profiles, found evidence suggesting that the vertical distribution of SOC is conditioned by the root distribution along the profiles. It is known that litter, dead materials, and biological activity accumulate at the soil surface, leading to the formation of soil organic matter (Melillo *et al.,* 1989), and hence to organic carbon contents in the top soil layer (Jobbágy & Jackson, 2000).

On the other hand, the results obtained showed the existence of a fertility gradient among the three ecosystems: *Q. pyrenaica* > *Q.suber* > *Q. rotundifolia.* Thus, *Q. rotundifolia* ecosystems would be found in nutrient poor soils, in other words, in less favoured zones. Cools *et al.* (2013) identified tree species as the major factor explaining C/N ratios in European forest. Also, *Quercus* sp. showed an ample range of C/N ratio distributions; the deciduous oak had low C/N ratios while evergreen oak (*Q. rotundifolia* and *Q. suber*) had high C/N ratios. The authors also found that forest of *Q. pyrenaica*, oak specie with intermediate characteristics between the Eurosiberian and the more sclerophyllous Mediterranean species, showed intermediate C/N ratios. Our results agree with these authors for *Q. pyrenaica* and *Q. rotundifolia.* However, in the case of *Q. suber,* our results are not consistent with the mentioned authors, which could be explained by the different scales of these studies (European *vs.* Northeast of Portugal). On the other hand, it is known that plant species differ in their ability to modify soil properties (Vinton & Burke, 1995, Cornelissen *et al*., 1999). These changes may be due, besides climate and edaphic properties, to the growth form, life cycle, and chemical properties that can significantly affect the decomposition of soil organic matter and nutrient dynamics (Hooper and Vitousek, 1998; Carrera *et al.,* 2009). The high C/N ratio found in *Q. rotundifolia* ecosystems (> 15) would result in a significant reduction of biological activity and, therefore lower rates of mineralization. This situation, and the fact that *Q. rotundifolia* ecosystems present higher canopy density (greater constraints of light) and lower soil nutrient content than *Q. suber* ecosystems could explain the low herbaceous biomass production found under *Q. rotundifolia*. The higher herbaceous biomass found in *Q.pyrenaica* and *Q.suber* ecosystems (almost twice that found under *Q. rotundifolia*) also contributes positively to higher soil nutrient contents. It is known that plants with rapid growth such as grasses show a faster rate of decomposition, due their high concentrations of N and low concentrations of secondary compounds (Carrera *et al.,* 2009).

It is known that slow-growing species as evergreen sclerophyllous can incorporate significant quantities of nutrients and soil organic matter in the soil (Gallardo, 2003; Moreno *et al.,* 2007), as well as a high concentration of secondary components (Aerts and Chapin, 2000; Satti *et al.,* 2003). In these situations, decomposition rate is very slow reflecting oligotrophic conditions in the case of *Q. rotundifolia* ecosystems.

Unlike the P and K, N dynamics in soil is not regulated by a chemical equilibrium, but primarily by biological processes, derived from soil biological activity. Thus, growth, productivity, and nutrient balance can mainly depend on the composition and soil microbial activity (Salazar *et al*., 2011), which in turn is influenced by weather conditions directly through moisture and soil temperature (Ley *et al*., 2004; Nielsen *et al*., 2009). Aponte *et al.* (2012, 2010) compared soil development under *Quercus. canariensis* (marcescent) with that under *Q. suber*. They found higher N and SOC in soils developed under marcescent species, such as *Q. pyrenaica* in our study Furthermore, the higher nutrient concentration in *Quercus* sp. is present in the leaves (Salazar *et al.,* 2011). The amount of leaf nutrients is of great importance in the case of *Q. pyrenaica* (marcescent) because the leaves are subject to annual shedding cycles, through which leaf biomass, and therefore nutrients, returns to the soil (Gallego *et al.,* 1993) and therefore nutrients. Moreover, it is known that litter under *Q. ilex* and *Q. suber* has a very slow decomposition rate, resulting in thick, complex, and structured humus, which increases the soil binding capability for nutrients (Alarcón-Gutiérrez *et al,* 2009)

Conclusions

This study suggests that in Northeast of Portugal there is a pattern of *Quercus* sp. distribution that correlates with different soil characteristics by soil characteristics. *Q. pyrenaica* ecosystems were found in more favoured areas (mesic conditions); *Q. rotundifolia* developed in nutrient-poor soils (oligotrophic conditions); and *Q. suber* were found in intermediate zones. Future research should be designed to test other factors (climate, forest structure, and management regimens) in a more extensive area that clearly stated the existence of *Quercus* sp. distribution pattern in a relation to soil fertility.

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