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Natural Forests of Oak in NW Spain: Soil Fertility and Main Edaphic Properties

I.J. Díaz-Maroto[1], P. Vila-Lameiro[1], O. Vizoso-Arribe[1],
E. Alañón[2] and M.C. Díaz-Maroto[2]
[1]*Santiago de Compostela University*
[2]*Castilla-La Mancha University*
Spain

1. Introduction

The species of *Quercus* genus dominates a large part of the temperate forests of the Northern hemisphere and in subtropical transition areas. At present, about 400 species are recognized, most of which occur in Mexico and extend all over North America, Europe and most of Asia (Díaz-Maroto et al., 2005). In the Northwest Spain, the climax vegetation that currently covers the largest area is the broad-leaved forest characterized by various oak species (Buide et al., 1998). According to different studies (palynological and dendrochronological studies, principally) these forests were established in the NW Iberian Peninsula between five and seven thousand years ago, after the last glaciation in Quaternary (Guitián, 1995). Historical factors, site conditions, and requirements of the species give rise to different forest types with various floristic compositions and structures (Peterken & Game, 1984). All the forests belong to *Querco-Fagetea* class (Atlantic Province) with the maximum possible degree of evolution, and they would remain in the current state if environmental conditions did not change (Rivas-Martínez, 1987; Rivas-Martínez et al., 2001).

The forests correspond to the following phytosociological associations (Rivas-Martínez, 1987; Díaz & Fernández, 1994; Rivas-Martínez et al., 2001): 1) *Myrtillo-Quercetum roboris* P. Silva, Rozeira & Fontes 1950; 2) *Rusco aculeati-Quercetum roboris* Br.-Bl., P. Silva &Rozeira 1956; 3) *Blechno spicanti-Quercetum roboris* Tx. & Oberdorfer 1958; 4) *Linario triornithophorae-Quercetum petraeae* (Rivas-Martínez, Izco & Costa ex. F. Navarro 1974) F. Prieto & Vázquez 1987; 5) *Luzulo henriquesii-Quercetum petraeae* (F. Prieto & Vázquez 1987) Díaz & F. Prieto 1994; 6) *Linario triornithophorae-Quercetum pyrenaicae* Rivas-Martínez et al., 1984; 7) *Holco molli-Quercetum pyrenaicae* Br.-Bl., P. Silva & Rozeira 1956; 8) *Genisto falcatae-Quercetum pyrenaicae* Rivas-Martínez in Penas & Díaz 1985.

According to EU Directive 92/43/EEC, these forests are habitats of importance to conservation and, consequently, they will be part of Natura Network 2000. For this, their distribution, floristic diversity and main edaphic properties knowledge is essential (Díaz-Maroto et al., 2005, 2006). The surface area covered by oak forest in Northwest Spain has gradually decreased over the historical period, until ours days, with observable forest fragmentation and decrease in species number, similar to other temperate zones (Graae &

Sunde, 2000; Acar et al., 2004). The main reasons for such a decrease were: 1) Land clearing for establishment of crops and pastures; 2) Timber and firewood extraction; 3) Forest fires; 4) Unfortunate silvicultural treatments and, 5) Massive reforestation with pine and eucalyptus, more recently, more and less, since beginning of last century (Guitián, 1995).

Recently, these forests have increased substantially (Direction General of Nature Conservation [DGCONA], 2001, 2003). Native hardwood forests account for approximately 27% (375,922 ha) of the total woodland area of Galicia. *Quercus robur* L. stands cover an area of 187,789 ha, representing almost 14% of total woodland area, and *Quercus pyrenaica* Willd. stands cover an area of 100,504 ha, corresponding to more than 7% of the woodlands. In Asturias, data for genus *Quercus* suggest that these cover 76,871 ha, 7.25% of total woodland area. The future perspectives for these forests are very positive, as data from the first of four Forest National Inventories shows an important increase, nearly of 20% surface area occupied by them in the third Forest National Inventory of start of XXI century.

Soils in study area tend to be acidic, with pH ranging from 6.00 to 4.00, approximately. The high precipitation rate of near to 1500 mm per year, particularly the intensity of rainfall (storms with more than 200 mm rainfall are common) during a continuous period within the annual cycle (Díaz-Maroto & Vila-Lameiro, 2005) is the decisive factor in this territory. In addition, drainage conditions that favour water infiltration into the soil, fast runoff flow, and a temperate temperature regime (Carballeira et al., 1983), allow for soil acidification. Therefore, acidity in soils should not imply low forest site quality, which is based on productivity, growth rates, diversity, overstory vegetation,..., (Díaz-Maroto et al., 2005).

Slightly acidic soils are even more likely to sustain varied forest vegetation than alkaline soils (Hardtle et al., 2005). Soil fertility, expressed as the macronutrient richness, is more relevant than soil pH and physical characteristics (Thomas & Buttner, 1998; Hagen-Thorn et al., 2006). The soils under oak forests that grow on acidic rocks are oligotrophic or mesotrophic, similar to soils under pine and eucalyptus forests (Díaz-Maroto & Vila-Lameiro, 2005). These soils show a high carbon (C)/nitrogen (N) ratio, a very low saturation percentage, and low concentration of exchangeable cations, in mg kg^{-1} [(potassium (K), calcium (Ca) and magnesium (Mg)]. However, phosphorus (P) concentration, in mg kg^{-1}, is high. Always, if these data are compared with the data obtained by other authors in similar soils under oak forests, in general, but, in different areas.

This study aims to contribute to the knowledge of soils under *Quercus* spp., in general, and, *Q. robur*, *Q. pyrenaica* and *Q. petraea*, in particular, to Northwest Iberian Peninsula. Particularly, the aim of present work is to analyze and characterize the edaphic habitat of oak forests in the study area and, also describe their main properties, mainly plant chemistry and nutrition related to soil fertility.

2. Material and methods

2.1 Study area

The study area is located in the Northwest Iberian Peninsula (latitude: 42-44 ºN and longitude: 6-9 ºW). For *Q. robur* and *Q. pyrenaica,* the area covers the whole of Galicia, while for *Q. petraea* (Matt.) Liebl., the area also includes sites of Autonomous Communities of Galicia and Asturias and, the León province (Fig. 1).

This area has a complicated topography, an average altitude higher than 550 meters, and slopes steeper than 20% in half of the surface area. It is a territory with a rich and different lithological composition (Díaz-Maroto et al., 2005, 2006).

The climate is quite varied, but follows a general oceanic pattern with annual rainfall from 600 to more than 3000 mm (Carballeira et al., 1983). The study area was defined and the sampling zones were chosen based on the Forest Map of Spain (Ruiz de la Torre, 1991).

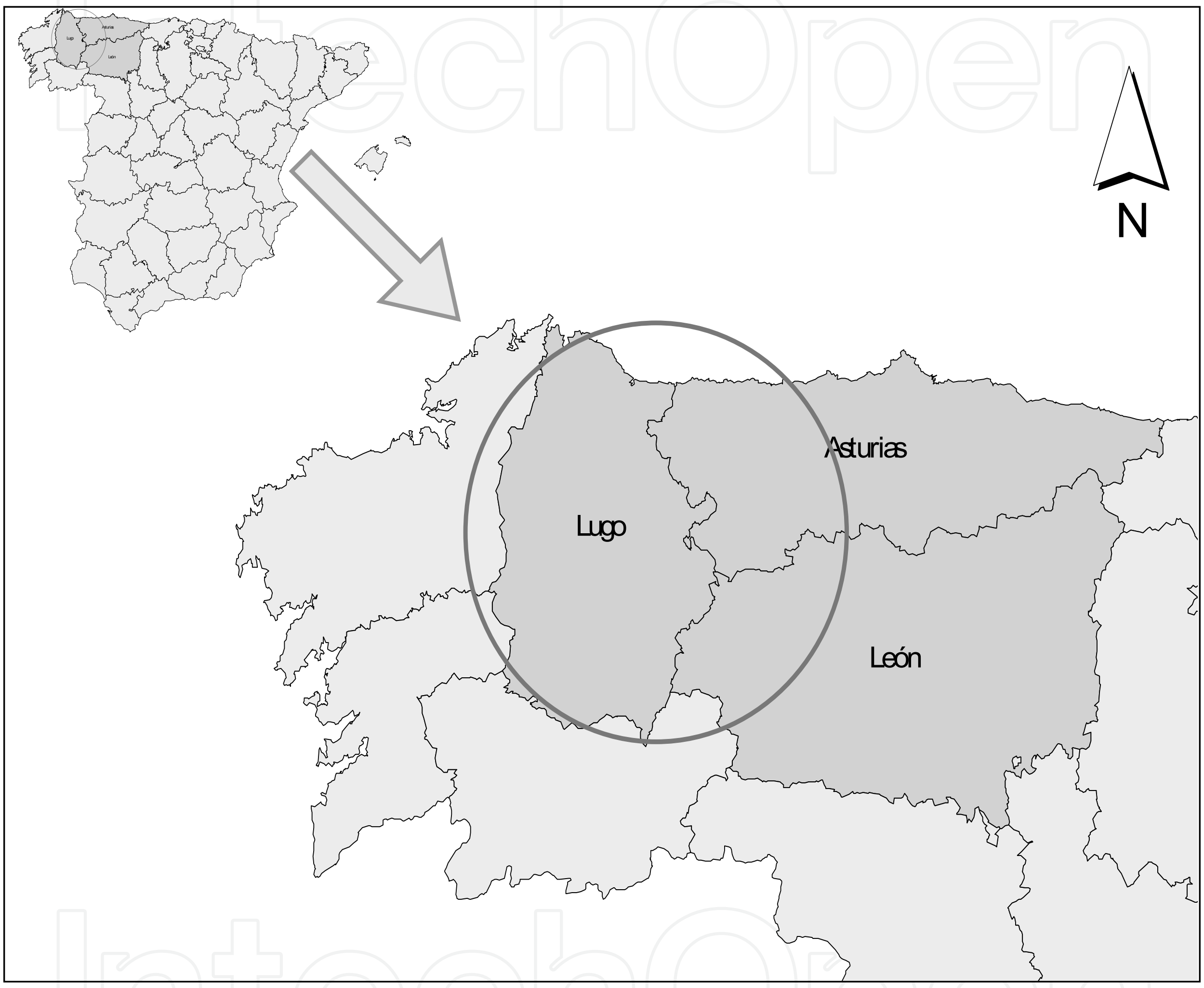


Fig. 1. Location of study area in the Northwest Iberian Peninsula

2.2 Experimental design and analysis techniques used

The number of sampling points was different for each species, but in all cases, we studied the physiographic features (altitude, slope, and orientation), general soil characteristics (parent material, depth, and description of horizons), soil profile, and physicochemical properties (Food and Agriculture Organization [FAO], 1977). To enable description of the soil profiles, a pit approximately 2 m long and 80 cm wide was dug at each site. The horizons were differentiated according to color and/or texture. One sample of each horizon (about 2 kg) was collected, and the following variables were analyzed (FAO, 1977; Klute, 1986): Munsell color, moisture (by oven drying to constant weight at 105 ºC), pH (potentiometrically in water at 1:2.5 soil–solution ratio), total nitrogen (N) (semi-micro-

Kjeldahl method), carbon (Walkley and Black method), organic matter (OM) (multiplying the percent of C by a factor of 1.724), C/N ratio, exchangeable cations [by extraction with 1 N ammonium acetate at pH 7 and quantified by atomic absorption (Ca and Mg) and by emission (K) using a Perkin-Elmer 603 spectrophotometer, Waltham, Mass.] and available P by the Bray and Kurtz method (Bray-1 P).

At each sampling point, soil different parameters were estimated. The parameter total value in the whole soil profile was determined by using a standard weighted mean for Sand (S), Silt (Si), and Clay (Cl). For the rest of studied parameters, the weighted mean was considered by applying the method of Russell & Moore (1968). In the case of surface values, the information from the upper 20 cm of the soil was considered, except when more than one horizon was present at this depth. In that case, it was calculated as a weighted mean (Díaz-Maroto et al., 2005).

2.3 Statistical analysis

Univariate statistics were calculated (Walpole et al., 1999) and the following values were presented for the measured soil parameters: lower limit (LL), parameter minimum value; lower threshold (LT) or 10th percentile; mean (M); upper threshold (UT) or 90th percentile; upper limit (UL), parameter maximum value. Based on these values, the optimal edaphic habitat of the oak forests, in relation to a parameter, can be defined as the interval between UT and LT. This interval is composed by 80% of the sampling points, excluding the areas where the parameter showed the highest and the lowest values, marginal habitats (Díaz-Maroto et al., 2005). The optimal habitat defines the most suitable soil conditions for a particular species, whereas, in the marginal is the condition where some parameter is not adequate so the area has questionable suitability for oak growth (Hardtle et al., 2005).

Normality of the soil parameters was evaluated (Walpole et al., 1999), the result allowed a bivariable correlation analysis by Pearson (normal) or by Spearman's rank (Rozados et al., 2000; Sas Institute Inc. [SAS], 2004) to be applied. When soil parameters were significantly ($p<0.05$) correlated, possible linear relationships between the parameters was studied.

3. Edaphic habitat of oak forests in NW Spain

3.1 Physiographic characteristics of the stands

Most of the oak stands are located in zones with a steep slope or at the thalwegs, due to historical anthropogenic activities in these forests, at low and medium altitude with variable orientations, but shady sites are dominated in *Q. robur* and *Q. petraea*, while sunny sites in *Q. pyrenaica* stands (Díaz-Maroto et al., 2005; Díaz-Maroto & Vila-Lameiro, 2006).

Some stands of *Q. robur* are located in continental influence zones that are relatively distant from their suitable habitat. In these cases, this species is very easily hybridized, with *Q. petraea* and *Q. pyrenaica* (Díaz-Maroto et al., 2006), thus it is complicated to distinguish between these three species in such zones (Rivas-Martínez et al., 2001).

3.2 Parent rock and soil type

The geological material is heterogeneous with rocks from Precambrian and Paleozoic ages, tertiary and quaternary sediments (Ruiz de la Torre, 1991). Siliceous substrates were present in most of the stands, with dominance of granite and schist (Díaz-Maroto & Vila-Lameiro, 2005). Soil depth is elevated, and the presence of loose, fresh, deep soils is especially suitable for *Quercus* spp., in general, and above all for *Q. robur*, because these species has an extensive root system that penetrates very deep into soil (Göransson et al., 2006).

The soils in *Q. robur* stands are mainly Dystric Cambisols (70%), with smaller proportions of the following soil types: Humic Umbrisols (10.26%), Humic Regosols (10.26%), Dystric Regosols (7.70%), and Gleyic Cambisols (2.55%). Dystric Cambisols occurs on all substrate types with an A/Bw/C profile. The Bw horizon is the most characteristic for brownification process, and it can greater than 100 cm (Van de Moortel et al., 1998). The *Q. pyrenaica* stands are mainly established on Umbric Regosols (54%) and, to a lesser extent, on Humic Umbrisols (25.64%), Dystric Cambisols (15.38%), Umbric Leptosols (5.12%), and Gleyic Cambisols (2.56%). Finally, in the study area, *Q. petraea* occurs on less well developed soils than the other oaks, *Q. robur* and *Q. pyrenaica*. More than 75% of the stands occur on Umbric Regosols with an "A" horizon that is usually no deeper than 50 cm.

3.3 Chemical and nutritional properties

3.3.1 *Quercus robur* soils

The main properties of the soils under *Q. robur* forests in NW Spain were characterized. Eleven edaphic parameters (pH, OM, N, C/N ratio, P, K, Ca, Mg, S, Si and Cl) were estimated in 39 soil samples (Table 1).

The parameters that reflect the chemical and biological soil properties (pH, OM, N, and C/N ratio) show average values similar to the values reported as adequate by Castroviejo (1988) and Rozados et al. (2000) for these formations, but, the values obtained for OM are an exception because they are slightly higher than optimal, its average value is equal to 8.64 ± 5.19. According to the acidity scale suggested by Wilde (1946), most soils are to strongly acidic ($4.7 \le pH < 5.5$). Some of them present a value lower than 4 (extremely acidic) or higher than 6 (moderately acidic).

However, the studied soils show satisfactory humification, which is revealed by high values of the C/N ratio (Mansson & Falkengren-Grerup 2003; Hagen-Thorn et al. 2004). The pH of the upper horizons is the most relevant pH in the biological processes (Nornberg et al., 1993). This is because it depends on the residues of the dominant species in the vegetal cover and because the first roots of young plants are developed in the upper layer. The leaching due to rainfall is very important, because it can move dissolved salts down through the soil and cause an overall increase in pH at depth. Therefore, the analysis of the data obtained in the topsoil, the upper 20 cm of the soil, would mean a low mineralization rate due to the relatively high OM content, the low pH, and the C/N ratio near 15 (Nornberg et al., 1993; Neirynck et al., 2000; Landgraf et al., 2006) (Table 1).

Nutrient concentration is considered in the low or medium category (for instance, the exchangeable K concentration is only 73 mg kg^{-1}) as compared with other forests in the study area, except the Bray-P concentration, which is considerably higher (21.8 mg kg^{-1} versus 1–6 mg kg^{-1}) (Castroviejo, 1988; Rozados et al, 2000).

The physical characteristics values are close to those reported by Castroviejo (1988) (Table 1). These data can be influenced by the steep slope on which the stands are located. Moreover, slight erosion occurs despite the vegetation cover and the soil protection by the extensive root system of *Q. robur*. This erosion leads to a gradual loss of the fine fractions, which are dragged downhill. The particle-size distribution of the soil determines the physical properties and influences the soil acidity (Van de Moortel et al., 1998).

Parameter	Average ± SD	CV %	Max-Min
pH	4.85 ± 0.46	9	6.15–3.92
OM (g kg^{-1})	8.64 ± 5.19	60	23.31–1.04
N (g kg^{-1})	0.307 ± 0.178	58	0.793–0.04
C/N	14.6 ± 4.5	31	29.6–6.9
P (mg kg^{-1})	21.8 ± 28.9	133	117.2–0.4
K (mg kg^{-1})	73 ± 40	55	231–9
Ca (mg kg^{-1})	120 ± 216	180	1297–3
Mg (mg kg^{-1})	29 ± 21	72	85–0
S (g kg^{-1})	66 ± 21	31	89–14
Si (g kg^{-1})	23 ± 20	92	85–7
Cl (g kg^{-1})	11 ± 5	45	27–1

Table 1. Average, standard deviation (±SD), coefficient of variation (CV), and the range of values (Max-Min) of soil parameters (n=39) in *Q. robur* forests in NW Spain

3.3.2 *Quercus petraea* soils

Soils under natural forests of *Q. petraea* in northwest Spain were characterized in an inventory of 52 stands in which the chemical properties and nutrient contents were determined by analyzing ten edaphic parameters (Table 2). Siliceous substrates (mainly slates) of high pH predominated in all stands. Umbric Regosols occurred in almost 80% of the stands, indicating that the soils were less well developed than those under *Q. robur*. The C/N ratio was particularly high and the OM content was less than 10 mg kg^{-1}.

In general, the soils are very acidic, with pH values that present little variation. The high rainfall in a large part of study area accentuates the acid character of the soils.

Although the mean value of the C/N ratio was close to 18, the low pH values do not allow adequate humification conditions (Mansson & Falkengren-Grerup, 2003). The rate of mineralization may be considered as slow, as analysis of the data corresponding to the topsoil shows that the mean content of OM is 10.09, the pH is 4.59 and the C/N ratio 17.92.

The concentrations of all macronutrients, except phosphorus, were higher than in the soils under pedunculate oak, and those of phosphorus and calcium were the most variable. The contents of base cations, fine earth (FE) and total gravel (GRA) were high in the optimal habitat (West of Galicia, East of Asturias and NW León).

Parameter	Average ± SD	CV %	Max-Min
pH	4.72 ± 0.36	8	5.65–4.23
OM (g kg^{-1})	7.82 ± 4.03	52	19.82–1.82
N (g kg^{-1})	0.250 ± 0.100	43	0.540–0.070
C/N	17.9 ± 3.8	21	25.1–8.9
P (mg kg^{-1})	9.5 ± 7.5	79	24.8–0.9
K (mg kg^{-1})	90.0 ± 52.9	59	275–26
Ca (mg kg^{-1})	203 ± 276	136	1135–13
Mg (mg kg^{-1})	46 ± 42	93	165–4
FE (g kg^{-1})	44 ± 11	26	67–18
GRA (g kg^{-1})	56 ± 12	20	82–33

Table 2. Average, standard deviation (±SD), coefficient of variation (CV), and the range of values (Max-Min) of soil parameters (n=52) in natural forests of *Q. petraea* in NW Spain

3.3.3 *Quercus pyrenaica* soils

The soils where natural stands of "rebollo" oak (*Quercus pyrenaica* Willd.) occur in NW Iberian Peninsula were characterized in an inventory of 40 different stands; the main properties of the soils were also determined by analyzing ten different edaphic parameters (Table 3).

The substrates are principally siliceous, with schist and quartzite predominating; the dominant textural composition is sandy-loam with small pockets of clay-loam and sandy textures. Soils are mainly the Umbric Regosol-type (about 60% of soils), although other soil types like Cambisols are found in areas with a soil depth greater than 80 cm and, normally located in thalwegs.

The values of the parameters that reflect the chemical properties of the soil, i.e., the pH, organic matter, nitrogen, and C/N ratio, are similar to those reported as suitable for *Quercus* spp. forests, in general, to the study area. However, the concentrations of macronutrients, except for phosphorous, were higher than in soils under *Q. robur* (Table 3) (Díaz-Maroto et al., 2006).

Parameter	Average ± SD	CV %	Max-Min
pH	5.19 ± 0.29	6	6.13–4.30
OM (g kg^{-1})	4.10 ± 2.69	66	11.30–1.01
N (g kg^{-1})	0.151 ± 0.118	78	0.555–0.024
C/N	18.4 ± 4.3	27	31.9–10.1
P (mg kg^{-1})	9.4 ± 13.3	140	71.6–0.8
K (mg kg^{-1})	101.4 ± 61.9	59	281–22
Ca (mg kg^{-1})	154 ± 223	144	935–0.1
Mg (mg kg^{-1})	61 ± 62	102	237–4
FE (g kg^{-1})	59 ± 16	27	88–28
GRA (g kg^{-1})	41 ± 16	39	72–12

Table 3. Average, standard deviation (±SD), coefficient of variation (CV), and the range of values (Max-Min) of soil parameters (n=40) in natural forests of *Q. pyrenaica* in NW Spain

3.4 Characterization of edaphic habitat of *Quercus robur* forests

The optimal habitat of *Q. robur* forests, which was considered statistically to fall between the 10th and 90th percentiles (80% of plots ≈ sampling points), allows determination of the most suitable ecological range, and may be considered as the minimum potential area of the species in the study area. Marginal habitats are defined as those between the limits of the optimal habitat and the absolute extremes; they include 20% of plots and provide an estimation of the species adjustment to site conditions according to parameters values that remain outside the optimal habitat, since not all of them have the same level of significance as biotope descriptors (Fig. 2) (Díaz-Maroto et al., 2005).

In *Q. robur* stands, 80% of soils are Cambisols, so we calculated the optimal and marginal edaphic habitats for this soil-type only (Fig.2).

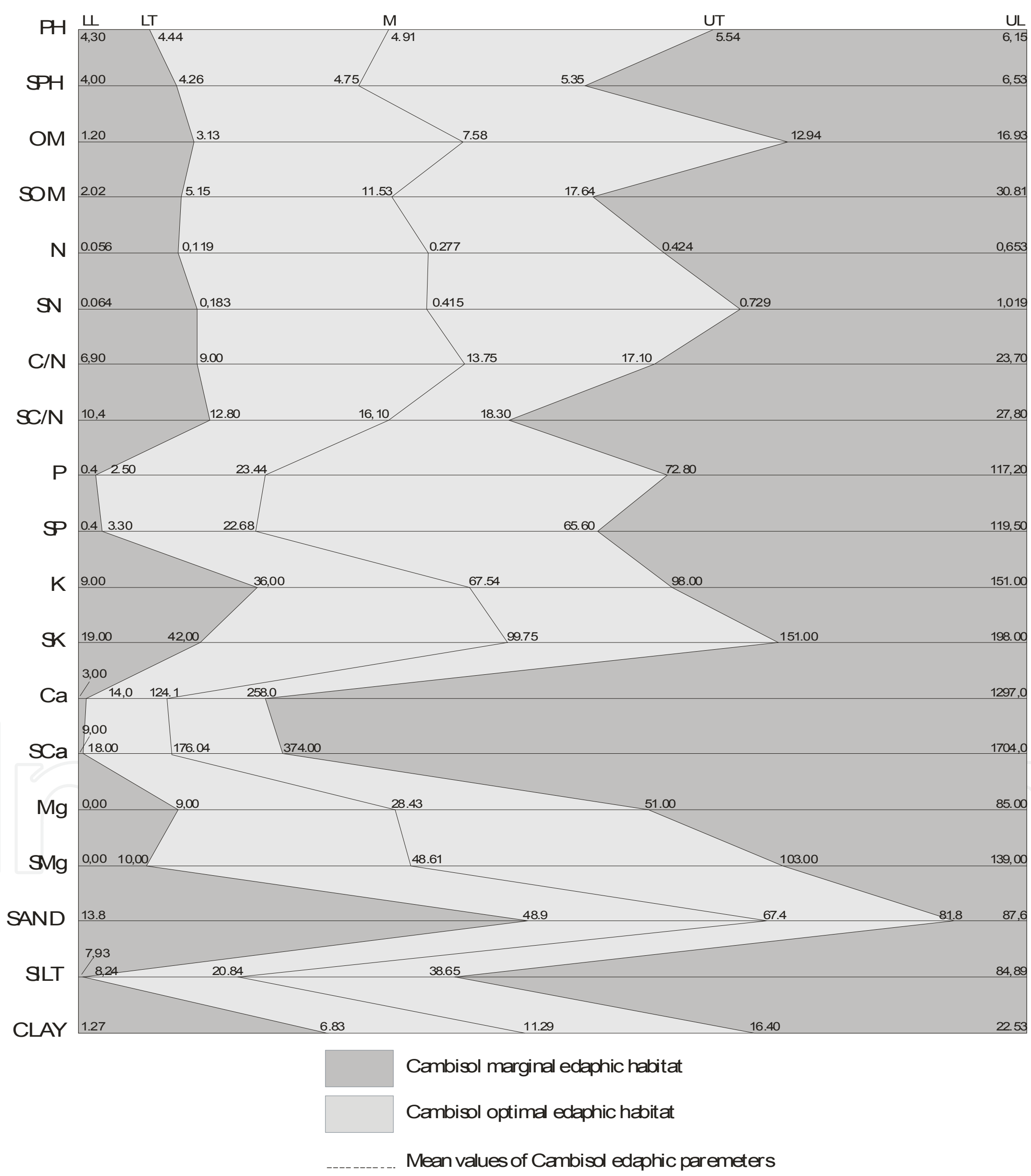


Fig. 2. Optimal and marginal edaphic habitats in Cambisols soils (*Q. robur* forests in Northwest Iberian Peninsula)

The wideness of the upper marginal intervals (upper threshold and limit) for Ca and SCa in the Cambisols edaphic habitat (Fig. 2), suggests that these parameters are not good indicators of the upper limit of optimal habitat (Díaz-Maroto et al., 2005, 2006):

- The soils located within the optimal edaphic habitat (Fig. 2) are mainly strongly acidic, with an average pH value equal to 4.91 for the whole profile, and equal to 4.75 for the topsoil. Within the marginal habitat, there are moderately acidic soils, with pH higher than 5.5 (Wilde, 1946). OM content is variable, with a minimum that does not reach 2 mg kg^{-1} for the whole profile and corresponds to the lower threshold of the edaphic habitat (Fig. 2), although the average is 7.58 mg kg^{-1} for the whole profile and 11.53 mg kg^{-1} for the topsoil, which characterizes a mull-moder humus (Camps et al., 2004).
- Optimal edaphic habitat shows low content of exchangeable cations (Fig. 2). However, the P has a considerably high value, with an average of 24 mg kg^{-1} for the whole profile.
- The soils have an elevated percentage of sand with an optimal habitat that ranges between 49-82 mg kg^{-1} and an average value of 67 mg kg^{-1}. Conversely, the clay proportion reaches a maximum of nearly 23 mg kg^{-1}, with an average of 11 mg kg^{-1}, because the substrates overlie parent material that releases a greater proportion of sand than clay during weathering (Castroviejo, 1988).

3.5 Characterization of edaphic habitat of *Quercus pyrenaica* forests

The same methodology was followed to distinguish the optimal and marginal edaphic habitats of *Quercus pyrenaica* forests in NW Spain. In this case, as about 60% of soils are Umbric Regosols. In the Fig. 3, we only calculated the optimal and marginal edaphic habitats to this soil-type. Also, it can be seen that certain edaphic parameters are not suitable for fixing the upper value of the optimal habitat, given the wide range of upper marginal values: OM, total and surface N, total and surface Mn and surface Ni as, to a lesser extent, total and surface P. The most notable characteristics were as follows (Fig. 3):

- The pH values of the optimal habitat ranged between 4.89 and 5.38, corresponding to strongly to moderately acidic soils (Wilde, 1946). In marginal habitats soil pH was less than 4.30 or greater than 6.13 (Fig. 3).
- The OM content was low and for optimal habitats ranged between 1.39-6.06 mg kg^{-1} for the total profile and between 1.89-7.72 mg kg^{-1} for the upper 20 cm (Fig. 3). The optimal values of the C/N varied widely and indicate adequate humification (Mansson & Falkengren-Grerup, 2003) and a normal rate of mineralization.
- The optimal habitat showed higher contents of exchangeable base cations than in the soils under *Quercus robur* within the study area. However, the concentration of P was lower, probably because the stands correspond to mature forests that had not undergone changes in land use (Díaz-Maroto et al., 2005).
- Wide suitable ranges of fine earth and total gravel contents were also apparent.

3.6 Characterization of edaphic habitat of *Quercus petraea* forests

Finally, the same methodology was followed to distinguish the optimal and marginal edaphic habitats of *Q. petraea* forests in NW Spain. In this species, more than 75% of the stands also occur on Umbric Regosols. Then, we analized the optimal and marginal edaphic habitats to this soil-type (Fig. 4). Parameters related to Ca concentration are not suitable for determining the edaphic habitat of sessile oak in northwest Spain, given the wide range of upper marginal values (Fig. 4):

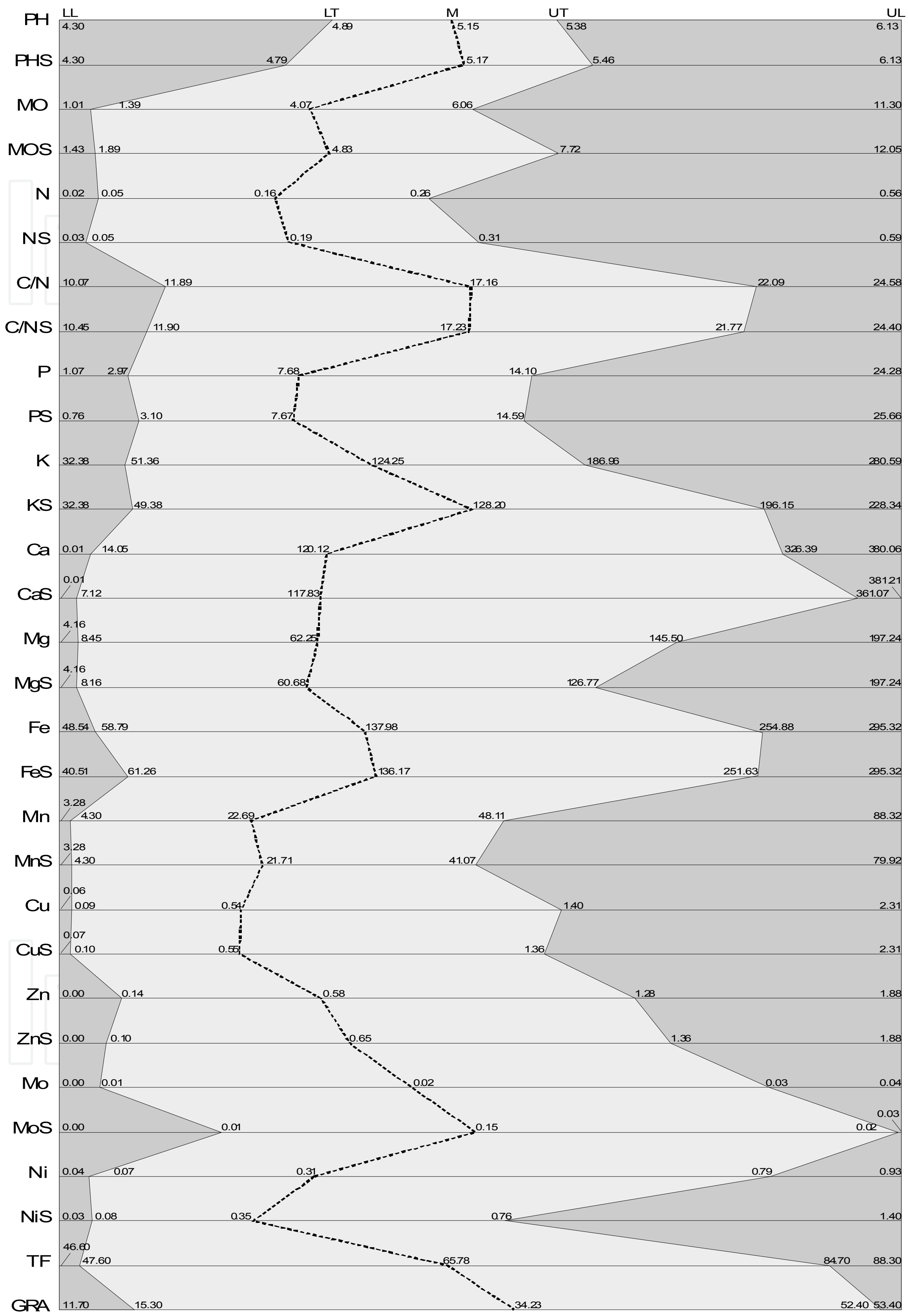


Fig. 3. Optimal and marginal edaphic habitats in Umbric Regosols (*Q. pyrenaica* forests in Northwest Iberian Peninsula)

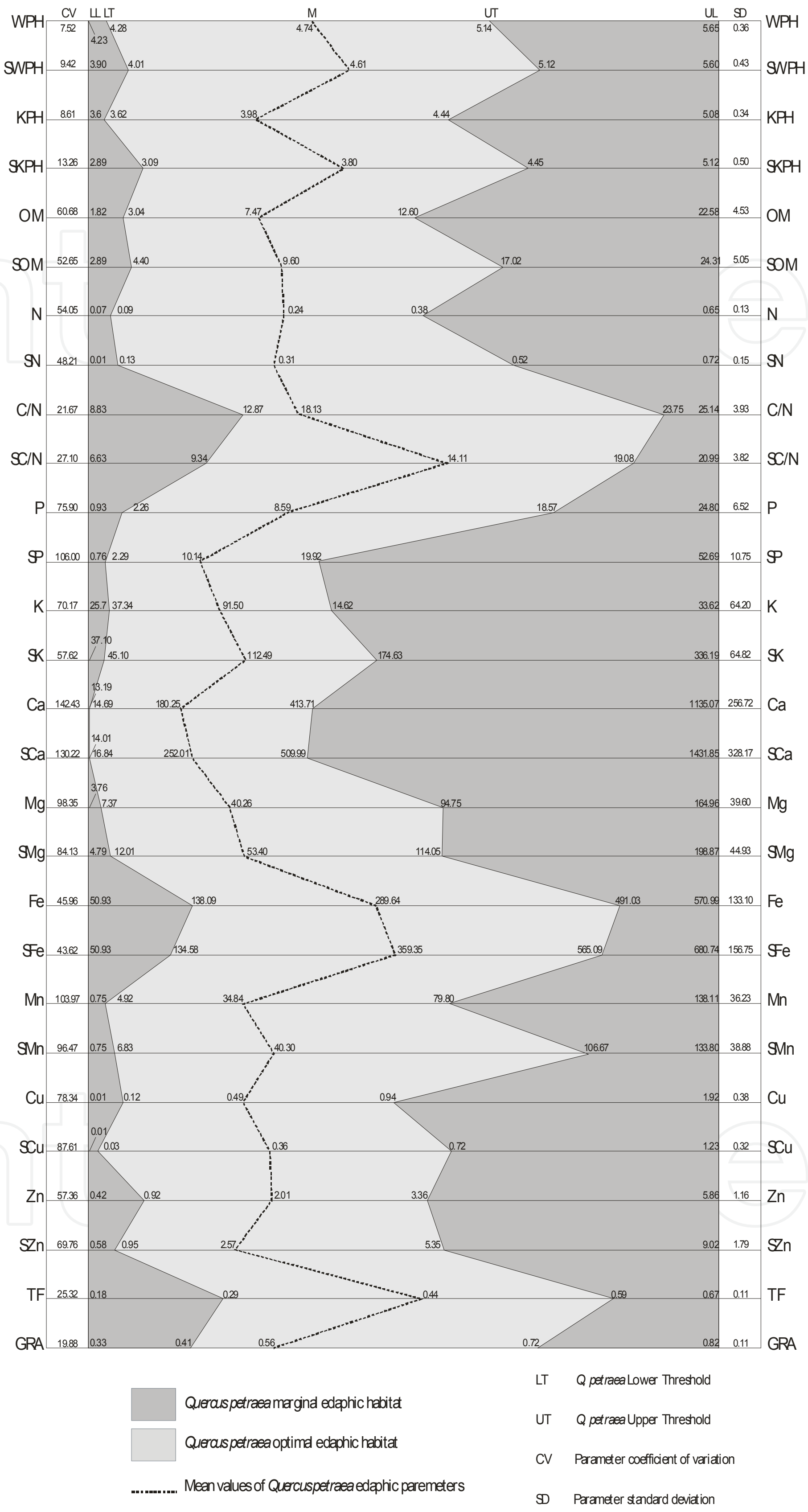


Fig. 4. Optimal and marginal edaphic habitats in Umbric Regosols (*Q. petraea* forests in Northwest Iberian Peninsula)

- The total pH in H_2O (WPH) values of the optimal habitat ranged between 4.28 and 5.14, corresponding to moderately or even extremely acidic soils (Wilde, 1946). In marginal habitats soil pH was less than 4.23 or greater than 5.65 (Fig. 4). These values varied little and, principally, the surface pH in H_2O (SWPH), partly due to a high rainfall that does not allow adequate humification.
- The OM matter content was intermediate (Hagen-Thorn et al., 2004) and for the optimal habitat ranged between 3.04 and 12.60 mg kg^{-1} for the total profile, and between 4.40 and 17.02 mg kg^{-1} for the topsoil (Fig. 4), giving rise to moder type humus with a slow rate of mineralization, in spite of suitable C/N ratio of more than 18 (Mansson & Falkengren-Grerup, 2003).
- The optimal habitat showed higher contents of base cations, except P, than in *Q. robur* soils (Díaz-Maroto & Vila-Lameiro, 2005).
- The concentration of the micronutrient Mn varied widely (4.92-79.80 mg kg^{-1}). Copper was the micronutrient present at lowest concentrations, with an average value of less than 0.5 mg kg^{-1} (Fig. 4).
- The total fine earth (FE) and total gravel (GRA) contents also varied widely, 29-59 mg kg^{-1} and 41-72 mg kg^{-1}, respectively.

4. Conclusions

Most of the studied soils correspond to stands located in areas with a complicated topography, a medium altitude and variable orientation. The substrates are mainly siliceous, with sandy-loam or loamy textures dominating. Soil depth is greater than 100 cm in more than half of the stands, although some stands can also develop on rocky substrates, mainly granite and schist.

Within the study area, *Quercus robur* is located on more developed soils than the other two species, principally, Dystric cambisol, with an A/Bw/C profile. *Q. pyrenaica* occurs predominately on Regosols and *Q. petraea* is present on poorly developed soils, with more than 75% of stands occurring on Umbric Regosols with an "A" horizon that is usually no deeper than 50 cm.

The chemical parameters of *Q. robur* soils (pH, OM, N and C/N ratio), show average values similar to those considered optimal for this species, except for the OM, which had higher values. They are strongly acidic ($4.7 \leq pH < 5.5$), however, they have a good humification. The macronutrient content can be considered low or medium, except for P, since soils develop on substrates that are poor in base cations.

Organic matter, pH and clay tended to be significantly ($p<0.05$) correlated with other soil parameters, and with each other. A positive linear relationship ($p<0.001$) was noted between pH and Bray-P concentration, suggesting that many oak forests are located on abandoned agricultural land. In these stands, the high P content increases with the value of pH. Clay content shows significant differences for surface and total OM and nitrogen.

The analysis of edaphic habitat by soil type does not differ greatly from the results of the stands considered as a whole. *Q. robur* forests show a tendency to occur on the best soils, cambisol type, and not on poorer soils, where the occurrence of this species is often due to anthropogenic pressure.

In *Quercus pyrenaica* soils, the pH values were quite homogeneous, giving rise to very acidic soils, although these were not conducive conditions for humification, as verified by the C/N ratios and the presence of moder or mull type humus. Mineralization occurs at a normal rate and the chemical-nutritive characteristics are suitable for "rebollo" oak forests. Although these forests are developed on parent rock, which are poor in base cations, all studied macronutrients, except P, were present at higher concentrations than in soils under *Q. robur*, probably because the stands correspond to mature forests that had not undergone changes in land use.

The statistical analyses reveal that Ca and Mg contribute to the greater number of significant relationships. The influence of the physical properties (fine earth and gravel) has a smaller importance.

Finally, in *Q. petraea* soils, the pH values were also quite homogeneous, giving rise to very acidic soils, although, in this case, this did not allow adequate conditions for humification too, giving rise to moder type humus. Mineralization occurs slowly and the biological-chemical characteristics are suitable for sessile oak forests. Although these soils are developed on substrates that are poor in base cations, all macronutrients except P were also present at higher concentrations than in soils under *Q. robur*, probably because no changes in soil use have taken place, and also because of the loamy textures of the substrates.

Analysis of the edaphic habitat reveals that most highly developed forest soils, within the study area, correspond mainly with *Quercus robur*, and even *Q. pyrenaica*. The optimal habitat in *Q. petraea* stands shows a wide range of values for base cations, pH and physical parameters (FE and GRA).

5. References

Acar, C.; Acar, H. & Altun, L. (2004). The diversity of ground cover species in rocky, roadside and forest habitats in Trabzon (North-Eastern Turkey). *Biologia*, Vol. 59, No.4, (July 2004), pp. 477–491, ISSN 0006-3088

Buide, M.L.; Sánchez, J.M. & Guitián, J. (1998). Ecological characteristics of the flora of the Northwest Iberian Peninsula. *Plant Ecology*, Vol. 135, No.1, (March 1998), pp. 1–8, ISSN 1385-0237

Camps M.; Mourenza C.; Álvarez E. & Macías, F. (2004). Influence of parent material and soil type on the root chemistry of forest species grown on acid soils. *Forest Ecology and Management*, Vol. 193, No.3, (June 2004), pp. 307-320, ISSN 0378-1127

Carballeira, A.; Devesa, C.; Retuerto, R.; Santillan, E. & Ucieda F. (1983). *Galicia Bioclimatology*. Xunta de Galicia-Fundación Barrie de la Maza, ISBN 84-85728-27-0, Santiago de Compostela (A Coruña, Spain)

Castroviejo, M. (1988). *Phytoecology of the Buio Forests and Sierra del Xistral (Lugo)*. Xunta de Galicia-Fundacion Barrie de la Maza, ISBN 978-84-96713-90-1, Santiago de Compostela (A Coruña, Spain)

Direction General of Nature Conservation [DGCONA] (2001). *Tercer Inventario Forestal Nacional. Galicia*. Ministerio de Medio Ambiente, ISBN 978-84-80144-30-8, Madrid, Spain

Direction General of Nature Conservation [DGCONA] (2001). *Tercer Inventario Forestal Nacional. Principado de Asturias*. Ministerio de Medio Ambiente, ISBN 978-84-80144-30-8, Madrid, Spain

Díaz T.E. & Fernández J.A., (1994). La vegetación de Asturias. *Itinera Geobotanica*, Vol. 8, pp. 243–528, ISSN 15771814

Díaz-Maroto, I.J. & Vila-Lameiro, P. (2005). Seasonal evolution of the chemical properties and macro nutrients of the soil in natural strands of *Quercus robur* L. in Galicia, Spain. *Agrochimica*, Vol. 49, No.5-6, (Sep-Dec 2005), pp. 201–211, ISSN 0002-1857

Díaz-Maroto, I.J. & Vila-Lameiro, P. (2006). Litter production and composition in natural stands of *Quercus robur* L., Galicia, Spain. *Polish Journal of Ecology*, Vol. 54, No.3, (September 2006), pp. 429–439, ISSN 1505-2249

Díaz-Maroto, I.J.; Vila-Lameiro, P. & Silva-Pando, F.J. (2005). Autecology of oaks (*Quercus robur* L.) in Galicia (Spain). *Annals of Forest Sciences*, Vol.62, No.7, (November 2005), pp. 737–749, ISSN 1286-4560

Díaz-Maroto, I.J.; Fernández-Parajes, J. & Vila-Lameiro, P. (2006). Autecology of rebollo oak (*Quercus pyrenaica* Willd.) in Galicia (Spain). *Annals of Forest Sciences*, Vol. 63, No.2, (March 2006), pp. 157–167, ISSN 1286-4560

Food and Agriculture [FAO] 1977. *Soil Profiles Description Guide*. FAO, ISBN 92-5-100508-7, Rome, Italy

Guitián, L. (1995). Origen y evolución de la cubierta forestal de Galicia. Ph.D. Thesis, University of Santiago de Compostela, Spain.

Graae, B.J. & Sunde, P.B. (2000). The impact of forest continuity and management on forest floor vegetation evaluated by species traits. *Ecography*, Vol. 23, No.6, (December 2000), pp. 720–731, ISSN 0906-7590

Göransson, H.; Rosengren, U.; Wallander, H.; Fransson, A.M. & Thelin, G. (2006). Nutrient acquisition from different soil depths by pedunculate oak. *Trees–Structure and Function*, Vol. 20, No.3, (May 2003), pp. 292–298, ISSN 0931-1890

Hagen-Thorn, A.; Callesen, I.; Armolaitis, K. & Nihlgard, B. (2004). The impact of six European tree species on the chemistry of mineral topsoil in forest plantations on former agricultural land. *Forest Ecology and Management*, Vol. 195, No.3, (July 2004), pp. 373–384, ISSN 1286-4560

Hagen-Thorn, A.; Varnagiryte, I.; Nihlgard, B. & Armolaitis, K. (2006). Autumn nutrient resorption and losses in four deciduous forest tree species. *Forest Ecology and Management*, Vol. 228, No.1-3, (June 2006), pp. 33–39, ISSN 1286-4560

Hardtle, W.; Oheimb, G. von & Westphal, C. (2005). Relationships the vegetation and soil conditions in beech and beech-oak forests of northern Germany. *Plant Ecology*, Vol. 177, No.1, (March 2005), pp. 113–124, ISSN 1385-0237

Klute, A. (1986). *Methods of Soil Analyses* (2nd ed.), Madison Wisc.: American Society of Agronomy, ISBN 089118841X, Madison (Wisconsin, USA)

Landgraf, D.; Leinweber, P. & Makeschin, F. (2006). Cold and hot water-extractable organic matter as indicators of litter decomposition in forest soils. *Journal of Plant Nutrition and Soil Science*, Vol. 169, No.1, (February 2006), pp. 76–82, ISSN 1436-8730

Neirynck, J.; Mirtcheva, S.; Sioen, G. & Lust, N. (2000). Impact of *Tilia platyphyllos* Scop., *Fraxinus excelsior* L., *Acer pseudoplatanus* L., *Quercus robur* L., and *Fagus sylvatica* L. on earthworm biomass and physico-chemical properties of a loamy topsoil. *Forest Ecology and Management*, Vol. 133, No.3, (August 2000), pp. 275–286, ISSN 1286-4560

Mansson, K.F. & Falkengren-Grerup, U. (2003). The effect of N deposition on nitrification, carbon and N mineralization and litter C:N ratios in oak (*Q. robur*) forests. *Forest Ecology and Management*, Vol. 179, No.1-3, (July 2003), pp. 455–467, ISSN 1286-4560

Nornberg, P.; Sloth, L. & Nielsen, K.E. (1993). Rapid changes of sandy soils caused by vegetation changes. *Canadian Journal of Soil Science*, Vol. 73, No.4, (November 1993), pp. 459–468, ISSN 0008-4271

Peterken, G.F. & Game, M. (1984). Historical factors affecting the number and distribution of vascular plant-species in the Central Lincolnshire woodlands. *Journal of Ecology*, Vol. 72, No.1, (January 2004), pp. 155–182, ISSN 0022-0477

Rivas-Martínez, S. (1987). *Memoria y mapas de series de vegetación de España. 1:400.000* (ICONA), ISBN 84-85496-25-6, Madrid, Spain.

Rivas-Martínez, S.; Fernández, F.; Loidi, J.; Lousã, M. & Penas, A. (2001). Syntaxonomical checklist of vascular plants communities of Spain and Portugal to association level. *Itinera Geobotanica*, Vol. 14, pp. 5–341, ISSN 15771814

Rozados, M.J.; Silva-Pando, F.J.; Alonso, M. & Ignacio, M.F. (2000). Edaphic and foliar parameters in a *Quercus robur* L. forest in Galicia (Spain). *Investigación Agraria: Sistemas y Recursos Forestales*, Vol. 9, No.1, (March 2000), pp. 17–30, ISSN 1131-7965

Ruiz de la Torre, J. (1991). *Forest Map of Spain* (General Direction of Nature Conservation, Environmental Ministry), ISBN 978-84-80144-22-3, Madrid, Spain

Russell, J.S. & Moore, A.W. (1968). Comparison of different depth weightings in the numerical analysis of anisotropic soil profile data. Proceedings of the 9th International Congress on Soil Science. International Society of Soil Science and Angus and Robertson, Adelaide (Australia), August, 1968.

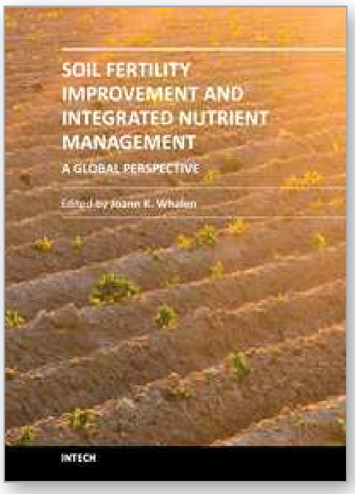
Sas Institute Inc. (2004). *SAS/STATw 9.1. User's guide* (SAS Institute Inc), ISBN 1590475135, Cary (North Carolina, USA)

Thomas, F.M. & Buttner, G. (1998). Nutrient relations in healthy and damaged stands of mature oaks on clayey soils: Two case studies in Northwestern Germany. *Forest Ecology and Management*, Vol. 108, No.3, (August 1998), pp. 301–319, ISSN 1286-4560

Van de Moortel, R.; Rampelberg, S. & Deckers, J. (1998). Condition of *Quercus robur* L. along a natural Luvisol microtoposequence on loess in Central Belgium. *Soil Use Management*, Vol. 14, No.3, (September 1998), pp. 184–186, ISSN 0266-0032

Walpole, R.E.; Myers, R.H. & Myers, S.L. (1999). *Probability and statistics for engineers* (Prentice Hall), ISBN 978-03-21694-98-0, México, D.F. (México)

Wilde, S.A. (1946). Forest soils and forest growth (Chronica Botanica Comp.), Waltham (Massachusetts, USA)



Soil Fertility Improvement and Integrated Nutrient Management - A Global Perspective
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Soil Fertility Improvement and Integrated Nutrient Management: A Global Perspective presents 15 invited chapters written by leading soil fertility experts. The book is organized around three themes. The first theme is Soil Mapping and Soil Fertility Testing, describing spatial heterogeneity in soil nutrients within natural and managed ecosystems, as well as up-to-date soil testing methods and information on how soil fertility indicators respond to agricultural practices. The second theme, Organic and Inorganic Amendments for Soil Fertility Improvement, describes fertilizing materials that provide important amounts of essential nutrients for plants.The third theme, Integrated Nutrient Management Planning: Case Studies From Central Europe, South America, and Africa, highlights the principles of integrated nutrient management. Additionally, it gives case studies explaining how this approach has been implemented successfully across large geographic regions, and at local scales, to improve the productivity of staple crops and forages.