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Nutritional edaphic limitations on *Quercus robur* L. temperate forests: relationship to soil quality and attributes

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Abstract: Have been analysed some edaphic and nutritional factors involving the soil conservation in 19 native temperate forests of pedunculate oak (*Quercus robur* L.) in the north-western Spain. These forests are the climax communities in the study area. Show a great diversity of tree plants and commonly happens in miscellaneous stands, "*fragas*", with other tree species as chestnut (*Castanea sativa* Mill.), birch (*Betula alba* L.), haze (*Corylus avellana* L.), and often yew (*Taxus baccata* L.) Other oak species hybridize easily between them may also could be present, e.g., *Quercus petraea* (Matts.) Lielb. and *Quercus pyrenaica* Willd. These ecosystems are highly vulnerable due to anthropogenic impacts suffered. Deficient edaphic status and nutrient removal because the forest fires, and also to the unsuitable management cycles, could reduce tree nutrition and influence their conservation. Thus, we have described the type of soil and the edaphic properties. In addition, we have evaluated the nutritional level from the result of the analysis of leaves. Soils are acidic or even extremely acidic and organic matter is abundant in all of them. The analysis of leaves revealed the most important restriction for these forests were the scarce concentration of nutrients, and in some soils, there were deficient levels of nitrogen. These deficiencies may to be associated to the low accessibility of the nutrients in the soil. Such restrictions may reduce the conservation options of these ecosystems, something that should be considered in future silvicultural treatments aimed to their sustainable protection and management.

Keywords: Plant nutrition, soil science, foliar analysis, conservation, management

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1. Introduction

Pedunculate oak (*Quercus robur* L.) is a native tree of the Euro-Siberian region and grows in most of Galicia. On the report of the data published by the IV National Forest Inventory, the forests of native broadleaves occupy a 31% of the forest area, more than 440,000 ha, highlighting the area covered by *Quercus robur* L. with 246,446 ha, 17.4% of the forest cover [1]. As it generally happens in forest ecosystems, the nutrient concentration in the leaves is a key factor for assessing the nutritional level of oak forests [2,3]. In this context, biogeochemical cycling of nutrients and their absorption are essential, and both processes are linked to their loss and imbalance; these procedures are associated with temporal stability in forest productivity [4]. The analysis of the possible interrelation of the edaphic and foliar nutrients —nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg)—, correlated primarily with the supplement to the topsoil, results essential to understand the nutrient cycle. So, the goal of our study was to calculate the nutritional status edaphic in the forests of *Quercus robur* through knowledge of normal values foliar nutrients and soil.

2. Material and Methods

2.1. Research area

The analysed stands are found in the Autonomous Community of Galicia, northwester Spain. The extension of study area represents a surface of almost 3 million hectares. The relief is complex with slopes greater than 20% in half of the territory and an average elevation of 508 meters. Galicia region has a heterogeneous lithology. The climate follows a general oceanic pattern with rainfall between 600 and more than 3,000 mm per year, but it has a Mediterranean influence towards the south, and the summer-green deciduous forests prevail [5]. To select the plots, data from the Forest Map of Spain [6] we were used. Later, the sampling sites were chosen to establish the 19 plots on them, describing the physiography at each location —elevation, slope, and orientation—, the edaphic features —superficial stoniness, existence of salts, and anthropogenic influence—, the soil profile —parent rock, depth, layers, texture—, and finally, soil type. The plots were designated by (1) a substantial heterogeneity of environmental conditions, (2) the greatest possible number of vascular woody species, (3) an evident diversity in the oak communities, and (4) facility in carrying out a study of this kind, which requires continuous monitoring of the selected plots.

2.2. Sampling and analysis techniques

On the one hand, for the edaphic data collection, samples were collected from the upper 20 cm of the soil because the exchange of nutrients between roots and leaves takes place mainly in the topsoil. Additionally, the edaphic profiles were described by pits with dimensions of 2 m wide and 80 cm deep, or to the parent rock. Next, for the differentiation of horizons and the definition of their colour according to the Munsell Soil Colour scale, samples of 2 kg per layer were collected for the posterior analysis in the laboratory. It was differentiated between surface values and total profile values. For the surface values, data were taken from the upper 20 cm of the profile, except when there was more than one horizon at that depth, being necessary in these situations to calculate a weighted average. The total value corresponds to a mean weighted value considering all the profile depth. The overall samples were air-dried, sieved (2 mm mesh), and analysed to determine the following parameters per horizon:

- moisture percentage —by drying in an air oven at 105°C to constant weight
- physical properties —separation and classification into fine earth (particles < 2 mm) and gravel, and finally, texture
- chemical analysis —pH with a glass electrode and micro pH 2001 potentiometer in H_2O and in 0.1M KCl in soil, medium suspension of 1:2.5, and nutrient concentrations
- total carbon and nitrogen concentrations —CNS-2000 autoanalyzer, organic matter (% carbon~1.724), and C/N ratio

A set of edaphic parameters were calculated. The data obtained was modified by a weighted mean with the Russell and Moore method [7].

In the other hand, by bimonthly sampling during the vegetative growth period, leaves data collection was done. Through the procedure proposed by [8], grown-up, sunny, healthy, and totally developed leaves were picked up from the upper third of the tree crown. The leaves were placed into polyethylene bags and later they carried to the laboratory in a portable fridge, where were preserved at 4 ºC for up to 24 hours. Following, the leaves were cleaned by distilled water and the midvein was separated. Finally, they were dried up to constant weight at 80 ºC, were finely ground by using a grinder, and stored in hermetically sealed topaz-coloured glass bottles for later analysis. Foliar analysis was done by applying the dry ash digestion method to the leave samples [8]. The nitrogen, phosphorus, potassium, calcium, and magnesium concentrations were determined and corrected as a function of the moisture percentage and the amount of ash.

2.3. Statistical analysis

First, data collection was analysed using a univariate statistic [9]. Next, it was studied the possible correlation between parameters in the leaves and soil, as well as the influence of climatic factors by applying Pearson correlation coefficient. Known these relations, the differences between mean values were tested by Student's t-test. All statistical analyses were performed by SPSS 22.0 for Windows.

3. Results

Table 1 shows the result of the foliar macronutrient analysis: N, P, K, Ca, and Mg in the studied plots. Mean values of nitrogen, potassium, and magnesium were greater in forests located in the north of Galicia; however, mean results for phosphorous and calcium are greater from the south plots. These initial results are significant since for the traditional fertilization of the Galician soils, the contribution of an NPK complex is important. The set of parameters showed a great fit to a normal distribution, founded on the kurtosis and bias values, and also adaptability to a Gaussian function. The coefficients of variation were less than 30%, except for the calcium concentration in some plots.

Table 1. Descriptive statistics of foliar macronutrient amounts (mg g^{-1}) on *Quercus robur* forests.

Macronutrient	Mean	Range	σ_{n-1}	Bias		Kurtosis	
				Statistical	Typical error	Statistical	Typical error
Ca	6,61	7,71	2,51	0,35	0,56	-0,92	1,09
P	1,61	1,31	0,40	0,36	0,56	-0,93	1,09
Mg	1,33	1,12	0,33	0,09	0,56	-0,49	1,09
N	22,34	11,18	2,89	0,78	0,56	0,97	1,09
K	7,82	4,94	1,46	1,32	0,56	1,00	1,09

When performing the same analysis with the edaphic parameters, it was found that these did not follow a normal distribution, detecting a lower variability (Table 2). In this sense, there is sometimes a difference between the profile data and the upper soil layer, as with N, K and Mg. This difference, joined with calcium data, the only element having queries about their normal distribution may suggest an influence of artificial fertilization of agricultural crops nearby.

Table 2. Descriptive statistics of edaphic parameter concentrations (mg g^{-1}) on *Quercus robur* forests.

Parameter	Mean	Range	σ_{n-1}	Bias		Kurtosis	
				Statistical	Typical error	Statistical	Typical error
pH	4,367	1,100	0,243	-1,136	0,35	1,402	0,69
OM	179,896	185,200	64,539	-0,649	0,35	-1,282	0,69
N	6,274	6,620	2,326	-0,720	0,35	-1,289	0,69
C/N	16,704	8,000	1,262	-0,597	0,35	3,797	0,69
K	0,129	0,086	0,022	0,108	0,35	-1,021	0,69
P	0,009	0,012	0,003	0,584	0,35	-0,782	0,69
Ca	0,109	0,339	0,073	1,683	0,35	3,155	0,69
Mg	0,066	0,055	0,014	0,091	0,35	-0,837	0,69

The pH data confirm the strongly acidic character of Galician soils (pH between 3.5 and 5), which explains the need for supplemental calcium. The geological material is very heterogeneous; however, lithology is mainly siliceous nature and the parent rock of schists, quartzites, slate, gneiss and granites predominate. Table 3 presents the seasonal trend of foliar macronutrient concentrations and Table 4, the seasonal trend of edaphic parameter concentrations on *Quercus robur* forests.

Table 3. Seasonal trend of foliar macronutrient concentrations (mg g^{-1}) on *Quercus robur* forests.

Macronutrient	Spring		Summer		Autumn	
	Mean	σ_{n-1}	Mean	σ_{n-1}	Mean	σ_{n-1}
Ca	4,193	1,459	7,377	2,210	8,282	1,996
P	1,846	0,354	1,419	0,320	1,643	0,515
Mg	1,505	0,252	1,277	0,271	1,202	0,484
N	24,328	3,365	22,846	1,376	18,953	0,698
K	8,507	2,303	7,645	1,037	7,260	0,339

In the analysis of seasonal data, foliar nitrogen shows a marked minimum during autumn because to the beginning of the diminution activity of vegetation and increased nutrient leaching due to higher rainfall. The maximum values of nitrogen and potassium occur during spring (Table 3).

Table 4. Seasonal trend of edaphic parameter concentrations (mg g^{-1}) on *Quercus robur* forests.

Parameter	Spring		Summer		Autumn		Winter	
	Mean	σ_{n-1}	Mean	σ_{n-1}	Mean	σ_{n-1}	Mean	σ_{n-1}
pH	4,21	0,31	4,38	0,21	4,44	0,20	4,45	0,16
OM	197,88	60,18	174,11	64,02	166,26	69,07	177,39	69,28
N	6,719	2,165	6,704	2,300	6,217	2,536	6,000	2,541
C/N	17,250	1,076	16,770	2,002	15,944	0,564	16,679	0,873
K	0,140	0,023	0,145	0,016	0,120	0,021	0,135	0,021
P	0,008	0,003	0,008	0,003	0,010	0,004	0,008	0,003
Ca	0,121	0,101	0,090	0,064	0,105	0,059	0,115	0,065
Mg	0,071	0,013	0,063	0,014	0,062	0,014	0,067	0,015

Seasonal trend of the concentration of the soil parameters shows a significantly marked minimum of nitrogen during winter due to the stop of vegetative activity, and also to the greater soil leaching because the increased rainfall. The maximum of nitrogen, calcium, and magnesium were found in spring, and by potassium in summer. Finally, highlight the uniformity of the phosphorus concentration throughout the year (Table 4).

4. Discussion

Foliar macronutrient concentration allows to affirm that the mean concentration of nitrogen, potassium and magnesium showed a higher content in the plots of north coast of Galicia. However, phosphorus and calcium concentration were higher in the south plots. Some authors suggest that a poor assimilation of several nutrients as potassium and magnesium can be due to an excess in calcium [10]. If the obtained foliar macronutrients content is contrasted with ideal and poor levels proposed for oak forests some interesting results are obtained [11]. With this information it is possible to define the optimum range of the concentration of leaf macronutrient for *Quercus robur* in the study area. Within it, they are the mean values obtained for all macronutrients except calcium, which are higher. In summary, the succession kept by the macronutrients in the leaves according to their concentration was nitrogen > potassium > calcium > phosphorus > magnesium, order noted in *Quercus robur* forests in other regions of Europe [12].

As mentioned, the nitrogen concentration shows a pronounced minimum in winter. This is mainly due to the activity of vegetation stops, and increases the leaching of the soil, especially of the surface layer of the profile, i.e., the topsoil. The maximum values occur during spring and summer. As was studied by [13], this is a logical behaviour due to the opposite effect. The nitrogen losses after summer are higher because the putrefaction of waste is more effective. This fact gives extra importance to the minimal level of nitrogen because the demand of the tree is lower, however, the leaching rate due to the increase in rainfall is much higher [14]. This is the reason why the nitrogen is linked to the carbonbased cycle, and because the main contributions of nitrogen are produced through the litterfall [15]. The results for calcium and magnesium were lower than the reported by other authors for the topsoil of hardwoods. Phosphorus content is generally scarce in the parent rock, however, is one of the most important nutrients for plants. The low mobility of the phosphorus gives their soil concentration to be relatively high [10], with a great trend to fixation on colloidal surfaces. However, in the analysed stands, the concentration of phosphorus was higher than the values suggested by other authors what implies that the mobility is low because a high-level soil fixation. Nutrient removal from plants to soil arises mainly by throughfall and stemflow and is completed via percolation water, and microorganisms putrefying [15].

5. Conclusion

Founded on the results of the analysis of the leaves we can verify the lack of nutrient deficiency; however, its concentration is low, with the exception of calcium. Correlations between foliar nutrients were not significant, except when its concentration was high; there is also no marked seasonal trend. Highlights the lack of correlations between the concentrations of nutrients of topsoil and leaves. In principle, we think that there is scarce incorporation of nutrients to the soil and therefore a very slow rate of mineralization.

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