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Significance of bedrock as a site factor determining nutritional status and growth of maritime pine

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ABSTRACT

Relationships between soil properties, foliar nutrients and growth were studied in 128 plots of *Pinus pinaster* established in soil over different types of bedrock in Galicia (NW Spain). Plots were classified into the following groups of bedrocks according to geological maps and samples: granitic rocks, quaternary sediments, quartzite and sandstone, slates and phyllites, biotitic schists, micaschists, gneiss and migmatites. Bedrock type significantly influenced exchangeable Ca, total N, soil depth, foliar N, P, Ca, K and Mg and site index. Bedrock was also related to elevation, temperature and slope, as a result of the distribution and geomorphology. Soils developed from biotitic schists, gneiss, migmatites and granitic rocks were the most favourable for tree growth. The poorest growth and most severe nutrient deficiencies were observed in soils developed from quaternary sediments, mica schists, phyllites and slates, quartzite and sandstone. Two regression models were developed to predict site index: a complete model explained 52% of the total variation in site index, and a model for granitic rocks explained 53% of the variation. Both indicated the importance of soil depth, elevation and foliar K and Ca as predictive variables.

1. Introduction

Pinus pinaster is one of the most important tree species in Spain, in terms of both area covered (1.68 Mha as pure and mixed species) and wood production (more than 3.1 Mm^3 felled in 2010, making it the second most important species in terms of volume production after *Eucalyptus globulus*). This species is not site demanding and is usually planted for wood production, restoration and landscaping. Its importance in Galicia (NW Spain), where it covers 0.53 Mha as pure and mixed stands, is due to its extraordinary adaptation to poor and sandy soils (Gandullo and Sánchez Palomares, 1994). However, use of the species in northern Spain has declined in favour of other faster growing but more nutrient-demanding species, such as *Pinus radiata D. Don* and *Eucalyptus globulus Labill* (Sánchez-Rodríguez et al., 2002; Merino et al., 2003).

Galician soils, which are characterised by very intense weathering, are highly acidic, with low concentrations of exchangeable Ca, Mg, K, a cationic exchange complex saturated by Al and a low concentration of available P (Macías and Calvo de Anta, 1992). This is due to the predominance of scarcely alterable minerals in the rocks, high rainfall and open systems that quickly eliminate the more mobile cations (Macías et al., 1982). These soils are also poor in P, possibly because the P binds with Fe and Al to form different compounds and is therefore not available to plants (Dambrine et al., 2000). The relationships between soil properties and nutritional status of the species depend greatly on factors such as climate, soil type and management practices (Ballard, 1980).

The nutrient status of a forest can be evaluated by comparing foliar concentrations of nutrients with limiting levels of nutrients. The nutrient deficiency levels for *P. pinaster* proposed in the area are as follows: <9.8 mg g^{-1} for N, <0.8 mg g^{-1} for P, <0.6 mg g^{-1} for Ca, <0.7 mg g^{-1} for Mg and <4.5 mg g^{-1} for K (Bara, 1998; Bonneau, 1995; Balboa Murias, 2005). Nutrient (particularly macronutrient) deficiencies are frequently observed in this species, in the following order, from most limiting to less limiting elements: P > K > Mg > Ca > N (Martins et al., 2009; Álvarez-Álvarez et al., 2011). Deficiencies in B and Cu are also observed in very sandy and acid soils (Bara, 1998). Foliar levels affect volume growth, and site index (defined by categorical classes) has been shown to be related to foliar K (Bará and Toval, 1983). Foliar nutrition concentrations have been studied in *P. pinaster* forests in France

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(Bonneau, 1995; Saur et al., 1992), and P has been indicated as the most limiting nutrient for forest growth in the sandy podzols of the Landes, whereas soluble elements can be provided by the fluctuating water table. P has also been shown to be the most limiting nutrient in Australia, and deficiency levels of other macro and micronutrients reported (Boardman et al., 1997).

The nature of bedrock is the main factor affecting forest soil properties, particularly in homogeneous climate zones (Hartmann and Moosdorf, 2012). The lithology of Galicia is very diverse, with a complex of igneous and methamorphic materials dating from the Precambrian until the last stage of the Hercynian Orogeny, together with tertiary and quaternary sedimentary deposits (Parga Pondal, 1969), mostly with rocks of acidic nature. Schists and shales with a low to medium degree of metamorphism are among the most abundant materials (occupying 46% of the total area), followed by rocks of more or less deformed granitic composition (45%), basic and ultrabasic rocks with variable degrees of metamorphism (5%), and tertiary and quaternary deposits (4%).

Although several studies have reported nutritional deficiencies in stands of this species, studies covering a complete set of plots considering bedrock information as a basis for land classification are scarce. As an example, land classification for forest purposes in Spain has considered lithological properties, particularly acidity, as one of the main bases for the establishment of biogeoclimatic classification (Elena-Roselló et al., 1997). Also, traditional studies of the ecology of Iberian pines have considered bedrock as a major factor for classification, especially rock type, degree of consolidation and the presence or absence of minerals produced by weathering (Gandullo and Sánchez Palomares, 1994).

The aims of the present study were (i) to investigate differences in the concentrations of available nutrients in soil, foliar levels of nutrients and site index in plots established on soils developed from a wide range of types of bedrock in Galicia, (ii) to propose site index models based on type of bedrock, and (iii) to determine nutritional deficiencies in relation to bedrock.

2. Materials and methods

2.1. Study plots

The study was carried out in 128 *P. pinaster* plots of varying age (8–50 years) located in Galicia (NW Spain). The plots were divided into two groups: one consisting of 31 plots, each of 600 m^2, installed in 2006 (López Varela et al., 2009), and a second one formed by a network of 97 plots, all larger than 625 m^2, established in 1974 and 1975 (Bará and Toval, 1983) (Fig. 1).

Soil depth was measured and three soil samples were obtained at random from the upper layer (0–20 cm) in each plot and combined to form a composite sample. Sample analysis included measurement of the following parameters: pH in H_2O and KCl (Guitián and Carballas, 1976); total C and N, by combustion in a Leco analyzer; organic matter, determined by considering a fixed proportion of 58% C; exchangeable Ca, Mg and K, measured by displacement with 1 M NH_4Cl (Peech et al., 1947); and available P (Olsen and Sommers, 1982).

Stand age was determined either using records of plantation age or in the case of naturally regenerated stands, by taking at least three wood cores for ring counting. Tree measurements included breast height diameter of all trees and total height of either all trees in the plot (first group of 31 plots) or a random sample of thirty trees per plot plus the dominant trees (second group of 97 plots). Site index was calculated to enable comparison of the potential growth of plots for a very broad range of ages and stand characteristics. Site index (SI) has been defined in the area as the dominant height of the stand, in metres, at a reference age of 20 years considering two different ecoregions (Ávarez-Gónzalez et al., 2005). Dominant height was calculated as the average total height of the 100 thickest trees per hectare. Average slope and elevation were also recorded.

A well-illuminated branch of the upper third of the crown was selected in three dominant trees of each plot, and a sample of one-year-old needles was obtained. The needles were dried at 65 °C and milled to pass through a 0.5 mm sieve. Total N was determined in a LECO-2000 analyzer and the plant material was digested with HNO_3 in a microwave oven for determination of macronutrients. The concentrations of P, K, Ca and Mg were measured by ICP-OES after sample digestion, and Barley 502-227 and EDTA were used as certified reference material.

The average annual temperature (T) data were obtained from thermopluviometric stations close to the plots.

Lithological information for the 128 plots was obtained using the SIGPAC display, Spanish geological map 1:50,000 (IGME, 1981), and maps of forests managed by the regional forest service. Each plot was identified by town council, parish, forest, location and elevation; the plot coordinates were also obtained and the bedrock was defined from the geological map and by analysis of samples collected at each site to verify the map classification.

The following lithological types were defined: granitic rocks (GRAN, comprising granites and granodiorites, which were quite diverse according to the grain size and composition, 55 plots), gneiss (GNEI, including orthogneiss and paragneiss, 13 plots), migmatites (MIGM, 14 plots), biotitic schists (BSCH, rich in biotite and calcium plagioclase, 5 plots), acid schists or mica schists

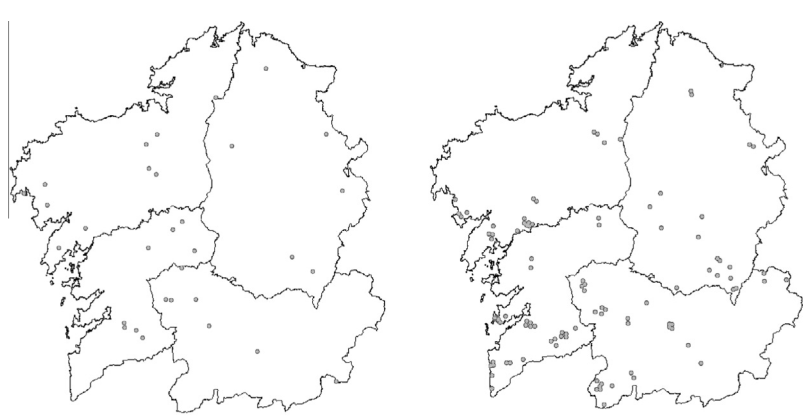

Fig. 1. Location of the 128 plots of *Pinus pinaster* in Galicia (NW Spain) considered in this study: the first group is shown in the map on the left (31 plots) and the second group on the right (97 plots).