Nutritional diagnosis of ‘Montenegrina’ mandarin orchards at the southern Brazil

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10.1590/0034-737X202370010008

ABSTRACT

The correct nutrition of orchards from fertilizer management directly influences fruit yield. Therefore, the objective was to evaluate the nutritional status of orchards of the ‘Montenegrina’ mandarin (*Citrus deliciosa* Tenore) grafted on *Poncirus trifoliata* Raf. in southern Brazil. The study included analyzes of soil and leaf tissue from 58 commercial orchards. More than 60% of the orchards were diagnosed with K and Mg insufficiency and more than 30% had an excess of N. There was an insufficiency in Mn and Zn of 60 and 96%, respectively, despite the levels of these micronutrients in the soil being high in both depths studied. In addition, no significant correlations were observed between the contents of a given nutrient in the soil and in the leaves, except for the Ca/Mg ratio. Insufficiency was observed in the leaf contents of K, Mg, Mn and Zn and excesses of N and Cu in the orchards. The use of phosphate and potassium fertilizers requires adjustments due to the excessive content of these nutrients in the soil. Pre-planting acidity correction and soil acidity management in ‘Montenegrina’ mandarin orchards already implanted needs to be optimized.

Keywords: *Citrus deliciosa;* orchard nutrition, citriculture; soil analysis; leaf analysis.

INTRODUCTION

The State of Rio Grande do Sul (RS) has the largest number of establishments that work with mandarin in the country. It is the third largest producer of this citrus group in Brazil, with an approximate production of 90 thousand tons (IBGE, 2021a). The citrus production in RS occurs mainly in the regions of Vale do Caí, Alto Uruguai and Fronteira Oeste, being the main activity of dozens of municipalities in these regions (Oliveira *et al.*, 2010).

According to João & Conte (2018), around 12,000 families in the Vale do Caí region have citrus as their main activity, with a predominance of mandarin cultivation, mainly of the Montenegrina cultivar. Based on the 2017 agricultural census of Brazil (IBGE, 2021a), the municipalities of Montenegro and Pareci Novo are the largest mandarin producers in RS. Both municipalities correspond to 42% of the State’s area, with 3490 ha, and 41% of mandarin production of RS.

The adequate distribution of nutrients in space, as well as the application rate, frequency and method of application of fertilizers can substantially affect the absorption of nutrients, yield and quality in citrus, in addition to the environmental issue (Kadyampakeni *et al.*, 2015). One

Submitted on June 19th, 2021 and accepted on June 01rst, 2022.
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form to discover if the factors mentioned above are being performed properly is through soil analysis in depth. Consequently, it is possible to evaluate how much of the nutrients applied on the surface may be being leached, among those that have greater mobility in sandy soils, such as N (Lorensini *et al.*, 2012) and K (Wong *et al.*, 1992). Because of that, the recommendation in citrus is to fractionate the fertilization of N (threefold) and K (twice) in citrus, and it is even more important in sandy soils (SBCS, 2004).

The nutritional status of the orchards is an essential factor to identify whether the fertilization management in the producing region is adequate, directly influencing the yield and quality of the fruits. The last one is an indispensable factor in fruits that are commercialized in natura, the case of 'Montenegrina'. Some examples of the involvement of the nutrients with fruit quality are: N is involved in the development of peel color and thickness, fruit size, acidity and vitamin C concentration (Jones & Embleton, 1959; Gravina *et al.*, 2012); K is also related to fruit size, peel thickness and total acidity (Nagy, 1980; Obreza *et al.,* 2017); boron helps with cell wall strength (Goldbach & Wimmer, 2007; Dong *et al.,* 2009); K/Ca and Mg/Ca ratios in the albedo are related to the incidence of albedo-splitting (Storey & Treeby, 2002).

Furthermore, it is also important to understand the rootstock/scion interactions, verifying the demand and management strategies for macronutrients and micronutrients (via soil, via foliar or via fertigation) in citriculture. Citrus rootstocks have a direct influence on the efficiency of N use in plants. Vigorous rootstocks have higher N requirements than slow growing ones. However, the scion variety also influences the regulation of the efficiency of the use of N (Mattos Jr. *et al.*, 2020).

There is a lack of studies evaluating regional assessments of nutrition, the last one performed in the region under study was in the late 1970s (Koller *et al.* 1986). Thus, the objective was to evaluate the nutritional status of orchards of the 'Montenegrina' mandarin grafted on *Poncirus trifoliata* in Vale do Caí, the main citrus producing region in the state of Rio Grande do Sul.

MATERIAL AND METHODS

A total of 58 commercial orchards were sampled in the municipalities of Montenegro and Pareci Novo, the main mandarin producers in the state of RS, Brazil. The predominant soil found in this region correspond to *Argissolo Vermelho distrófico espessarênico*, a typic Ultisol (Santos *et al.*, 2018). The orchard's cultivar studied was Montenegrina (*Citrus deliciosa* Tenore) grafted on *Poncirus trifoliata* Raf. The average age of it was 14 years, ranging between 2 and 30 years. The sampled orchard area occupied 260 ha, representing 2.7% of the area occupied by mandarin orchards in RS and 10.2% of the orchard area of the two municipalities in 2015 (IBGE, 2021b).

The soil samples were collected at depths of 0-20 cm and 20-40 cm along the fertilized strip in each orchard, with ten subsamples each. As for leaf analysis, ten plants were selected. Soil and leaf collection was executed between February and March 2015 according to regional recommendations (SBCS, 2004). The chemical analyzes were performed according to the following methodologies: pH in water 1: 1; exchangeable Ca, Mg, Al, and Mn were extracted with KCl 1 mol L^{-1}; cation exchange capacity ($CTC_{pH\ 7}$); organic matter (M.O.) was perfomed by moist digestion. P and K were determined by the Mehlich I method; $S\text{-}SO_4$ was extracted with $CaHPO_4$ 500 mg L^{-1} of P. Zn and Cu was extracted with HCl 1 mol L^{-1} and B was extracted with hot water. In addition, the saturation of the effective CTC by aluminum (m) and the saturation of the $CTC_{pH\ 7}$ by bases (V) were also calculated (SBCS, 2004).

In the vast majority, orchards were conducted in a conventional manner, reproducing what occurs in the region. Within the group of evaluated producers 65.5% make use of liming. As for the distribution of fertilizers, 89.7% split the fertilizers more than once, with 41.4% split twice, 48.3% using at least three fractionation, and four subdivisions are adopted by 10.3% of total producers. Organic fertilizer is used in 79.3% of the orchards, with mainly poultry litter being used. About the use of fertilizers with formulated mineral fertilizers, 58.6% use formulated fertilizers (containing N, P and K or N and K), with 37.9% using only fertilizers formulated N, P and K and 13.8% does not use formulated fertilizers, using only simple fertilizers. More than 80% of producers do not make top dressing fertilizer in the recommended periods (SBCS, 2016). The use of foliar fertilizers is adopted by 44.8% of the producers. There are windbreaks in 72.4% of the sampled orchards. Regarding weed management, 79.3% use chemical control in the plant line and mowing between the lines, 17.2% only use mowing in the entire production area and 3.4% use chemical control in total area.

The results of the leaf analysis were interpreted according to Quaggio *et al.* (2010). The soil attributes were interpreted according to technical criteria described in the regional recommendations (SBCS, 2004; SBCS, 2016), where the levels of available nutrients in the soil are classified in VL (very low), L (low), M (medium), H (high) and VH (very high). The data of the variables were presented in a descriptive way, in box plot graphs and histograms. Additionally, correlation analyzes were performed between nutrients in the leaf tissue and between nutrients in the leaf tissue and in the soil. All graphics were generated by the R program (R Development Core Team, 2010).

RESULTS AND DISCUSSION

The results of soil analysis showed that in the 0-20 cm layer the soil pH (Figure 1) had an average of 5.7 and in depth (20-40 cm) the average pH was similar (5.6). However, there was a larger dispersion of the pH data at 20-40 cm (Figure 1), which presented negative asymmetry. Thereby, the pH data showed a tendency to be more acidic in the 20-40 cm than the pH data at the depth of 0-20 cm. Even though liming is a widespread technique in the agronomic environment, it was adopted in only 65.5% of the evaluated orchards. It may be one of the factors that explain the average pH of the soil below the reference pH indicated for the citrus crop (pH 6.0) (SBCS, 2016). Analyzing the pH data in relation to the reference pH, it appears that 67% and 56% of the data are inside the pH range of 5.5 to 6.5 in the layers of 0-20 cm and 20-40 cm, respectively.

The average base saturation (V) decreased in depth (Figure 1), from 54.2% to 45.7%. These values fell into the low class of interpretation (SBCS, 2004), below the V = 70% recommended for citrus (Mattos Jr *et al.*, 2020). On the sampled orchards, 72.4% had V less than 70% at a depth of 0-20cm and at a depth of 20-40 cm, 77.6% of the orchards had V < 70%.

In depth chemical attributes can also be analyzed to diagnose possible root growth restrictions caused by, for example, aluminum toxicity and soil acidity. Whereas the rootstock *Poncirus trifoliata* Raf. is more sensitive to these factors mentioned compared to other rootstocks, such as 'Cravo' and 'Cleópatra' (Auler *et al.*, 2011). Samples had 77.6% of aluminum saturation (m) greater than zero at 0-20 cm soil layer and 81.0% had an aluminum saturation greater than zero at 20-40 cm soil layer. Of the samples with high aluminum saturation (m > 20%) (SBCS, 2004), 74% of these samples had macronutrient deficiencies (Figure 2).

The average aluminum saturation showed an opposite behavior, improving in depth (7.5% to 16.2%), classified as low and medium at depth 0-20 cm and 20-40 cm, respectively. As shown in Figure 1, base saturation and aluminum saturation exhibited a more sample variability at depths of 20-40cm. Aluminum saturation had a pronounced positive asymmetry, indicating that the sample values tend to be higher in depth. The lack or insufficiency of liming over the years in the orchards is evidenced by the average values of V and the substantial presence of exchangeable aluminum in the soil.

The organic matter (Figure 1) presented average interpreted in the low class at both sampled depths. The sample distribution was homogeneous in relation to this attribute. This is a reality in the study region, as the soil is highly weathered, with low levels of organic matter (Mattos Jr. *et al.*, 2020). Due to the low content of organic matter, the use of organic sources of fertilization are interesting alternatives. In this case, 79.3% make use of organic compost in at least one of the fertilization split.

Yet at Figure 1, both macronutrients and micronutrients had a higher concentration in the 0-20 cm layer the soil, which indicates that even those nutrients that have a high probability of leaching are being used by the plant. Since, in conditions suitable for root growth, 70% of the roots were up to 40 cm depth, forming a network of lateral roots that support the fibrous roots. In greater depth, there is another layer of fibrous roots that develop below 40 cm in depth. The upper fibrous roots quickly absorb water and nutrients applicated by top dressing. A lower layer acts under conditions of water stress, absorbing water from the deepest layers of the soil, as well as leached nutrients. However, this deeper layer of roots is quantitatively less important than the surface layer and, in some circumstances, is very underdeveloped (Primo-Millo & Agustí, 2020).

According to Wong *et al.* (1992), K can leach about 10%, while Ca and Mg reach 34% and 37%, respectively. However, much of the potassium fertilizer can also be trapped within the expanding clay mineral structure. This authors observed that a large part of the fertilizers applied are lost through leaching, volatilization and fixation, reaching losses of 85% for N and 95% for P and K.

The nutritional levels of P (Figure 3) at a depth of 0-20 cm showed that 82.7% of samples were within the high and very high classes. The same occurred for P depth of 20-40 cm, where most classes (65.5%) also occur in the high and very high classes, but in a smaller percentage when compared to the depth of 0-20 cm. K (Figure 3) presented a similar behavior, since 81.0% and 62.0% of the orchards was in the high and very high class for depths of 0-20 cm and 20-40 cm, respectively.

The high levels of P and K may be linked to the excessive use of chemical fertilizers and organic compounds. In the case of compounds, such as poultry litter, commonly used in large quantities in orchards in the region, they may contain 4% P_2O_5 and 3.5% K_2O, both percentages in dry matter (SBCS, 2004). The high levels of P and K in the soil can also be explained by the management of this nutrients throughout the cycle, because the majority producers do not make top dressing fertilizer in the recommended periods (SBCS, 2016), disfavoring the absorption of nutrients by citrus plants.

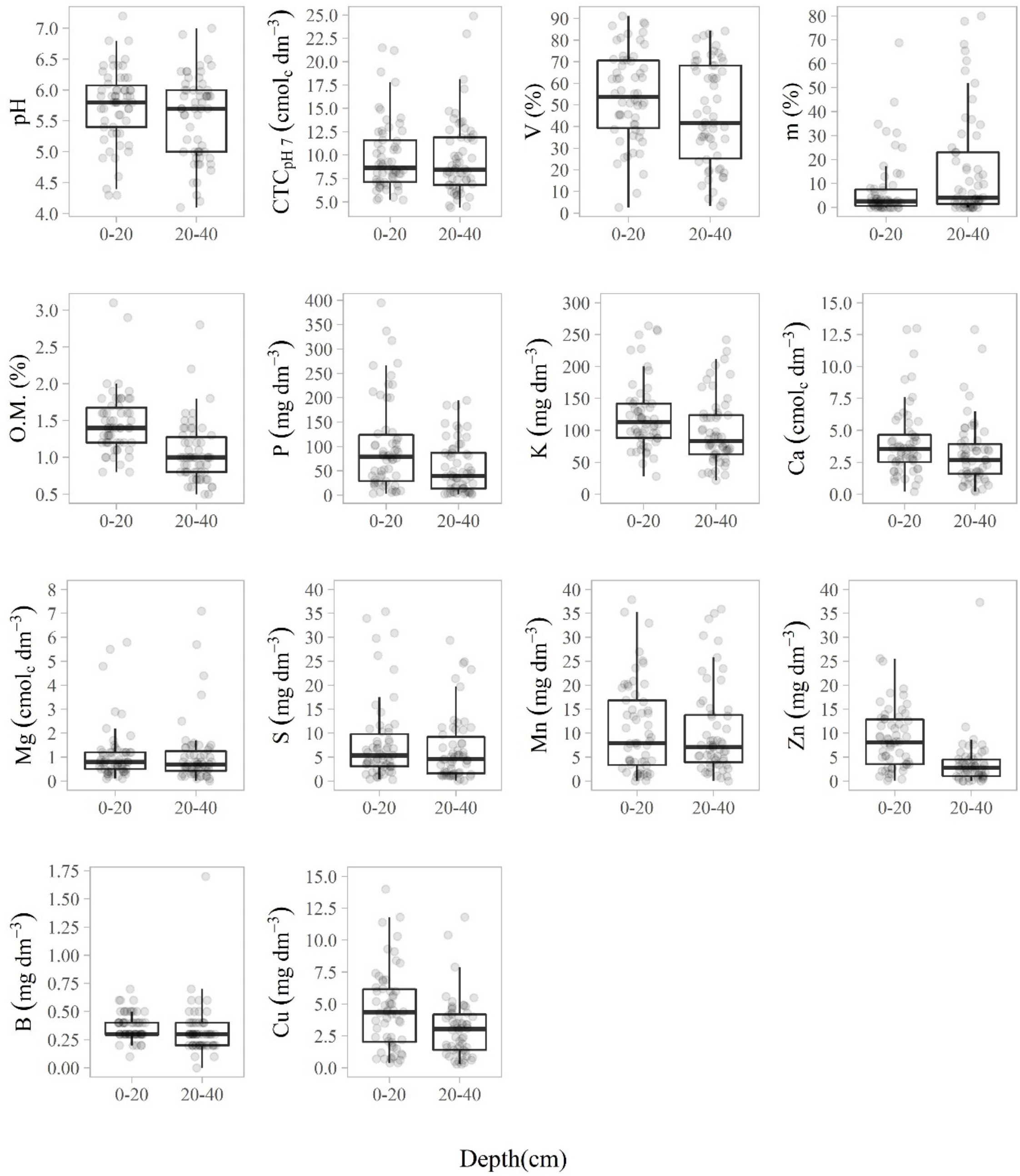

Figure 1: Distribution of data regarding pH, CTCpH$_{7.0}$, base saturation (V), aluminium saturation (m), organic matter (O.M.), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), zinc (Zn), boron (B) and copper (Cu) at 0-20 cm and 20-40 cm depth in the soil of 'Montenegrina' mandarin orchards in southern Brazil, 2015.

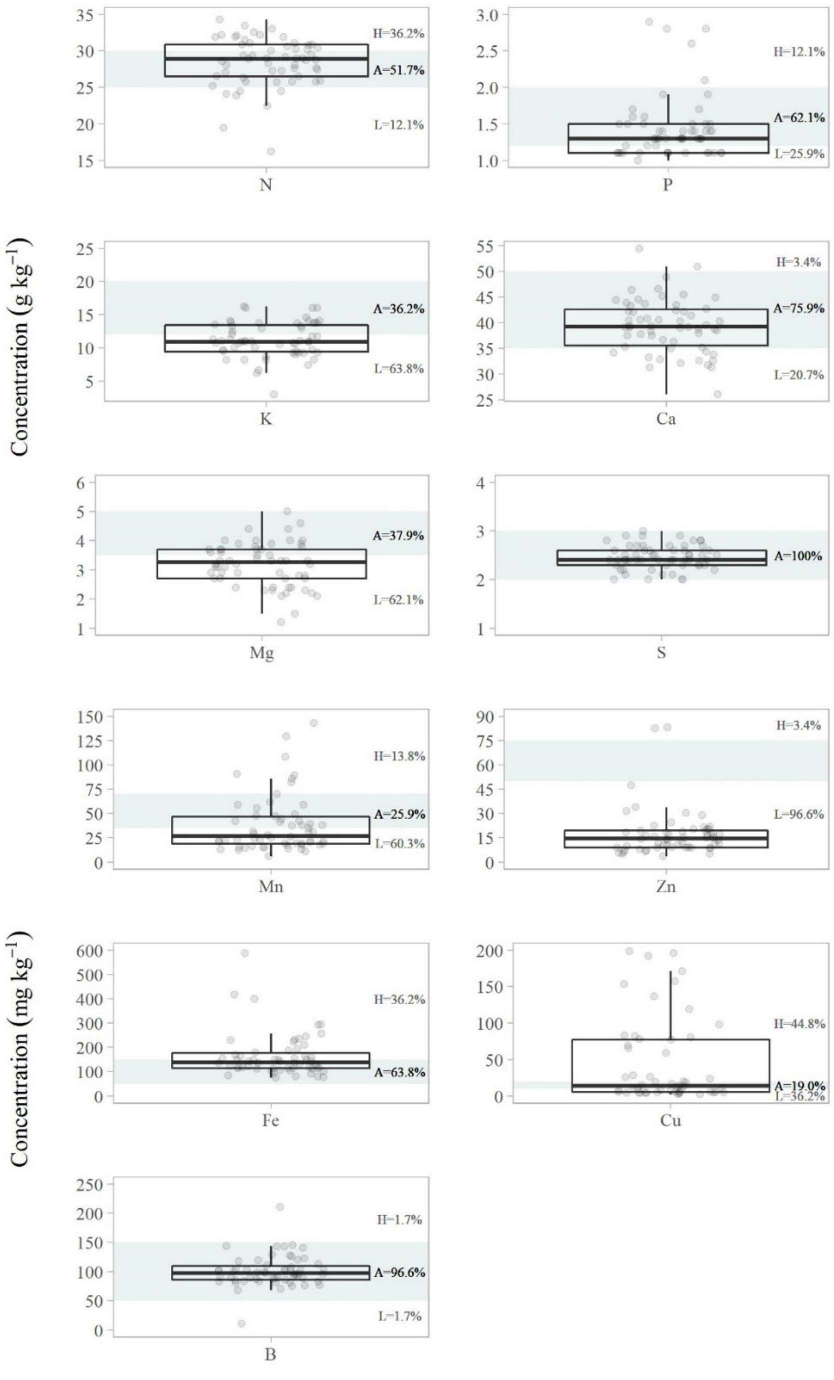

Figure 2: Concentration and distribution of macronutrient (N, P, K, Ca, Mg and S) and micronutrient (Mn, Zn, Fe, Cu and B) data in the leaf tissue of 'Montenegrina' mandarin orchards in southern Brazil, 2015. A hatch indicates the adequate (A) levels of each nutrient. The percentage refers to the sufficiency classes, from top to bottom in the graphs: high (H), adequate (A) and low (L) (Quaggio *et al.*, 2010).

Most samples were within the medium class for Ca and Mg at a depth of 0-20 cm. However, at the same depth, 36.2% of the samples were in high class for both nutrients. At the depth of 20-40 cm, Ca had most samples (39.7%) in the lower class, which is probably due to the lack of pH correction in the implantation of the orchard associated with insufficient incorporation of it into the soil, since the pH in depth is also more acidic.

Sulfur at depths of 0-20 cm and 20-40 cm (Figure 3) had 51.7% and 44.8% of orchards within the high class (SBCS, 2004). Even so, the results of foliar analysis demonstrate that 100% of the orchards have the sulfur content (Figure 2) within the adequate class (Quaggio *et al.*, 2010).

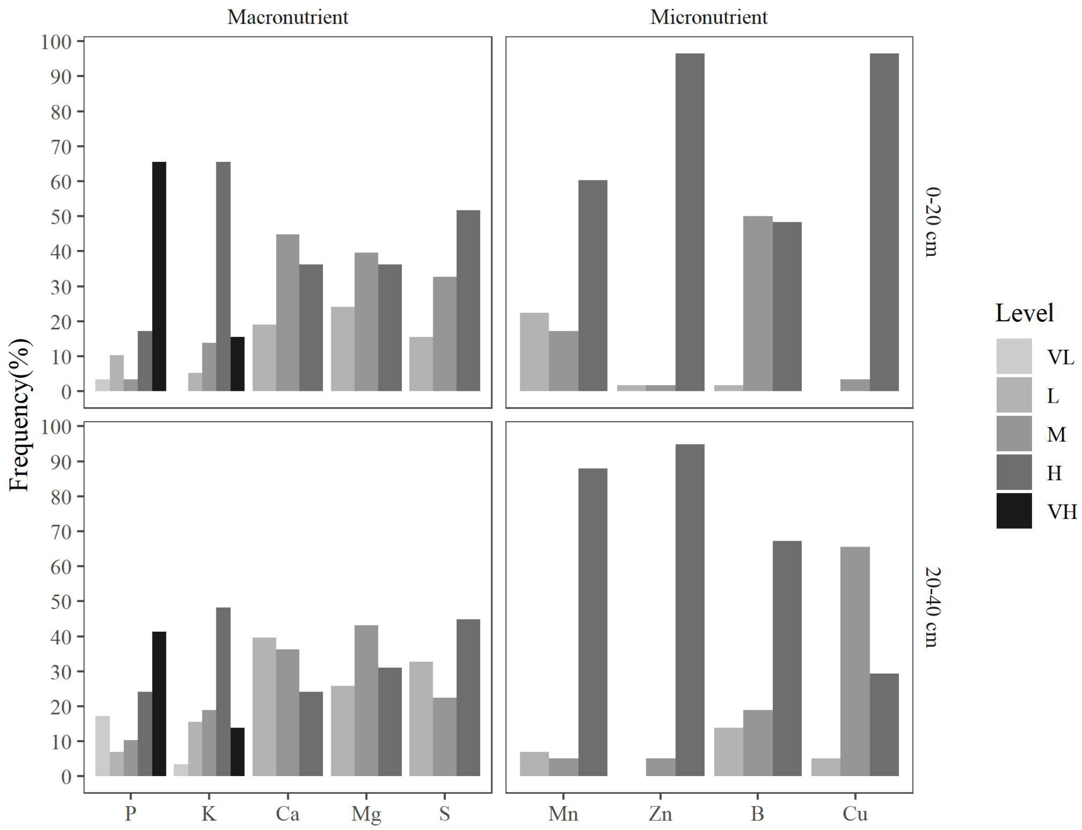

Figure 3: Frequency of macronutrient and micronutrient sufficiency classes in 'Montenegrina' mandarin orchard soils at depths of 0-20 cm and 20-40 cm in southern Brazil, 2015. VL (very low), L (low), M (medium), H (high), VH (very high) (SBCS, 2004; SBCS, 2016).

The micronutrients Mn and Zn (Figure 3) showed the same trend at both depths, with the highest frequencies in the high class. Boron had the majority samples in the medium and high classes at a depth of 0-20 cm, while at a depth of 20-40 cm the highest frequency was in the high class with 67.2%. On the other hand, Cu had 96.6% of the samples in the high class in the 0-20 cm layer. In the 20-40 cm layer, the highest percentage was found in the medium class (Figure 3).

The high concentration of Cu, Mn and Zn in the soil may be related to the applications of organic compounds, since most producers use this source of nutrients. Also, the application of foliar fungicides containing these elements contributes to their increase in the soil (Brunetto *et al.*, 2017), such as mancozeb and copper salts. The higher concentration of copper at a depth of 0-20 cm could be connected to the higher content of organic matter, attributed to the formation of Cu internal sphere complexes with humic acids (Komárek *et al.* 2010). In addition, excess copper can reduce soil biodiversity (Zhou *et al.* 2011).

In a research of the nutritional status of citrus in the Vale do Caí, in the late 1970s (Koller *et al.* 1986), was observed an insufficiency in the foliar levels of N in 45% of the orchards, of K in 60%, of Mg in 90%, Zn in 75% and 35% in Mn. Likewise in this study, a reduction in the insufficiency of N and Mg was observed (Figure 2), with N having the highest percentage (51.7%) of samples within the adequate class. The foliar magnesium content was found in its highest percentage (62.1%) in the low class of the nutrient. Acid soils usually have problems with Mg deficiency, which can be induced due to competition with high levels of Ca in the soils, as a result of unbalanced fertilization. The use of dolomitic limestone may be a solution. Nevertheless, it may be insufficient to maintain adequate Mg levels, especially when the use of calcium nitrate is constant (Quaggio *et al.*, 2014; Mattos Jr *et al.*, 2020). On the other hand, Mg deficiency can be caused by the high soil K/Mg > 0.4 (Papadakis *et al.,* 2005), that occurs in 55% of de soil samples at 0-20 cm in this study. In this way, foliar applications of magnesium nitrate can be effective when applied to leaves with two thirds of expansion in spring and summer sprouts (Zekri & Obreza, 2013).

In comparison with the research of Koller *et al.* (1986), K had an increased frequency of deficiency (63.8%) in the total of sampled orchards. For Zn and Mn (Figure 2) it was also observed an increase in the frequency of orchards with insufficiency, 96.6% and 60.3%, respectively. In orange orchards on the Fronteira Oeste of RS there is also a great deficiency in the leaf contents of Zn and Mn (Griebeler *et al.*, 2020).

Even though there is a three times split of the fertilizers in 48% of the evaluated orchards, there are still more than half that do not do this split, or do not do it efficiently, contributing to the the insufficiency of foliar potassium. The insufficiency of leaf P (Figure 2) in 25.9% of the samples, even though this nutrient is more frequent in the high and very high classes in the soil (Figure 1), may be related to the soil pH, because in acidic soils the P becomes if less available for plant absorption (Obreza *et al.*, 2017). The excess of P in the soil might be linked to surface applications, after planting, of NPK formulas. Further, the levels of P in depth in the soil (Figure 3) showed lower frequencies at high classes, which may be related to the lack of P correction in pre-planting, recommended by SBCS (2004).

The levels of B and Fe in the leaf tissue (Figure 2) are mostly (96.6% and 63.8%, respectively) in the adequate class. The majority (44.8%) of the orchards showed excess Cu in the leaves. The repeated use of cupric fungicides in citriculture, as already mentioned, causes this metal to accumulate.

Despite of Mn and Zn were in the highest frequency in the high interpretation class in the soil (Figure 3), there was a predominance for the low interpretation class for these same nutrients in the leaves (Figure 2). Foliar application of products containing Zn and Mn (Godoy *et al.*, 2013), during sprouting flows, can be a management alternative to supply their deficiency. Less than half of the producers (44.8%) used foliar fertilization as part of nutrient management.

Opposed to the recommendation of Zn and Mn, the application of boron has a better efficiency when applied via soil (Mattos Jr. *et al.*, 2020). Nevertheless, in some circumstances, the nutrient can be translocated when applied via foliar by the phloem to the roots, especially in situations of boron deficiency (Du *et al.*, 2020).

Weed management allows the improvement of fertilizers use for crops of commercial interest (Granatstein *et al.*, 2014). In the region under study, 79.3% of the producers use mowing between the lines and chemical control in the orchard line.

Zn and N deficiencies are considered the most common in the field (Srivastava & Singh, 2005). Zinc deficiency can be induced due to competition with P, Mn and Ca (Smith & Rasmussen, 1959; Burleson *et al.*, 1961; Singh & Khan, 2012). Soil properties also influence the availability of Zn, such as the binding Zn with chelates, which increases its the solubility and mobility in the soil, improving the availability of Zn for plants (Srivastava & Singh, 2005). However, in the soil of the study region, this effect was not observed since Zn is poorly soluble in sandy soils, with little mobility in the soil (Obreza *et al.*, 2017).

The only significant correlation of the contents of a given nutrient in the soil and leaves, with correlation coefficients (r) greater than 0.50, was the Ca/Mg ratio (Figure 4).

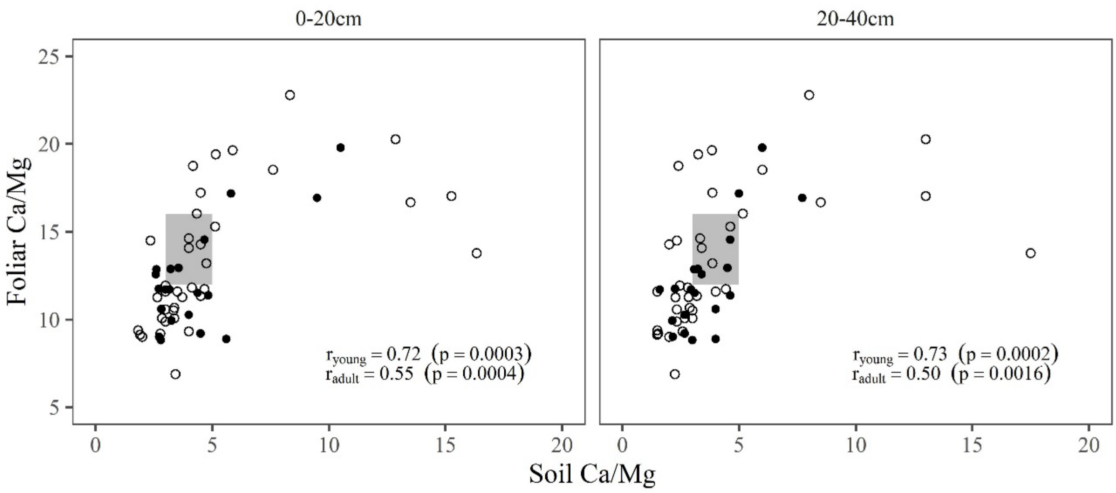

Figure 4: Correlation of the Ca/Mg leaf ratio with Ca/Mg of soil depths (0-20 cm and 20-40 cm) of ‘Montenegrina’ mandarin orchards in southern Brazil, 2015. Hatch area indicates as optimal ranges of Ca/Mg in the soil (SBCS, 2016) and in the leaf (Malavolta *et al.*, 1994). Black dots represent orchards up to eight years old and hollow dots represent orchards over ten years old.

Therefore, the levels of minerals presented in the soil are not associated with the composition of the leaves, since there was no significant correlation of the same nutrient in the soil and in the plants. Hence, there is an evidence of the need to complement the evaluation of soil fertility with foliar analyzes for the recommendation of citrus fertilization (Tang *et al.*, 2013; Griebeler *et al.*, 2020).

In general, the Ca/Mg ratio of the soil varied between 1 and 5, with tolerance of crops to greater amplitudes (0.5 to more than 10) without prejudice to productivity. However, there cannot be limitation in the availability of these nutrients in soil (SBCS, 2016). In this study, the Ca/Mg ratio of the soil was found to be within the range 3-5 in most samples (53.6%) at a depth of 0-20 cm (Figure 4). In the 20-40 cm soil sampling, most of the samples (44.6%) were below the ratio of 3. The below ideal Ca/Mg ratio can be harmful to the crop, as Ca is fundamental for ideal absorption of nutrients, greater resistance to pests / pathogens and high yield (Eticha *et al.*, 2017).

The Ca/Mg ratio in the leaf should be between 12 and 16 (Malavolta *et al.*, 1994). Most samples (56.1%) were below this range. Only 21.1% was within the ideal range. Orchards up to eight years old at a depth of 0-20 cm showed $r = 0.72$ ($p = 0.0003$) and at a depth of 20-40 cm, $r = 0.73$ ($p = 0.0002$). The older orchards (over 10 years old) had $r = 0.55$ ($p = 0.0004$) and $r = 0.50$ ($p = 0.0016$) at a depth of 0-20 cm and 20-40 cm, respectively. At the depth of 0-20 cm, 54.4% of the samples were within the ideal ratio, while at the depth of 20-40 cm, only 40.4% of the samples were within the range. The frequency of samples that were simultaneously in the ideal ranges of Ca/Mg in the soil and in the leaves was only 17.5% and 15.7% in the depths of 0-20 cm and 20-40 cm, respectively. Orange groves located in the Fronteira Oeste region of RS also had a low Ca/Mg ratio in soil and leaves (Griebeler *et al.*, 2020).

CONCLUSIONS

There is significant variability in the nutritional status of ‘Montenegrina’ mandarin orchards on *Poncirus trifoliata*.

The nutrition of ‘Montenegrina’ mandarin orchards needs adjustments due to the insufficiency of K, Mg, Mn and Zn and the excess of N and Cu.

The management of phosphate and potassium fertilization requires adjustment due to the excessive content of these nutrients in the soil.

Pre-planting acidity correction and soil acidity management in ‘Montenegrina’ mandarin orchards already implanted needs to be optimized.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

We would like to thank the Brazilian National Council for Scientific and Technological Development (CNPq) and Brazilian Agency for Support and Evaluation of Graduate Education (CAPES) for financial support. There is no conflict of interests.

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