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MAGNESIUM DEFICIENCY IN CHESTNUT GROVES: THE INFLUENCE OF SOIL MANGANESE

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MAGNESIUM DEFICIENCY IN CHESTNUT GROVES: THE INFLUENCE OF SOIL MANGANESE

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□ *In northeastern Portugal, it has been difficult to identify the threshold value of exchangeable magnesium (Mg) below which Mg deficiency occurs in chestnuts (*Castanea sativa *Mill.), since discrepancies have been observed in some areas, apparently associated with parent material. A regional survey was carried out in chestnut groves established in soils derived from bedrock of several geological formations, some of them rich in manganese (Mn). Leaf sampling and soil analysis were performed in 38 groves. The lowest value of foliar Mg concentration under good growing conditions was 1.8 g kg^{-1} and the highest value in trees with Mg deficiency symptoms was 1.5 g kg^{-1}. Under acidic soil conditions higher levels of extractable Mn propitiate Mg deficiency. The soils need to reach higher exchangeable Mg ($\geq$0.34 cmolc kg^{-1}) in order to supply Mg. For lower values of extractable Mn, the deficiency appears when exchangeable Mg is $<$0.20 cmolc kg^{-1} of soil.*

Keywords: chestnut, *Castanea sativa*, magnesium, manganese

INTRODUCTION

Magnesium (Mg) deficiencies in chestnut (*Castanea sativa* Mill.) were described and assessed by Portela et al. (1999, 2003). They were identified in orchards in northeastern (NE) Portugal in acid soils derived from base-poor granites and metamorphic materials of various geological origins. The Mg deficiency areas are characterized by variable base-poor bedrocks of several geological formations: two-mica Hercynian alkaline granites, schists, and greywackes of the Silurian and Ordovician. The following

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lithological materials can be found: feldspar quartz-phyllites, phyllites, micaschists, graphytic slates, siltstones, ampelites, lydites, psamites, greywackes, phyllito-quartzites, and quartzitic schists. Only the soils derived from basic materials (as intrusions) or derived from the basic and ultrabasic rocks are well supplied with magnesium (Portela et al., 2007, 2003; Martins and Coutinho, 1991).

The soil parameter mostly used as diagnostic for assessing Mg nutrition is exchangeable Mg. Significant correlations have been found between exchangeable Mg in the soil and foliar concentrations of Mg or the occurrence of Mg deficiencies in tree species in a number of studies (Ende and Evers, 1997, Landmann et al., 1997).

Portela et al. (2003) showed that the foliar concentration of Mg in chestnuts is better explained by the combination of several soil fertility parameters such as Mg/ potassium (K), Mg/ ammonium (NH_4) and Mg/ aluminium (Al)+ hydrogen (H) ratios than by exchangeable Mg. Yet, in a number of reviews (Ende and Evers, 1997; Landmann et al., 1997; Mengel and Kirkby, 2001) the threshold value of 0.20 cmolc kg^{-1} for exchangeable Mg below which Mg nutrition of many crops is compromised was referred to, but no further restrictions were provided. However, as far as the chestnut is concerned, in NE Portugal, it has been difficult to identify such level in the soil, since discrepancies have been observed in some areas, apparently associated with parent material. In fact, it was found that most deviations were detected in chestnut groves established on certain geological formations, in which the soils are manganese (Mn)-rich. Therefore, this study aims to verify whether extractable Mn in the soil has any influence for defining the threshold value of exchangeable Mg below which Mg deficiencies in chestnut occur.

MATERIALS AND METHODS

Regional Survey

The study was conducted in NE Portugal (6° 55′−7° 30′ W, 41° 30′−42° N) at an elevation of 600–900 m. The climate is mild Mediterranean, with annual rainfall in the range of 700–1200 mm and annual average temperature between 11°C and 13°C. The physiography of the area varies from gently sloping in plateaus to more hilly landforms. The soils are well drained to excessively drained, with light texture, from loamy sand to silty loam, classified as dystric and umbric Leptosols, umbric Regosols, dystric and umbric Cambisols. The bedrock of the surveyed area is quite heterogeneous: two-mica alkaline granites, feldspar quartz-phyllites, phyllites, micaschists, graphytic slates, siltstones, ampelites, lydites, greywackes, phyllito-quartzites, quartzitic schists, and chloritic schists.

Methodology

Between 1996 and 2006 the data collected in chestnut groves of two eco-regions (Padrela and Bragança) were analyzed, in soils derived from Hercynian granite, from schists and greywackes of the Silurian and Ordovician and from greywackes of the Devonian (Pereira, 1992, 2000). Only one pair of chestnut groves was surveyed on granitic substrate, though the occurrence of Mg deficiencies is quite frequent in this substrate (Portela and Louzada, 2007). The reason for selecting mainly soils derived from metamorphic bedrock was due to the greater heterogeneity found in this type of material. The groves were located from gently sloping gradients (2–5%) to more strongly sloping (10–15%).

A set of 38 chestnut groves were selected: 19 groves with several trees showing symptoms of Mg deficiency (as described by Portela et al., 2003) and 19 groves with healthy and vigorous tree growth in the same vicinity. The ages of trees varied from 10 to 30 years old, each pair being of about the same age. The average number of trees in each grove was 70, with spacing from 10 m × 10 m to 12 m × 12 m. From 21 August to 7 September, leaf sampling was carried out in five trees in the following three categories: green trees in the healthy grove (good production conditions), green trees in the chlorotic grove, and trees with evident Mg deficiency also in the chlorotic grove. A composite sample of 25–40 fully developed leaves (fourth to seventh from the terminal shoots) in branches with burs, light exposed, from the upper-middle crown in the four quadrants of the tree, were collected and analyzed for macro and micronutrients [nitrogen (N), phosphorus (P), K, calcium (Ca), Mg, iron (Fe), Mn, zinc (Zn), copper (Cu), and boron (B)]. Leaves were dried at 65°C for 48 h, and ground to pass through a 1-mm screen. Analytical methods are described by Portela et al. (2003).

In each grove, composite soil samples (0–20 cm and 20–40 cm depth) were taken from four quadrants beneath the canopy of three trees and were analyzed for soil fertility parameters. Soil organic matter was determined by oxidation with potassium dichromate ($K_2Cr_2O_7$) following the modified Walkley-Black method; pH was measured with a 1:2.5 soil solution ratio; P_2O_5 was extracted with ammonium lactate according to the Egner-Riehm method; the exchangeable bases were extracted with 1N ammonium acetate at pH 7 and the H+Al by the 1N potassium chloride (KCl) method. The effective cation exchange capacity (CEC effective) was calculated by adding exchangeable bases plus exchangeable H+Al. For the determination of extractable Mn the acid ammonium acetate-ethylenediaminetetracetic acid (EDTA) extraction solution was used (Lakanen and Erviö, 1971), which is the most common method for assessing the soil available Mn.

Some soil properties of the surface layer (0–20 cm) in the groves surveyed are given in Table 1. The soil properties of the 20–40 cm depth followed the same pattern of variation of the upper one, so they are not given.

TABLE 1 Range of analyzed soil properties in chestnut groves surveyed

Soil properties (0–20 cm)	Mean	Minimum	Maximum
Organic matter (g kg^{-1})	29.1	7.8	68.0
pH (H_2O)	5.0	4.0	5.9
pH (KCl)	4.0	2.8	5.0
Extractable P_2O_5 (mg kg^{-1})	59	9	221
Exchangeable cations (cmolc kg^{-1})			
Ca	1.04	0.11	4.42
Mg	0.28	0.02	1.45
K	0.29	0.05	0.67
Na	0.04	0.01	0.12
H+Al	1.09	0.22	1.89
Base saturation (% CEC effective)	54	12	95
Extractable Mn (mg kg^{-1})	69	3.5	472

Pearson's correlations coefficients were determined between foliar nutrient concentrations and soil parameters. Multiple backward linear regression analysis between foliar Mg concentration and several soil fertility parameters was carried out, using the JMP Statistical Package (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

In Figure 1 the relationship between the foliar means Mg concentration (dry weight) of each group of trees and the corresponding soil exchangeable

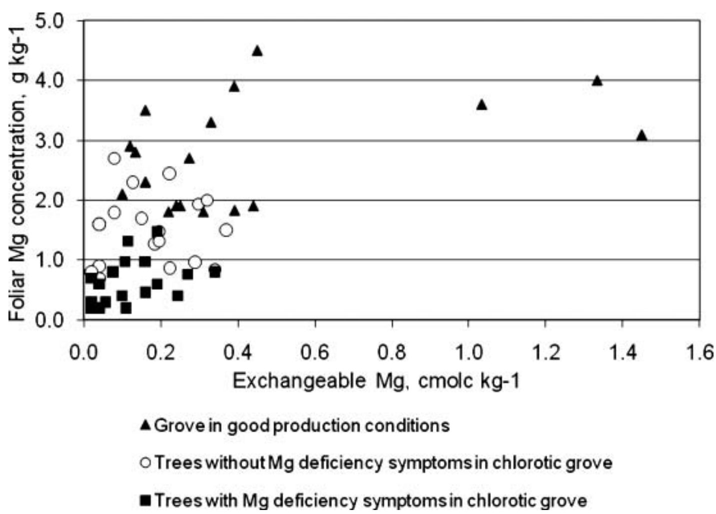

FIGURE 1 Relationship between soil exchangeable Mg and the foliar Mg concentration in the three groups of chestnut trees: good growing conditions, symptom-free in the chlorotic grove and acute deficiency in the same chlorotic grove.

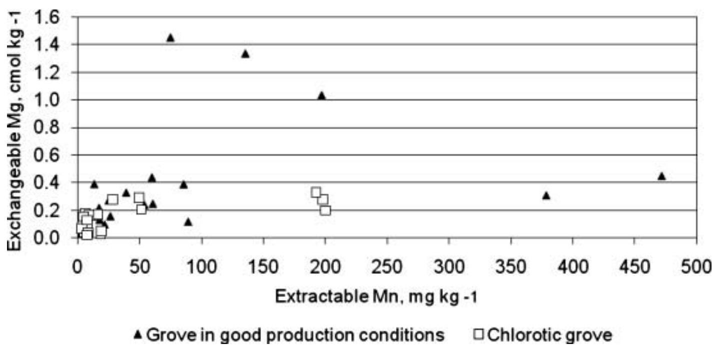

FIGURE 2 Relationship between soil exchangeable Mg and the extractable Mn and the occurrence of Mg deficiency in the 38 chestnut groves.

Mg is displayed. The chestnut trees were grouped in three categories: good growing conditions, no Mg deficiency symptoms in the chlorotic groves, and Mg deficiency in the chlorotic groves. It is worth noting that, in the chlorotic groves, significant differences ($P < 0.05$) in the soil fertility parameters were seldom observed in the samples collected underneath the two groups of trees, regardless of the evidence of Mg deficiency.

As shown, the lowest value of Mg concentration in leaves of trees in good growing conditions was 1.8 g kg^{-1} and the highest value in trees with evident symptoms of Mg deficiency was 1.5 g kg^{-1}. So the critical range for Mg deficiency in chestnut might be established between 1.5 and 1.8 g kg^{-1} of foliar Mg concentration.

As shown in Figure 1, the exchangeable Mg was, in most cases, above 0.20 cmolc kg^{-1} of soil in the groves under good growing conditions and in the majority of chlorotic groves exchangeable Mg was recorded below 0.20 cmolc kg^{-1}. In this last group, six groves were the exception and the common feature among them was the occurrence of higher levels of soil extractable Mn. So, in Figure 2 the average values of exchangeable Mg against the extractable Mn were plotted in the 38 groves which were categorized into two groups: groves in good growing conditions and chlorotic groves. The six chlorotic groves with exchangeable Mg $\geq$0.20 cmolc kg^{-1} have extractable Mn higher than 25 mg kg^{-1}. Among the chlorotic groves, the greatest value of exchangeable Mg observed was 0.33 cmolc kg^{-1}, which corresponds to a high value of extractable Mn in the soil (220 mg kg^{-1}) and also a greater concentration of Mn in the leaves (2880 mg kg^{-1} d.w.).

The groves with the highest content of Mn in soils and plants are established on Mn-rich schists of the Ordovician and the Silurian. In these groves, both intrusions of basic rock and chloritic schist (in groves with high values of exchangeable Mg) as well as acid intrusions of rhyolite (in groves with symptoms of Mg deficiency) were observed on the soil surface. In both cases pyroluzite (MnO_2) in crystalline form was identified, precipitated on the rock fragments of the coarse fraction of the soils. As is known, pyroluzite provides a pool for Mn. Its solubility is greatly influenced by pH; increasing as pH decreases (Lindsay, 1979). In contrast to these parent materials, the lowest Mn content (3.5–17.5 mg kg^{-1} of extractable Mn) was recorded in soils derived from granite and quartzitic schists. As expected, a significant correlation between extractable Mn in the soil and foliar Mn concentration in the chestnuts ($r = 0.630^{***}$) was observed.

In the present study, no significant correlation ($P < 0.05$) between foliar Mn and foliar Mg was found. However, when the analysis of the data was restricted to one single grove, a positive correlation ($r = 0.71^{**}$, $n = 15$, unpublished data of Portela et al., 1999) between the two nutrients was observed.

The results of the multiple linear regression analysis, which are displayed in Table 2, show that 52% of the foliar Mg variation might be explained by exchangeable Mg, the ratio Mg/K, organic matter and indices of soil acidity: pH (KCl) and base saturation (V); and no relevant role can be ascribed to extractable Mn. A former study, carried out by Portela et al. (2003), confirms the importance of the acidity indices and the ratio Mg/K, but instead of soil organic matter the ratio Mg/NH_4 emerged as an important parameter to explain the variation in foliar Mg. Though Mn was not shown to be relevant to explain foliar Mg variation, the two parameters relative to soil acidity [pH (KCl) and base saturation] could be associated with the variation of available Mn. It is known that acid soil conditions have a direct negative effect on the availability of Mg (Mengel and Kirkby, 2001), in addition to the enhancement of Mn solubility (Lindsay, 1979), which could induce Mg deficiency.

In fact, in the present study, the increase of the soil extractable Mn was associated with the appearance of Mg deficiency in chestnuts for values of exchangeable Mg $\geq$0.20 cmolc kg^{-1}. That is, when Mn is high, symptoms of Mg deficiency are observed unless the exchangeable Mg is $\geq$ 0.34 cmolc kg^{-1}. These data suggest that when Mn is above a certain value, it may have an inhibitory effect on Mg absorption. According to Marschner (1995) Mn^{2+} not only competes more efficiently, but also blocks binding sites for Mg^{2+} uptake. This inhibitory effect is referred to by Mengel and Kirkby (2001) and Bergmann (1992), and has been demonstrated by some researchers in water culture experiments. Goss and Carvalho (1992) showed that to reach the maximum production of dry matter of wheat, the more Mn present in the nutrient solution, the higher the concentration of Mg required. Similarly, the experiments of Heenan and Campbell (1981) provide evidence of the competing effect of Mn^{2+} on the Mg^{2+} uptake in annual species, such as soybean.

As observed in Table 1, most soils are acidic and very acidic, propitiating though the solubility of manganese, which is greatly determined by the soil pH (Lindsay, 1979; Khanna and Mishra, 1978). It is worth noting that in

TABLE 2 Multiregression analysis between foliar Mg in chestnuts and soil fertility parameters

Step	Intpt	MO	P	pH H_2O	pH KCl	Ca	Mg	K	H+Al	V	Mn	Mg/H+Al	Mg/K	Mg/CTC effective	R^2
1	0.346	−0.027	−0.00	0.016	−0.094	0.029	0.189	−0.014	0.069	0.002	0.00	−0.040	−0.068	0.079	0.556
		(13.3)	(0.24)	(1.6)	(10.0)	(8.0)	(16.5)	(0.8)	(9.9)	(18.2)	(1.9)	(6.0)	(12.4)	(1.3)	
2	0.345	−0.027	E	0.015	−0.092	0.029	0.188	−0.013	0.069	0.002	0.00	−0.040	−0.068	0.085	0.556
		(13.4)		(1.4)	(9.8)	(8.2)	(16.5)	(0.74)	(10.0)	(18.2)	(2.0)	(6.0)	(12.5)	(1.4)	
3	0.344	−0.027	E	0.016	−0.094	0.025	0.199	−0.013	0.069	0.002	0.00	−0.039	−0.066	E	0.556
		(13.4)		(1.6)	(10.0)	(7.2)	(17.6)	(0.7)	(10.1)	(19.2)	(2.1)	(5.9)	(12.2)		
4	0.347	−0.027	E	0.016	−0.094	0.026	0.192	E	0.067	0.002	0.00	−0.040	−0.063	E	0.556
		(13.8)		(1.6)	(10.3)	(7.7)	(17.4)		(10.0)	(18.9)	(2.2)	(6.2)	(12.0)		
5	0.371	−0.027	E	E	−0.081	0.026	0.190	E	0.067	0.002	0.00	−0.038	−0.063	E	0.555
		(14.2)			(9.2)	(7.8)	(17.7)		(10.4)	(20.1)	(2.3)	(5.9)	(12.3)		
6	0.376	−0.026	E	E	−0.088	0.025	0.129	E	0.079	0.003	0.00	E	−0.060	E	0.554
		(15.4)			(11.0)	(8.2)	(13.2)		(13.4)	(23.4)	(2.6)		(12.9)		
7	0.406	−0.027	E	E	−0.093	0.021	0.137	E	0.075	0.003	E	E	−0.059	E	0.551
		(16.1)			(11.9)	(7.0)	(14.3)		(13.0)	(24.7)			(13.0)		
8	0.321	−0.027	E	E	−0.078	E	0.171	E	0.083	0.003	E	E	−0.059	E	0.547
		(16.3)			(9.8)		(17.8)		(14.3)	(29.0)			(12.8)		
9	0.554	−0.029	E	E	−0.091	E	0.208	E	E	0.002	E	E	−0.065	E	0.517
		(21.6)			(14.3)		(27.0)			(19.2)			(17.8)		

Key: E indicates that the soil parameter is not significant at $P < 0.05$ and was eliminated (n = 38).
Note: the values indicate the regression coefficient and in brackets the Beta values.

Portuguese soils the study of Costa and Fernandes (1996) showed that the amounts extracted by the method of Lakanen, considered to be a reference method for determination of Mn status of soils (Sillanpää, 1990), correlated well with soil pH (H_2O, 1:2.5).

In conclusion, under acidic soil conditions higher levels of extractable Mn propitiate the appearance of Mg deficiency in chestnuts. The soils need to reach higher levels of exchangeable Mg ($\geq$0.34 cmolc kg^{-1}) in order to supply Mg to chestnuts. As long as soils have extractable Mn below 25 mg kg^{-1}, Mg deficiency in chestnuts only appears when exchangeable Mg is below 0.20 cmolc kg^{-1} of soil.

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