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Research Paper

Diagnosing the nutritional condition of chestnut groves by soil and leaf analyses

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ABSTRACT

Chestnuts have always been a marginal fruit crop, and the trees seldom fertilized as a result. Few studies have been devoted to the management of soil fertility and the nutritional status of this crop. This work reports results of soil and plant analyses of a population of respectively 1041 and 198 soil and leaf samples taken across nine municipalities in the district of Bragança, NE Portugal. A second population of 80 soil, leaf and fruit (only 64) samples were taken across the three most productive municipalities in the district of Bragança, from the same orchards, to allow the establishment of relationships between soil fertility parameters and the nutritional status of the trees. The results of the two soil populations showed high soil acidity, low organic matter content, low phosphorus and high potassium content. A high percentage of leaf samples showed concentrations of nutrients below the lower limit of the sufficiency range in both the first and second sample populations, for nitrogen (respectively 63 and 47%), phosphorus (18 and 15%), potassium (34 and 31%), calcium (19 and 52%), magnesium (21 and 13%) and boron (40 and 43%). In the case of boron, 6 and 8% of leaf samples of the first and second populations displayed values within the excessive concentration range. The results of this work also revealed absence or poor relationships between soil properties and/or soil available nutrients and leaf concentration of nutrients. In this crop, therefore, it seems necessary to start applying regular fertilization programs, mainly based on regular evaluation of the nutritional status of trees through leaf analysis.

1. Introduction

European chestnut (*Castanea sativa* Mill.) and several other species of the genus *Castanea* have been grown in many countries for timber and/or nut production. From statistical data of 2014 (FAO, 2017), China is by far the world's largest nut producer (1680 300 t), followed far behind by Turkey (64 000 t) and The Republic of Korea (57 000 t). In Europe, Italy is the largest producer (52 000 t) followed by Greece (28 000 t), Portugal (18 000 t), Spain (16 000 t) and France (9 000 t).

In Portugal, the chestnut tree has been a crop of major importance to the rural communities of the mountainous regions of the north of the country where the species has suitable ecological conditions to grow. The long shelf life of the nut makes it a valuable staple food for human consumption. In the past, chestnut wood was also highly valued for cooperage, furniture, fencing stakes and several other uses.

Nowadays, the crop is facing great challenges. The fall in the value of the wood and a diversity of phytosanitary problems have severely damaged the chestnut plantations for wood and fruit, namely root rot (*Phytophthora cinnamomi* Rand) and chestnut blight [*Cryphonectria parasitica* (Murrill) Barr.] diseases (Maurel et al., 2001; Gouveia et al., 2005). *Dryocosmus kuriphilus* Yasamatsu, an invasive gall wasp originating in Asia, is also entering the country, after having caused huge losses across Europe (Maltoni et al., 2012). The negative impact of pests and diseases in several producing countries, together with the increasing recognition of the high nutritional value of the nut (Blomhoff et al., 2006; Borges et al., 2008), have increased its price which has become very attractive to farmers. Taking into account also that there are few or no other options to cultivate the terrain where the chestnut is usually grown, the farmers have responded with new plantations and a renewed interest in the crop. In the mountain regions of the north of Portugal the chestnut is currently one of the few cash crops available, thus having a significant role in maintaining populations in rural areas and significantly encouraging weekend farming.

The cropping system for nut production is undergoing rapid and extensive change. Areas formerly cultivated with rye (*Secale cereale* L.) have been converted into chestnut orchards. In contrast to the large and isolated trees or fields covered sparsely with trees, the new orchards are planted in higher densities. Throughout several decades this crop was not fertilized or was only rarely amended with farmyard manures when available. Recently, however, farmers have started to apply chemical

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fertilizers and a few are often using foliar sprays.

The economic and social importance of chestnut stands and orchards has precipitated diverse studies on the nutrient dynamic in the soil/plant system (Colin-Belgrand et al., 1996; Regina et al., 2001; Raimundo et al., 2009; Álvarez-Álvarez et al., 2010; Nunes et al., 2011) as well as on the environmental impact of chestnut fertilization (Zeng et al., 2008). However, few have been carried out to study aspects of mineral nutrition and crop fertilization. Some studies conducted in the north of Portugal have shown that the plant frequently displays symptoms of boron (B) deficiency (Portela and Louzada 2012; Portela et al., 2015a) and responds to the application of B as a fertilizer (Portela et al., 2011; Portela et al., 2015b), as has been observed in other tree species in the region (Arrobas et al., 2010; Rodrigues et al., 2011). In the NE of Portugal the plants also may display symptoms of magnesium (Mg) deficiency, at least in some lithological formations (Portela et al., 2003; Portela et al., 2010). The importance of Mg in chestnut was also reported from NW Spain by Afif-Khouri et al. (2011), who identified soil Mg as one of the most important indicators of site productivity. However, little data is available about nitrogen (N), phosphorus (P) and potassium (K) fertilization, although rare studies with young potted plants have shown that tree growth is enhanced by supplying these nutrients (El Kohen et al., 1992; Laroche et al., 1997). A study carried out by Pérez-Cruzado et al. (2011) using ash as a fertilizer, a product rich in calcium (Ca), K, Mg and to a lesser extent in P, also showed increased growth in a young plantation of chestnut.

Fertilizer companies are advising farmers to apply lime and P based on the most recognized soil fertility problems of the region, soil acidity and low levels of extractable P in the soils. Nitrogen and K tend to be recommended in much smaller amounts. In the case of N, there is a latent fear of a negative interaction of N fertilization with plant diseases. Reduced rates of K applied tend to be justified by the satisfactory levels of K in the soil that are usually found.

The main objective of this work is to provide an overview of soil fertility levels and plant nutritional status of the chestnut orchards of the NE of Portugal. There will also be investigated the existence of relationships between selected soil properties or the levels of the nutrients in the soils with the concentration of the nutrients in the leaves and in the fruits. Removal of nutrients in the crop will also be estimated since it is an important component of the fertilizer recommendation systems. For this purpose, two sources of data will be used: i) the database of the analyses of soils and leaves available in the Soil Testing and Plant Analysis Laboratory of the Polytechnic Institute of Bragança, which includes 1041 soil samples and 198 leaf samples taken from orchards across nine municipalities in the district of Bragança; and ii) soil, leaf and fruit analyses of samples taken from 80 orchards dispersed in the three larger nut producing municipalities of the Bragança district. These latter samples permit the searching for relationships between soil properties and leaf and fruit nutrient concentrations, since soil, leaf and fruit samples were collected in the same orchards. The information provided is expected to be useful to the countries of the Mediterranean basin, where chestnut is grown in similar agroecological conditions and to other countries in the world where there is a lack of data on the subject.

2. Material and methods

2.1. Site characterization and sample collection

The study was conducted in Bragança, NE Portugal. The district of Bragança is characterized by a rugged mountainous relief. Currently the cultivation of annual herbaceous crops is limited. Commercial agriculture is based on perennial vines and tree species that can withstand rainfed growing conditions. In the areas of lower altitude (∼100–400 m), characterized by higher temperatures and reduced rainfall, the grape is the most important crop. At altitudes between 100 and 600 m olive and almond trees are grown abundantly. The chestnut appears at higher altitude (600–800 m), where temperatures are lower and precipitation higher. In Bragança, one of the most important municipalities producing chestnuts, annual average temperature and accumulated precipitation are 12.3 °C and 758 mm.

The work is based on soil and plant analyses of two populations of data. The first includes 1041 soil samples that farmers of nine municipalities of the Bragança district voluntarily delivered to the laboratory from 2010 to 2016, when asking for a fertilizer recommendation plan. This first population of data also includes 198 leaf samples that were received in the laboratory through a similar process and during the same period. In this population of data, the soil and leaf samples did not necessarily come from the same orchards, or at least it was not possible to establish this connection. According to the information that the farmers provided to the laboratory, the soil samples were collected at 0–30 cm depth beneath the projection of the canopy. Young fully expanded leaves were sampled in the lower branches of the canopy during summer.

The second population of data includes soil, leaf and fruit samples collected in 80 orchards spread across the three largest nut-producing municipalities of Bragança district (Bragança, Vinhais and Macedo de Cavaleiros) during 2015. The farmers were invited to participate in this study by delivering soil, leaf and fruit samples of the same orchards to the laboratory and receiving in return the results of the analyses for free and also a fertilizer recommendation. Leaf samples were collected during August and soil and nut samples in November. The sampling process was similar to that reported for the first population of data. Some farmers did not provide fruit samples. In total only 64 fruit samples were received.

2.2. Laboratory analysis

The pre-treatments of soil samples consisted of oven drying at 40 °C and sieving in a mesh of 2 mm. Leaf and fruit samples were oven-dried at 70 °C to constant weight and ground to pass through a 1 mm sieve. The fruit samples were previously weighed as fresh to estimate the dry matter percentage of the fruits.

Soil samples were analyzed for organic carbon (Walkley-Black), pH (H_2O), pH(KCl) (soil:solution, 1:2.5) and cation-exchange capacity [Ca, Mg, K, sodium (Na) and exchangeable acidity] (ammonium acetate, pH 7.0). Extractable P and K were determined by Ammonium Lactate method (P_{AL}, K_{AL}). In the second population of data, extractable P was also determined by the Olsen method (P_{OL}). Soil B was extracted by hot water and the extracts analyzed by azometine-H method. The availability of other micronutrients in soil [cooper (Cu), iron (Fe), zinc (Zn), and manganese (Mn)] was determined by atomic absorption spectrometry after extraction with ammonium acetate and EDTA.

Elemental analyses of plant tissues were performed by Kjeldahl (N), colorimetry (B and P), and atomic absorption spectrophotometry (K, Ca, Mg, Fe, Mn, Cu, Zn) methods, after tissue samples were digested with nitric acid in a microwave.

2.3. Data analysis

The results of soil and plant analyses were subjected to linear regression and correlation. Soil properties were used as independent (or predictor) variables and the concentration of nutrients in the leaves as dependent (or response) variables. Soil properties and the concentration of the nutrients in the leaves also served as independent variables in the relationships with the concentration of nutrients in the fruit. Regression analysis was used to model the relationship between the response variables and the predictor variables. When significant linear regressions were found, the coefficient of determination was also determined to show the proportion of the variance in the dependent variable that is predictable from the independent variable.

Data were also subjected to Multiple Correspondence Analysis (MCA), carried out in SAS Institute Inc. 2017, JMP® 13, which was used