

Correlations among nutrient contents in soil, leaf, and fruit tissues and yield of *Olea europaea* L. cv. Arbequina in the South of Brazil

Correlações entre os teores de nutrientes em solo, folhas, frutos e rendimento de *Olea europaea* L. cv. Arbequina no Sul do Brasil

Correlaciones entre nutrientes en suelo, tejidos de hojas y frutos y rendimiento de *Olea europaea* L. cv. Arbequina en el sur de Brasil

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Abstract

The objective of the work was to relate the nutritional status of olive orchards from the central region of the Rio Grande do Sul with fruit yield and identify unadjusted points in the fertilization recommendation system to be improved. Soil, leaf, and fruit samples were taken from eight orchards, between 2018 and 2020, and were evaluated for the contents of N, P, K, B, pH, TOC, Al⁺³, and soil texture. The 20-40 cm layer in soil showed acidity and Al⁺³ content at potentially restrictive levels. The available P and B contents in soil were considered low. In leaf tissue, K and N presented high contents. The correlations revealed that fruit yield was limited by high N contents on leaves, especially in winter. B content in fruits diminished in higher soil pH, suggesting that the B threshold value in soil for olives in the south of Brazil should be pH-dependent.

Keywords: Olive growing; Nutrition; Fertilization.

Resumo

O objetivo desse estudo foi relacionar o status nutricional de pomares de oliveiras da região central do Rio Grande do Sul com o rendimento de frutos e identificar pontos não ajustados no sistema de recomendação de fertilizantes que podem ser melhorados. Amostras de solo, folhas e frutos foram coletadas de oito pomares entre 2018 e 2020 e analisadas quanto ao conteúdo de N, P, K, B, pH, TOC, Al⁺³ e textura no solo. No solo, a camada 20-40 cm mostrou acidez e níveis de Al⁺³ potencialmente restritivos. Os níveis de P e B disponíveis no solo foram considerados baixos. No tecido foliar, K e N apresentaram altos teores. As correlações revelaram que o rendimento de frutos foi limitado

pelo alto teor de N em folhas, especialmente no inverno. O teor de B nos frutos diminuiu com o aumento do pH do solo, sugerindo que o nível crítico de B para oliveiras no sul do Brasil possa ser pH-dependente.

Palavras-chave: Olivicultura; Nutrição; Fertilização.

Resumen

El objetivo del trabajo fue relacionar el estado nutricional de los huertos de olivos de la región central de Rio Grande do Sul con el rendimiento de los frutos e identificar los puntos más débiles del sistema de recomendación de fertilización para que sean mejorados. Se tomaron muestras de suelo, hojas y frutos de ocho huertos, entre 2018 y 2020, y se evaluaron los contenidos de N, P, K, B, pH, COT, Al⁺³ y textura del suelo. En el suelo, la capa de 20-40 cm mostró acidez y contenido de Al⁺³ en niveles potencialmente restrictivos. Los contenidos de P y B disponibles en el suelo se consideraron bajos. En el tejido foliar, el K y el N presentaron contenidos elevados. Las correlaciones revelaron que el rendimiento de los frutos fue limitado por los altos contenidos de N en las hojas, especialmente en invierno. El contenido de B en los frutos disminuyó a mayor pH del suelo, lo que sugiere que el nivel crítico de B en el suelo para las aceitunas del sur de Brasil debería depender del pH.

Palabras clave: Olivicultura; Nutrición; Fertilización.

1. Introduction

The olive tree (*Olea europaea* L.) has been cultivated for millennia in the Mediterranean region, from where it originates (Ramos et al. 2018). Its production and consumption have been growing globally, especially motivated by the health benefits from the consumption of both olive and olive oil demonstrated by the research studies. Among several benefits, the main ones are linked to the prevention of cardiovascular diseases and diabetes, alleviation of blood pressure, and reduction in the risk of gastric reflux (Internacional Olive Council - IOC 2020a).

Currently, Brazil is the 3rd biggest importer of olive oil in the world (IOC 2020b). Within a promising market, olive cultivation has grown a lot in the country recently, especially in the southern state of Rio Grande do Sul. The cropland area with olives on the state increased from 80 ha in 2005 to 5986 ha in 2022 (Secretaria da Agricultura, Pecuária e Desenvolvimento Rural do Rio Grande do Sul - SEAPDR 2022). At the same time, favorable soil, and climate conditions (Alba et al. 2013) support a great potential to crop expansion in the Rio Grande do Sul state. This potentiality has been confirmed by the growing olive yields, oil production, and the high quality of the extra virgin oils. In 2022, a record was reached in the state, with 448 thousand liters of olive oil produced (SEAPDR, 2022). However, the current national production of olive oil can supply only 2% of the country's demand.

To maximize the potential of the crop, however, research studies are required to adequate orchard management to regional demands. Liming and fertilization recommendation systems for olive have been suggested (Comissão de Química e Fertilidade do Solo -CQFS-RS/SC 2016; Empresa de Pesquisa Agropecuária de Minas Gerais - EPAMIG 2012). Nevertheless, such recommendations are mostly based on studies conducted in the United States, especially Chapman (1966), Childers (1966), Beutel et al. (1983), and studies from the Mediterranean region, i.e., semi-arid regions with the dominance of limestone soils, very different from soil and climate in the south of Brazil.

Due to the great expansion of olive cultivation around the world, research on fertilization is being carried out in different countries to fine-tune practices according to the behavior of different cultivars in different soil, climate, and relief conditions, in addition to recent innovative studies in the Mediterranean region (Fernández-Escobar et al. 2014; Fernández-Escobar et al. 2016; El-Fouly et al. 2014; Rodrigues et al. 2012, Zouari et al 2020, Deliboran et al. 2020, among others). The current knowledge state of knowledge in olive fertilization in these regions/countries, however, does not match necessarily with the best fertilization practices for olive orchards in the south of Brazil. Different soil, climate, and relief conditions may influence the recommendation of fertilizing and liming, since plants respond differently, which can result in distinct nutritional demands, requiring adjustment of the liming and fertilization program for each region and context (i.e. rates, the optimal season for application, frequency, the requirement of incorporation, plant response to sources of fertilizer – as solid vs. foliar

fertilizer, best soil layer for sampling, among other aspects). Compared to the semi-arid regions, in the south of Brazil the larger soil humidity availability, well distributed along the year, increases the nutrient supply by diffusion and mass flow mechanisms, but the subsoil acidity can restrain root growth to surface soil layers. Such parameters can affect both plant growth, olive fruit yields, and oil quality.

One of the first steps to the finest adjustment of the fertilizer recommendation program is to carry out correlation studies between plant productivity and leaf and soil chemical analysis parameters. Given the scarcity of studies on olive growing in the south of Brazil, this study aims to evaluate the nutritional status of young and adult orchards located in the central region of Rio Grande do Sul, correlating them to olive fruit yield and searching for the main gaps in the recommendation program.

2. Methodology

The study was carried out between 2018 and 2020 in eight olive orchards located in the central region of the state of Rio Grande do Sul, Brazil, in the municipalities of Caçapava do Sul, Cachoeira do Sul, and São Gabriel. Details of each orchard are reported in Table 1. In each orchard, 10 representative individuals were selected, identified, and georeferenced. Each one constituted an experimental unit.

Table 1 – Location and characteristics of the orchards analyzed.

Location	Identification	Age at 2021	Type of soil*	Coordinates	Integrated livestock
Caçapava do Sul	1	14	Regosol	30°39'38.09"S 53°27'40.78"O	Bovine cattle
Caçapava do Sul	2	14	Regosol	30°39'39.38"S 53°27'35.64"O	Bovine cattle
Caçapava do Sul	3	11	Regosol	30°24'53.95"S 53°26'48.62"O	Bovine cattle
Cachoeira do Sul	4	12	Acrisol	29°55'27.03"S 52°54'25.92"O	Sheep
Cachoeira do Sul	5	12	Acrisol	29°55'29.78"S 52°54'34.40"O	Sheep
Cachoeira do Sul	6	12	Acrisol	29°55'32.63"S 52°54'35.16"O	Sheep
Caçapava do Sul	7	18	Luvisol	30°37'29.21"S 53°20'42.83"O	Pigs
São Gabriel	8	6	Acrisol	30°04'05.2"S 54°27'44.8"O	Sheep

* Classification by World Resource Base-FAO (WRB/FAO). Source: Authors (2022)

Soil samples were taken one meter away from the trunk of each individual, in the row and the interrow, from mini-trenches, at depths 0-10 cm, 10-20 cm, and 20-40 cm. The row and interrow samples of the same tree were joined and homogenized to get only one sample per depth. After collection, the soil was air-dried, ground, and sieved (2 mm).

Samples of leaf tissue were constituted of approximately 100 youngest fully mature leaves per tree, taken from branches of the year, in the middle third of the canopy height, from the four quadrants. In the laboratory, leaf samples were washed with distilled water, oven-dried at 50°C until constant mass, and ground at 1 mm.

Fruit tissue was sampled simultaneously to the harvest of olives to oil extraction and, therefore, each orchard owner determined the maturation stages to harvesting. In each tree, all fruits were harvested manually and the fresh mass constituted the olive fruit yield. The fruit samples were stored in plastic bags and frozen (-20°C) until the moment of analysis, when the fruits were washed with distilled water, ground (whole fruit, without pulp separation), and dried at 60°C.

The soil samples were chemically evaluated by $\text{pH}_{\text{H}_2\text{O}}$, contents of total nitrogen (N), exchangeable aluminum (Al^{3+}), and exchangeable potassium (K) according to Tedesco et al. (1995); exchangeable phosphorus (P) extracted with Mehlich-I method and determination according to Murphy and Riley (1962), and available boron (B) according to Reis et al. (2006) with adaptations; total organic carbon (TOC) was analyzed according to Allison (1960), and the soil texture was determined according to Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA 1997) with modifications. In leaf tissue and fruits, contents of total N, P, K, and B were evaluated according to Tedesco et al. (1995). The results of the chemical analysis of soil and leaf tissue were interpreted according to the Manual of Fertilization and Liming for the states of Rio Grande do Sul and Santa Catarina (CQFS – RS/SC 2016) and EPAMIG (2012).

The data were submitted to Pearson correlations analysis, where the correlations among leaf, fruit, and soil chemical parameters with relative production of olive trees were evaluated. Correlations were considered significant when $P \leq 0.05$.

3. Results

3.1 Chemical Analysis

pH and exchangeable Aluminum (Al^{3+}) from the soil

In general, the orchards presented adequate parameters of acidity for the crop in superficial soil layers (Table 2). However, in the deepest layer studied (20-40 cm), pH was lower than 5.5 in 35% of the samples.

The soil pH differences between the layers affected the exchangeable Al^{3+} contents. In layer 0-10 cm, contents of Al^{3+} greater than 1.0 $\text{cmol}_c \text{ kg}^{-1}$ were not observed and, in layers 10-20 cm and 20-40 cm, most samples were in the range between 0.1-1.0 $\text{cmol}_c \text{ kg}^{-1}$ (Table 2). Nevertheless, in layer 20-40 cm, some of the samples presented Al^{3+} values greater than 1.0 $\text{cmol}_c \text{ kg}^{-1}$.

Table 2 – Relative distribution of soil samples (%) as to pH-H₂O values and exchangeable aluminum content (cmol_c kg⁻¹) according to soil depth in olive orchards.

Attribute	Value range	Depth (cm)		
		0-10	10-20	20-40
		-----%-----		
pH-H ₂ O	<5.5	0.00	7.50	35.00
	5.6-6.0	2.50	26.25	23.75
	6.1-6.5	30.00	25.00	18.75
	>6.5	67.50	41.25	22.50
Exchangeable Al (cmol _c kg ⁻¹)	>1.0	0.00	3.75	31.25
	0.1-1.0	66.25	73.75	57.50
	0	33.75	22.50	11.25

Source: Authors (2022).

Phosphorus contents in soil, leaves, and fruits

Soil contents of available P (Mehlich-1 P) were predominantly Low in the topsoil layer (0-10 cm depth) and Very Low in the subsurface (10-20 and 20-40 cm depth layers; Table 3), suggesting a restriction to the orchards by the scarcity of the element (CQFS-RS/SC 2016). In the present study, P contents are low even in the surface layer, as 54% of the soil samples from the 0-10 cm layer are ranked in the Low and Very Low classes. However, this apparent scarcity was not followed by low P levels in the leaf contents (Table 3), in which a small percentage of samples were classified as having insufficient P content.

Tables 4 and 5 show the averages of P in fruits. Orchard 3 has similar averages to the studies of Bender et al. (2018) and Rodrigues et al. (2012), while orchard 7 was half of the values of these studies.

As a consequence of the low P concentration in the olive fruits, the exportation by the fruit harvest is small (Tables 4 and 5). Given the values and the CQFS-RS/SC (2016) recommendation to apply 4kg of P₂O₅ ton⁻¹ of exported fruit (equivalent to 1.74kg P ton⁻¹ fruit), it can be said that the recommendation for this nutrient is sufficient to replace P exportation by harvest observed in this study, even considering that part of the phosphate fertilizer will be fixed in the soil and become unavailable to the plant.

Potassium in soil, leaves, and fruits

The exchangeable K contents of the soil presented, in general, adequate levels for the olive tree, since in most soil samples of the superficial layers the K content was above the threshold level (Table 3). However, in the deepest layer, the Very Low content was predominant. Along with the profile, as well as for the P content, a lower content is also observed in the 20-40 cm layer, which is coherent with the applications of potassium fertilizer on the surface. However, it is noteworthy that the 10-20 cm layer presented a higher percentage of samples with Very High exchangeable K than the surface layer. Probably the low CTC of tested soils and the mobility of K were decisive for this behavior (data not shown).

Among the orchards that had fruit production (3 and 7), opposite situations were observed about the interpretation class of soil K predominant in experimental units: in orchard 3, the predominance of Very High content, while in orchard 7, Very Low. This result is associated with both fertilization management and the parent material of the sites. Despite both orchards being located in Caçapava do Sul city, the first one is situated in a region whose soils are shallow and stony,

presenting in their composition granite, with an abundance of potassium feldspar as primary mineral, favoring higher levels of the element.

The K content of leaf tissue, both in winter and summer, showed similar results. Most samples were ranked within the high level, followed by the insufficient and adequate content (Table 3), which in general is consistent with the soil exchangeable K results.

The averages of K in the fruits are in Tables 4 and 5. The high K levels in the fruits mean a higher export of the nutrient by production. The average removal of the nutrient for orchards 3 and 7 are in Tables 4 and 5, respectively. It can be seen that the difference in K exported between both orchards is mainly to the contrasting productivity and not to the K content in fruits.

In the condition of greater water availability in southern Brazil, K deficiency is easily corrected with the exclusive application of soil fertilizer. In southern Brazil, the recommendation of CQFS-RS/SC (2016) is to apply 20 kg of K₂O or 16.6 kg K per ton of harvested fruit.

Boron in soil, leaves, and fruits

Available B content in the soils was predominantly classified as high only in the surface layer (0-10 cm), while in 10-20 cm and 20-40 cm it ranked predominantly in the medium level classification (Table 3).

The analysis of leaf tissue collected in the winter revealed that the vast majority of the 80 experimental units showed B content classified as adequate (Table 3). The remaining percentage was recorded as high. For the samples collected in the summer, most of the samples were also classified as adequate, but the remaining percentage was insufficient for leaf B.

Boron content in fruits is reported in Tables 4 and 5. Comparing B content in the fruits with the content found in the soil, it can be observed that orchard 3 also had higher soil contents, and this is probably the cause for B being in the fruits with a higher average. Another reason is the type of soil since orchard 7 is located on sandy soil, where B is less adsorbed. The fruit yield had a marked effect on B exportation: orchard 3 had average exportation much higher than orchard 7 (Table 4 and 5).

The CQFS-RS/SC (2016) does not present a maintenance fertilization recommendation for B, but Mesquita et al. (2012) recommend applying 25-40 g of B per plant in the soil in case of deficiency, in addition to the application of a 0.1% concentration solution via foliar. Since the removal of B through the harvest is small, the amount of 25-40 g B per tree could promote the correction of B in the soil to adequate levels and the maintenance of these levels for the long term, in case of low losses of this element through leaching and runoff.

Nitrogen in leaves and fruits

In the leaf tissue sampled during the winter, more than half of the samples fell within the adequate content, followed by the high content. During the summer, more than half of the samples obtained high content (Table 3). In the present study, in most of the orchards, foliar N levels were highest in summer, probably because these orchards receive most of the N fertilizer after the winter.

The averages of N in the fruit and yield are in Tables 4 and 5. The recommendation of N fertilization in adult olive orchards in south Brazil is 16 kg N ha⁻¹ per ton of harvested fruit (CQFS – RS/SC 2016). Considering that the use efficiency of nitrogen fertilizers is generally low due to losses by volatilization and leaching, along with possible exports of N via pruning, the application recommendation for the crop seems to be adequate. However, it is important to monitor carefully and periodically, through leaf analysis, to avoid excessive N, especially in the post-harvest period until the end of winter, to avoid possible losses in flowering, fruit formation, and production.

Table 3 – Percent distribution of soil samples, per layer, and leaf tissue in the interpretation classes of N, P, K, and B contents in the evaluated orchards, according to CQFS-RS/SC (2016) and EPAMIG (2012).

Interpretation	Soil					Leaf Tissue			
	Concentration mg kg ⁻¹		Distribution of samples in each soil layer (%)			Interpretation	Concentration N, P, K (%m/m) B (mg kg ⁻¹)	Distribution of samples (%)	
			0-10 cm	10-20 cm	20-40 cm			Winter	Summer
			-----N-----						
						Insufficient	≤1.5	19.0	2.0
						Adequate	1.5-2.0	51.0	40.0
						High	>2.0	30.0	58.0
			-----P-----						
	Class 3¹	Class 4²							
Very low	<6.0	<10.0	21.25	62.50	70.0				
Low	6.1-12.0	10.1-20.0	32.50	11.25	8.75	Insufficient	≤0.10	10.0	2.0
Medium	12.1-18.0	20.1-30.0	7.50	5.00	5.00	Adequate	0.1-0.3	55.0	58.0
High	18.1-36.0	30.1-60.0	10.00	7.50	8.75	High	>0.3	35.0	40.0
Very high	>36.0	>60.0	28.75	13.75	7.50				
			-----K-----						
Very low		0-30	6.25	23.75	40.00				
Low		31-60	18.75	23.75	21.25	Insufficient	≤0.8	23.0	14.0
Medium		61-90	11.25	12.50	10.00	Adequate	0.8-1.2	15.0	10.0
High		91-180	33.75	22.50	17.50	High	>1.2	62.0	76.0
Very high		>180	30.00	17.50	11.25				
			-----B-----						
Low	<0.1		3.75	16.25	16.25	Insufficient	<14	0.0	14.0
Medium	0.1-0.3		42.50	55.00	61.25	Adequate	19-150	98.0	86.0
High	>0.3		53.75	28.75	22.50	High	150-185	2.0	0.0

¹: Clay content class 3 = 40 to 21%; ²: Clay content class 4 = ≤20%; ³: CTC_{pH7.0} = 7.6 – 15.0. Source: Authors (2022)

Table 4 - Data on total production, nutrient content of fruit, and nutrient exportation by fruit in g tree⁻¹ e kg ha⁻¹ for orchard 3, Caçapava do Sul-RS. E.U: Experimental Unit.

E.U.	Fruit production (kg tree ⁻¹)	Nutrient content of fruit				Nutrient exportation by fruit									
		N	P	K	B	N	P	K	B	N	P	K	B		
		--- g 100 g ⁻¹ DM --		mg kg ⁻¹ DM		----- g tree ⁻¹ -----				mg tree ⁻¹				----- kg ha ⁻¹ * -----	
		-													
1	2,18	0.73	0.12	1.74	32.38	6.57	1.09	15.74	292.65	4.39	0.73	10.49	0.020		
2	11.28	1.37	0.24	1.09	39.36	62.63	11.36	50.41	1806.24	41.76	7.58	33.61	0.120		
3	20.47	0.86	0.10	2.79	84.44	68.26	8.67	221.51	6695.40	45.51	5.79	147.68	0.446		
4	12.28	1.24	0.15	1.79	46.34	59.99	7.53	86.97	2244.12	39.99	5.02	57.98	0.150		
5	37.07	0.88	0.10	2.06	49.84	133.35	16.54	311.65	7536.00	88.91	11.03	207.77	0.502		
6	26.325	1.30	0.17	1.96	58.09	135.87	18.03	205.48	6062.57	90.58	12.02	136.99	0.404		
8	23.56	1.09	0.15	2.21	60.95	102.09	14.00	206.70	5698.84	68.07	9.34	137.81	0.380		
9	28.09	1.01	0.13	1.97	28.25	109.99	15.08	215.57	3083.11	73.33	10.06	143.71	0.206		
10	14.95	0.78	0.11	3.99	30.15	47.01	6.97	241.44	1824.98	31.35	4.65	160.96	0.122		
Average	19.58	1.03	0.14	2.18	47.76	80.64	11.03	172.83	3915.99	53.76	7.36	115.22	0.261		

* For each hectare, considering a plant density of 666.7 per hectare; the average dry mass content of fruit: 39.95% (W/W). Source: Authors (2022).

Table 5 - Data on total production, nutrient content of fruit, and nutrient exportation by fruit in g tree⁻¹ e kg ha⁻¹ for orchard 7, Caçapava do Sul-RS. E.U: Experimental Unit.

E.U.	Fruit production (kg tree ⁻¹)	Nutrient content of fruit				Nutrient exportation by fruit							
		N	P	K	B	N	P	K	B	N	P	K	B
		----- g 100 g ⁻¹ DM -----		mg kg ⁻¹ DM		----- g tree ⁻¹ -----		mg tree ⁻¹		----- kg ha ⁻¹ * -----			
1	2.078	2.04	0.081	2.162	11.811	17.679	0.70	18.69	102.132	4.209	0.166	4.45	0.002
2	3.572	1.81	0.037	1.751	10.630	26.614	0.54	25.76	156.422	6.337	0.129	6.13	0.004
3	3.649	1.17	0.047	1.375	5.512	18.224	0.74	21.38	85.731	4.339	0.175	5.09	0.002
4	2.341	1.79	0.055	1.574	14.567	17.457	0.54	15.40	142.458	4.156	0.128	3.67	0.003
5	6.058	1.24	0.110	2.902	13.386	32.598	2.89	76.14	351.204	7.761	0.688	18.13	0.008
6	7.830	0.89	0.025	0.987	17.717	30.550	0.87	33.93	609.103	7.274	0.207	8.08	0.015
7	3.515	1.31	0.064	2.080	13.780	18.858	0.93	29.86	197.880	4.490	0.220	7.11	0.005
8	2.733	1.71	0.055	1.657	16.142	0.006	0.00	0.01	0.052	0.001	0.000	0.00	0.000
9	0.460	1.50	0.046	1.610	16.142	16.281	0.50	17.45	174.973	3.876	0.119	4.15	0.004
10	2.078	1.67	0.042	1.269	18.898	2.937	0.07	2.24	33.294	0.699	0.018	0.53	0.001
Average	3.57	1.51	0.06	1.74	13.86	18.12	0.78	24.08	185.32	4.31	0.18	5.73	0.004

* For 1 hectare, considering a plant density of 238.09 per hectare; mean dry mass content of fruit: 41.30% (W/W). Source: Authors (2022).

3.2 Pearson correlations between nutrients in the soil, leaf tissue, fruits, and relative yield

Pearson correlation analysis was carried out with both the weighted average of soil attributes (layer 0-40 cm) (Table 6) and separately by layers (0-10 cm; 10-20 cm and 20-40 cm) (Tables 7-9), where a large number of significant correlations among attributes were found ($P \leq 0.05$).

Of all the attributes (Table 6), the only ones that correlated with relative fruit yield were the N content in fruit and foliar N in winter, with an inverse relation.

The correlations involving soil pH were mostly inverse, which is in agreement with the fact that low pH values for olive trees (less than 5.5) are harmful to root development, decreasing water and nutrients uptake, especially when high levels of Al^{3+} are present. In general, the greatest availability, both of macro and micronutrients, is in the pH range between 5.5-7.0, which may vary according to the type of soil and plant species (Brady and Weil 2013). In this study, inverse correlations of pH with Al^{3+} are recorded in the 0-40 cm, 10-20 cm, and 20-40 cm layers.

Specifically regarding B uptake by olive trees, soil pH seems to affect markedly, as B content in fruits had an inverse relation with soil pH (Figure 1 A-C). Strong and inverse correlations were obtained in all layers and in the average of them (Tables 6-9). According to Figure 1, in all layers, it is possible to notice that soil pH exerted a greater influence on the B content of fruits than the B content in the soil, with the influence being easier to observe on the surface of 0-10 cm layer (Fig. 1A).

3.3 Timing for sampling leaf tissue and effect on correlations

Among the correlations of soil and foliar attributes, the number of significant relations ($P \leq 0.05$) was very similar when comparing leaf samples collected in the summer vs. winter period (Tables 7-9). In the winter sampling event, a total of 10, 13, and 10 significant relations were found for the layers 0-10, 10-20, and 20-40 cm, respectively, while in summer a total of 14, 11, and 9 significant relations were observed for the same respective layers.

3.4 Diagnostic soil sampling layer and effect on correlations

The total number of significant correlations ($P \leq 0.05$) per layer was similar: 105, 103, and 94 at 0-10, 10-20, and 20-40 cm, respectively. Therefore, it could be concluded that more superficial layers could be sufficient for sampling orchards in general. However, probable chemical restrictions due to the high Al^{3+} content in part of orchards were evident in the 20-40 cm layer.

Table 6 - Correlation between soil parameters (0-40 cm), leaf, and fruit nutrients, and relative yield of evaluated orchards.

Nut.	Al	N _s	P _s	K _s	B _s	TOC	N _{fw}	P _{fw}	K _{fw}	B _{fw}	N _{fs}	P _{fs}	K _{fs}	B _{fs}	N _{fr}	P _{fr}	K _{fr}	B _{fr}	RY
pH	-0,69**	-0.17	-0.07	-0.37**	-0.08	-0.02	0.04	-0.14	0.48**	-0.35***	0.38**	0.03	-0.16	0.09	0.63***	0.87**	-0.85**	-0.82**	-0.26
Al	1	0.12	-0.19	-0.04	-0.19	0.04	0.14	0.01	-0.46**	0.56**	-0.26*	-0.22	-0.22	-0.26*	-0.42	-0.56*	0.65***	0.36	0.15
N_s		1	-0.06	0.29***	0.46**	0.69*	0.36**	0.54**	-0.35***	0.31***	0.15	0.24*	0.48**	0.37***	-0.58***	-0.84**	0.74**	0.71**	-0.00
P_s			1	0.25*	0.46*	0.02	0.02	0.11	-0.20	-0.01	-0.25*	0.35***	0.14	0.47**	-0.54*	-0.69***	0.73**	0.81**	-0.00
K_s				1	0.56**	0.01	-0.05	0.27*	-0.11	0.06	-0.32***	0.32***	0.24*	0.54**	-0.60***	-0.85**	0.82**	0.70**	0.04
B_s					1	0.35***	0.18	0.28*	-0.11	0.09	-0.13	0.21	0.25*	0.77**	-0.57*	-0.65***	0.75**	0.70***	0.00
TOC						1	0.29***	0.16	-0.42**	0.05	-0.14	-0.06	0.14	0.20	-0.56*	-0.83**	0.69***	0.70**	0.07
N_{fw}							1	0.18	-0.29***	0.50**	-0.10	0.02	0.18	0.26*	0.34	0.17	-0.18	-0.10	-0.46*
P_{fw}								1	-0.19	0.32***	-0.30***	0.49**	0.52**	0.40**	-0.47*	-0.53*	0.59***	0.72**	0.34
K_{fw}									1	-0.43**	0.50**	-0.09	-0.01	-0.11	0.77**	0.74**	-0.74**	-0.66***	-0.40
B_{fw}										1	-0.37***	0.12	0.20	-0.30***	-0.41	-0.70**	0.56***	0.66***	-0.15
N_{fs}											1	-0.14	-0.13	-0.22	0.66***	0.77**	-0.71**	-0.62***	-0.28
P_{fs}												1	0.47**	0.35***	-0.63***	-0.64***	0.85**	0.62**	0.25
K_{sv}													1	0.39**	-0.28	-0.42	0.29	0.30	-0.31
B_{fs}														1	0.60***	-0.79**	0.82**	0.89**	0.13
N_{fr}															1	0.64***	-0.68***	-0.50*	-0.46*
P_{fr}																1	-0.81**	-0.75**	-0.15
K_{fr}																	1	0.74**	0.20
B_{fr}																		1	0.26

Nut: nutrient; N_s: soil nitrogen; P_s: soil phosphorus; K_s: soil potassium; TOC: total organic carbon; Al: aluminum; N_{fw}: foliar winter nitrogen; P_{fw}: foliar winter phosphorus; K_{fw}: foliar winter potassium; B_{fw}: foliar winter boron; N_{fs}: foliar summer nitrogen; P_{fs}: foliar summer phosphorus; K_{fs}: foliar summer potassium; B_{fs}: foliar summer boron; N_{fr}: fruit nitrogen; P_{fr}: fruit phosphorus; K_{fr}: fruit potassium; B_{fr}: fruit boron; RY: relative yield; *:significant p<0.05; **: significant p<0.001; ***: significant p<0.01. Source: Authors (2022)

Table 7 - Correlation between soil parameters (0-10 cm), leaf and fruit nutrients, and relative yield of evaluated orchards.

Nut.	Al	N_s	P_s	K_s	B_s	TOC	N_{fw}	P_{fw}	K_{fw}	B_{fw}	N_{fs}	P_{fs}	K_{fs}	B_{fs}	N_{fr}	P_{fr}	K_{fr}	B_{fr}	RY
pH	-0.09	-0.26*	0.03	-0.66**	-0.25	0.08	0.10	-0.26*	0.01	-0.22*	0.13	-0.15	0.00	-0.20	0.64***	0.82**	-0.85**	-0.75**	-0.38
Al	1	0.23*	-0.09	0.02	-0.24*	-0.01	0.20	0.38**	-0.28*	0.56**	-0.26*	0.10	0.26*	0.01	-0.24	-0.55*	0.26	0.30	0.06
N_s		1	-0.12	0.32***	0.41**	0.45**	0.32***	0.56**	-0.18	0.19	-0.04	0.33***	0.54**	0.28*	-0.53*	-0.71**	0.57***	0.63***	-0.02
P_s			1	0.16	0.28**	-0.00	0.02	0.11	-0.15	0.00	-0.23*	0.37***	0.19	0.48**	-0.54*	-0.67***	0.73**	0.77**	-0.02
K_s				1	0.46**	-0.07	-0.13	0.39**	0.04	0.14	-0.24*	0.35***	0.33*	0.54**	-0.62***	-0.85**	0.87**	0.71**	0.09
B_s					1	0.32***	0.16	0.25*	-0.04	-0.02	-0.08	0.18	0.24*	0.65**	-0.56*	-0.63***	0.69***	0.71**	0.06
TOC						1	0.17	0.06	-0.31***	-0.04	-0.08	-0.02	0.03	0.12	-0.53*	-0.77**	0.68***	0.76**	0.12
N_{fw}							1	0.18	-0.29***	0.50**	-0.11	0.02	0.18	0.26*	0.34	0.17	-0.18	-0.10	-0.46*
P_{fw}								1	-0.19	0.32***	-0.30***	0.49**	0.52**	0.40**	-0.47*	-0.53*	0.59***	0.72**	0.34
K_{fw}									1	-0.43**	0.50**	-0.09	-0.01	-0.11	0.77**	0.74**	-0.74**	-0.66***	-0.40
B_{fw}										1	-0.37***	0.12	0.20	0.30***	-0.41	-0.70**	0.56*	0.66***	-0.15
N_{fs}											1	-0.14	-0.13	-0.22	0.66***	0.77**	-0.71**	-0.62***	-0.28
P_{fs}												1	0.47**	0.35***	-0.63***	-0.64***	0.85**	0.62***	0.25
K_{sv}													1	0.39**	-0.28	-0.42	0.28	0.30	-0.31
B_{fs}														1	-0.60***	-0.79**	0.82**	0.89**	0.13
N_{fr}															1	0.64***	-0.68***	-0.50*	-0.46*
P_{fr}																1	-0.81**	-0.75**	-0.15
K_{fr}																	1	0.74**	0.20
B_{fr}																		1	0.26

Nut: nutrient; N_s: soil nitrogen; P_s: soil phosphorus; K_s: soil potassium; TOC: total organic carbon; Al: aluminum; N_{fw}: foliar winter nitrogen; P_{fw}: foliar winter phosphorus; K_{fw}: foliar winter potassium; B_{fw}: foliar winter boron; N_{fs}: foliar summer nitrogen; P_{fs}: foliar summer phosphorus; K_{fs}: foliar summer potassium; B_{fs}: foliar summer boron; N_{fr}: fruit nitrogen; P_{fr}: fruit phosphorus; K_{fr}: fruit potassium; B_{fr}: fruit boron; RY: relative yield; *:significant p<0.05; **: significant p<0.001; ***: significant p<0.01. Source: Authors (2022)

Table 8 - Correlation between soil parameters (10-20 cm), leaf and fruit nutrients and relative yield of evaluated orchards.

Nut.	Al	N _s	P _s	K _s	B _s	TOC	N _{fw}	P _{fw}	K _{fw}	B _{fw}	N _{fs}	P _{fs}	K _{fs}	B _{fs}	N _{fr}	P _{fr}	K _{fr}	B _{fr}	RY
pH	-0.56**	-0.25*	-0.00	-0.38**	-0.23*	-0.00	0.08	-0.18	0.37**	-0.35***	0.28*	-0.05	0.12	-0.04	0.62***	0.86**	-0.87**	-0.81**	-0.25
Al	1	0.18	-0.22	-0.10	-0.10	-0.02	0.09	0.10	-0.26*	0.48**	-0.15	-0.08	-0.03	-0.16	-0.11	0.12	0.11	0.04	0.11
N _s		1	-0.16	0.17	0.39**	0.65**	0.32***	0.49**	-0.34***	0.24*	-0.17	0.19	0.47**	0.30*	-0.57*	-0.82**	0.71**	0.64***	0.00
P _s			1	0.19	0.41**	-0.07	-0.00	0.10	-0.23*	-0.04	-0.29*	0.25*	0.07	0.36***	-0.48*	0.68***	0.70**	0.62***	0.00
K _s				1	0.57**	0.00	-0.17	0.24*	0.08	0.01	-0.21	0.29*	0.25*	0.51**	-0.65***	-0.84**	0.85**	0.67***	0.11
B _s					1	0.30***	0.06	0.27*	-0.07	0.10	-0.16	0.16	0.27*	0.78**	-0.59***	-0.69***	0.81**	0.73**	-0.01
TOC						1	0.23*	0.14	-0.34***	0.01	-0.15	-0.14	0.17	0.20	-0.58***	-0.83**	0.71**	0.70**	0.23
N _{fw}							1	0.18	-0.29***	0.50**	-0.11	0.02	0.18	0.26*	0.34	0.17	-0.18	-0.10	-0.46*
P _{fw}								1	-0.19	0.32***	-0.30***	0.49**	0.52**	0.40**	-0.47*	-0.53*	0.59***	0.72**	0.34
K _{fw}									1	-0.43**	0.50**	-0.09	-0.01	-0.11	0.77**	0.74**	-0.74**	-0.66***	-0.40
B _{fw}										1	-0.37***	0.12	0.20	0.30***	-0.41	-0.70**	0.56*	0.66***	-0.15
N _{fs}											1	-0.14	-0.13	-0.22	0.66***	0.77**	-0.71**	-0.62***	-0.28
P _{fs}												1	0.47**	0.35***	-0.63***	-0.64***	0.85**	0.62***	0.25
K _{sv}													1	0.39**	-0.28	-0.42	0.28	0.30	-0.31
B _{fs}														1	-0.60***	-0.79**	0.82**	0.89**	0.13
N _{fr}															1	0.64***	-0.68***	-0.50*	-0.46*
P _{fr}																1	-0.81**	-0.75**	-0.15
K _{fr}																	1	0.74**	0.20
B _{fr}																		1	0.26

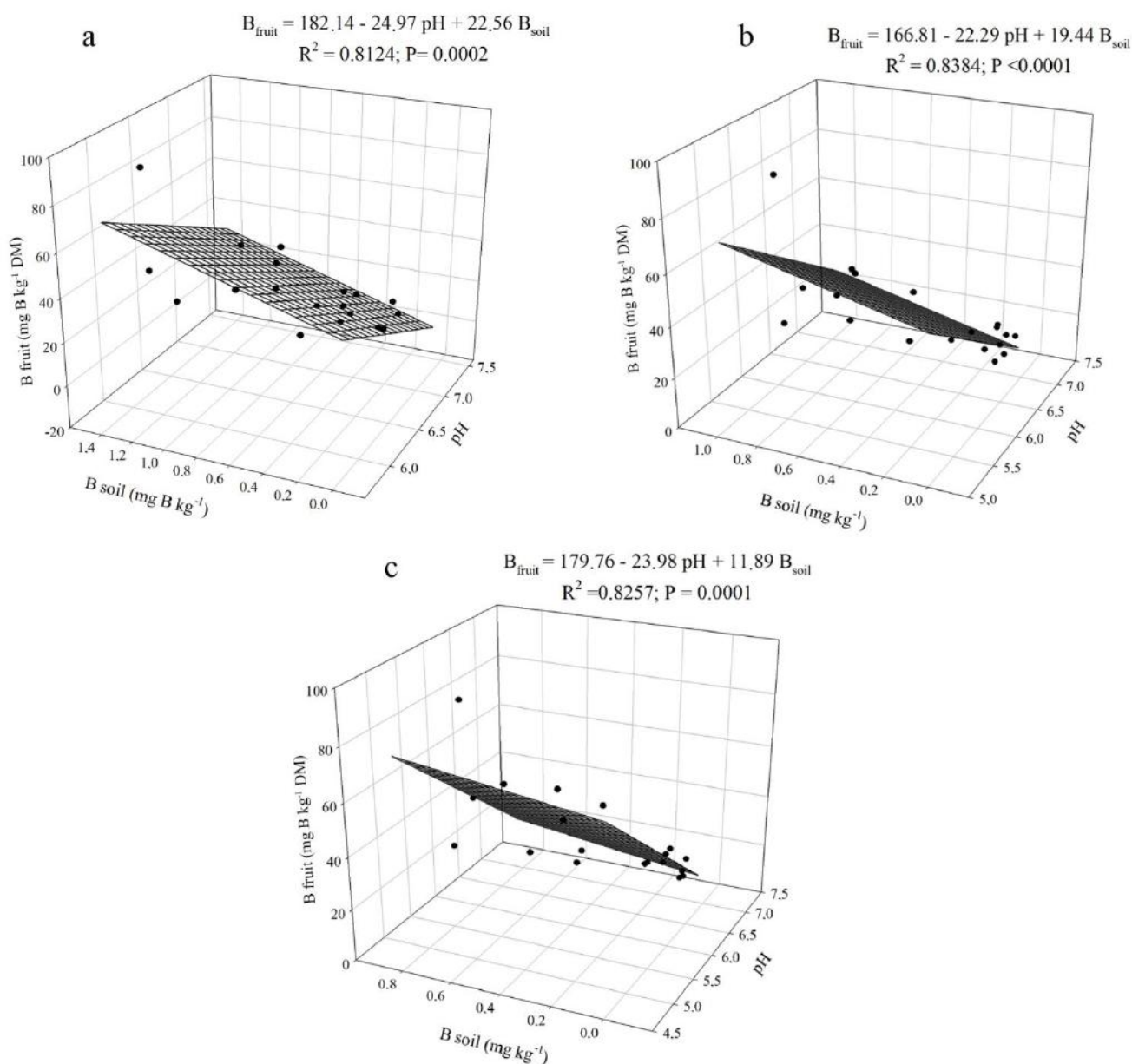
Nut: nutrient; N_s: soil nitrogen; P_s: soil phosphorus; K_s: soil potassium; TOC: total organic carbon; Al: aluminum; N_{fw}: foliar winter nitrogen; P_{fw}: foliar winter phosphorus; K_{fw}: foliar winter potassium; B_{fw}: foliar winter boron; N_{fs}: foliar summer nitrogen; P_{fs}: foliar summer phosphorus; K_{fs}: foliar summer potassium; B_{fs}: foliar summer boron; N_{fr}: fruit nitrogen; P_{fr}: fruit phosphorus; K_{fr}: fruit potassium; B_{fr}: fruit boron; RY: relative yield; *: significant p<0.05; **: significant p<0.001; ***: significant p<0.01. Source: Authors (2022)

Table 9 - Correlation between soil parameters (20-40 cm), leaf and fruit nutrients and relative yield of evaluated orchards.

Nut.	Al	N _s	P _s	K _s	B _s	TOC	N _{fw}	P _{fw}	K _{fw}	B _{fw}	N _{fs}	P _{fs}	K _{fs}	B _{fs}	N _{fr}	P _{fr}	K _{fr}	B _{fr}	RY
pH	-0.73**	-0.22*	-0.12	-0.24*	-0.04	-0.11	0.01	-0.06	0.57**	-0.33***	0.44**	0.09	0.20	0.18	0.65***	0.86**	-0.91**	-0.81**	-0.18
Al	1	0.20	-0.10	0.02	-0.12	0.10	0.14	-0.01	-0.47**	0.53**	-0.25*	-0.24*	-0.26*	-0.28*	-0.38	-0.53*	0.61*	0.31	0.14
N_s		1	0.03	0.12	0.43**	0.60**	0.31***	0.41**	-0.45**	0.38**	-0.20	0.10	0.34*	0.41**	-0.52*	-0.79**	0.71***	0.68***	-0.01
P_s			1	0.25*	0.17	0.16	0.00	-0.01	-0.21	-0.08	-0.11	0.07	-0.04	0.22	-0.21	-0.30	0.27	0.40	0.01
K_s				1	0.30**	0.02	-0.07	0.02	-0.13	-0.09	-0.21	0.05	-0.08	0.25*	-0.64***	-0.85**	0.84**	0.71**	0.03
B_s					1	0.26*	0.15	0.21	-0.11	0.12	-0.11	0.19	0.19	0.74**	-0.53*	-0.60***	0.73**	0.64***	-0.01
TOC						1	0.28*	0.18	-0.42**	0.07	-0.12	-0.04	0.13	0.14	-0.46*	-0.74**	0.58***	0.57*	-0.08
N_{fw}							1	0.18	-0.29***	0.50**	-0.11	0.02	0.18	0.26*	0.34	0.17	-0.18	-0.10	-0.46*
P_{fw}								1	-0.19	0.32**	-0.30**	0.49**	0.52**	0.40**	-0.47*	-0.53*	0.59***	0.72**	0.34
K_{fw}									1	-0.43**	0.50**	-0.09	-0.01	-0.11	0.77**	0.74**	-0.74**	-0.66***	-0.40
B_{fw}										1	-0.37***	0.12	0.20	0.30***	-0.41	-0.70**	0.56*	0.66***	-0.15
N_{fs}											1	-0.14	-0.13	-0.22	0.66***	0.77**	-0.71**	0.62***	-0.28
P_{fs}												1	0.47**	0.35***	-0.63***	-0.64***	0.85**	0.62***	0.29
K_{sv}													1	0.39**	-0.28	-0.42	0.28	0.30	-0.31
B_{fs}														1	-0.60***	-0.79**	0.82**	0.89**	0.13
N_{fr}															1	0.64***	-0.68***	-0.50*	-0.46*
P_{fr}																1	-0.81**	-0.75**	-0.15
K_{fr}																	1	0.74**	0.20
B_{fr}																		1	0.26

Nut: nutrient; N_s: soil nitrogen; P_s: soil phosphorus; K_s: soil potassium; TOC: total organic carbon; Al: aluminum; N_{fw}: foliar winter nitrogen; P_{fw}: foliar winter phosphorus; K_{fw}: foliar winter potassium; B_{fw}: foliar winter boron; N_{fs}: foliar summer nitrogen; P_{fs}: foliar summer phosphorus; K_{fs}: foliar summer potassium; B_{fs}: foliar summer boron; N_{fr}: fruit nitrogen; P_{fr}: fruit phosphorus; K_{fr}: fruit potassium; B_{fr}: fruit boron; RY: relative yield; *:significant p<0.05; **: significant p<0.001; ***: significant p<0.01. Source: Authors (2022).

Figure 1 – Multiple regression among soil pH, available boron in soil and average content of B in fruit. a) Layer 0-10 cm; b) Layer 10-20 cm; c) Layer 20-40 cm.



Source: Authors (2022).

4. Discussion

The acidity conditions of the soil can be restrictive to the root deepening of olive trees, decreasing the volume of soil explored, as well as water and nutrients uptake (Jones & Ryan 2017; Shetty et al 2020), decreasing the crop yield. The proper correction of these attributes in deep layers is only possible to be made at the orchard implementation. Considering the long lifespan expected for an olive grove and the occurrence of naturally acidic and aluminic soils in southern Brazil, the soil pH correction along the profile is of utmost importance before the orchard implantation.

In adult orchards with subsoil acidity problems, the application of agricultural gypsum is an alternative to favor calcium descent in the profile and attenuate Al^{3+} toxicity to roots in the subsurface (Tiecher et al. 2018), but the effectiveness

of such subsoil amelioration is smaller than that from adequate incorporation of liming at implementation. The gypsum does not alter the soil pH and, in sandy soils (as verified in several olive orchards in southern Brazil), the gypsum rate should be estimated with severe criteria, to maximize the benefits of this technique without promoting damage by leaching of nutrients such as K.

Since P has low mobility in the soil, its stratification along the soil profile tends to accentuate over the years (Mesquita et al. 2012). In orchards in which P fertilizers are not incorporated in the soil before establishment, the stratification tends to be even greater.

In orchards in the same region, Bender et al. (2018) described olive orchards with adequate P contents in leaves from trees where available P in the soils was considered low, as the results presented in this study. The same authors suggested the classification of olives in the group of Low P demanding species in the CQFS-RS/SC (2016) manual. The contradiction between leaf and soil P contents may be also related to the low P exportation through the harvest of olive fruits (Tiecher et al. 2020). In addition, olive trees seem to be efficient in absorbing the nutrient from soils, which can be related to the association with arbuscular mycorrhizae, improving the uptake of nutrients, including less labile P forms from the soil (Chenchouni et al. 2019).

Broadcast and incorporation of P fertilizers onto the soil at orchard implementation and maintenance fertilizations are advised (CQFS-RS/SC 2016; Tiecher et al. 2020) even though reports of P deficiency in olive orchards are rare (Jiménez-Moreno and Fernández-Escobar 2016) and few studies are conducted in the world (Chatzistathis et al, 2020). In the states of Rio Grande do Sul and Santa Catarina, a replenishment rate of 4kg of P₂O₅ ha⁻¹ for each ton of fruit produced is recommended (CQFS-RS/SC 2016). Although olive trees have low P exportation rates, such replenishment is important to avoid losses in yield or quality by P deprivation (Fernández-Escobar et al. 2015). After all, P is an important constituent of nucleic acids and phospholipids, which form cell membranes (Jiménez-Moreno & Fernández-Escobar 2016), acting on the processes of photosynthesis and respiration, root growth, and cell division (Mesquita et al. 2012).

Potassium is the nutrient in the largest concentration in the fruits, as already expected and reported (Fernández-Escobar et al. 2015). The averages obtained are close to that found by Bender et al. (2018), in southern Brazil, and by El-Fouly et al. (2014) in Egypt.

In olive groves in the Mediterranean region, K is the element with the highest frequency of deficiency-related nutritional problems (Fernández-Escobar et al. 2015; Fernández-Escobar et al. 2018), caused by the high exportation of K by fruit harvesting and pruning. The lower annual precipitation of the Mediterranean region and calcareous soil of the region contribute to this behavior, as K shows less movement towards the roots, where it is supplied predominantly by diffusion. Besides that, the abundance of Ca and Mg can cause antagonism with K, exacerbated in periods of drought. For this reason, in many olive groves in the Mediterranean region, foliar K fertilization is recommended to improve tree nutrition with this element.

Although the B levels in the soil are within the level considered adequate, they are very close to the value of the critical level (0.3 mg B kg⁻¹ of soil). Orchard 3, which was the only one with fruit production in the year 2018, had available B levels five times higher than the considered as critical level in some experimental units, an unusual situation to what is found in most Brazilian orchards, whose deficiency is easily observed. Boron is one of the micronutrients with more records of deficiency in Brazilian crops (Prado et al. 2006) and according to Deliboran et al. (2020), symptoms of deficiency and toxicity are common.

The availability of B to plants is affected by numerous factors, including soil texture, pH, and organic matter content. According to Rosolem and Bísvaro (2017), most of the available B in soils is bound to the organic fraction, but it can also be adsorbed in clays and iron and aluminum oxides (International Plant Nutrition Institute - INPI 2018). Thus, soils with low

organic matter contents tend to present lower B availability. Regarding texture, sandy soils or coarser soils tend to have a lower sorptive capacity and lower organic matter content, which favors greater leaching of B and lower natural availability of the element (Shibli & Srebnik 2002; INPI 2018). In acidic soils, B tends to remain less available for uptake, according to Shibli and Srebnik (2002). In the present work, these two conditions were observed separately, obtaining two orchards with lower contents of the nutrient: orchard 4, with acidic soils, and orchard 8 with a sandier texture soil. Associated with the above factors, historical B fertilization can be a master factor - there is no such information previously to the orchard implementation.

In most of the regions where olive is traditionally cultivated, B contents in the leaf tissues are considered adequate when the value falls within 19 to 150 mg B kg⁻¹ DM (Beutel et al. 1983), which is a wide range of concentrations. In the soil and climate conditions of southern Brazil, the same assortment was adopted, but up to now, there is no scientific support from local research for the critical levels of micronutrients in olive leaf tissue. We speculate, based on empirical observations, that the threshold value of 19 mg B kg⁻¹ is insufficient to provide adequate olive yields in the region.

It is possible to notice a large amplitude of contents among the orchards: the average of orchard 3 (47.76 mg B kg⁻¹ DM) was similar to other studies conducted in Portugal (Rodrigues et al. 2012; average 53.36 mg B kg⁻¹ DM) and orchard 7 obtained an average (13.86 mg B kg⁻¹ DM) closer to that found in the study by Bender et al. (2018; average 6.69 mg B kg⁻¹ DM), in the same region of the present study.

Nitrogen is the most required nutrient in most plants and olive trees and, together with K, is the element usually applied in the greatest amounts (Fernández-Escobar et al. 2002; Fernández-Escobar et al. 2014; INPI 2018). A study by Fernández-Escobar et al. (2004) described that in 'off'-year and in plants without fertilization, N accumulated in new leaves, so that can be used in the period of differentiation and growth of new shoots, occurring at the end of winter and with minimum peak seen in summer, during the harvest period. In fertilized plants, the levels are dependent on the fertilization seasons.

Monitoring N status periodically, through leaf analysis, is crucial to avoid excessive N, especially in the post-harvest period until the end of winter, to avoid possible losses in flowering, fruit formation, and production. Although the correlation coefficient was not so high between relative fruit yield and the N content in fruit and foliar, this result suggests that the nitrogen fertilization applied in high amounts to olive trees in the pre-flowering period is limiting fruit yield by an excess of the nutrient, which was warned in a previous study by Bender et al. (2018) in the same region. It is known that high N contents in the olive leaf can inhibit the flowering and fruiting, favoring the growth of the vegetative part at the expense of the reproductive one, as well as sensibility to pests and difficulty in absorbing other nutrients, like B, Fe, Mg and K (Erel et al. 2008; Fernández-Escobar et al. 2002; Fernández-Escobar et al. 2018; Zamora et al. 2010). Besides the loss in production, there is a greater need for pruning and there may be losses in the quality of the olive oil produced and a higher incidence of diseases.

At high soil pH, as required by the olive tree, available soil B must be higher for this element to reach higher levels in the fruit. The establishment of a threshold value of soil B for olive orchards in south Brazil, therefore, should be dependent on soil pH – the higher soil pH, the larger threshold values of available B in the soil should be. The present study corroborates the study of Bender et al. (2018) in the sense that the critical level of soil B for olives should be higher than that currently adopted in the subtropical climate of south Brazil.

It is not possible to state that correlations with foliar nutrient levels in summer are of greater relevance than those in winter. This is a relevant result from a practical point of view. After all, there is no standardization on the timing of leaf tissue sampling in olive trees in the south of Brazil. Although in summer there is the greatest demand for nutrients from the fruit, in winter there is greater stability of the contents (Mesquita et al. 2012). However, recent studies showed that the best timing for sampling to verify the nutritional status depends on the element evaluated and the variety studied. The studies conducted by Bueno et al. (2011) and Nieto et al. (2017) showed that for N and K the best sampling period would be in spring, when the development of fruits occurs. Additionally, for Nieto et al. (2017), P also could be analyzed at the same period as N and K, but

for B the collection must be between autumn and spring, when the trees are in dormancy, and at the beginning of the development of the inflorescences, corroborating with the findings of the present study, where the average of the element was higher in the winter period in seven of the eight orchards evaluated. In a study with six varieties of olive, Manolikaki et al. (2022) observed that concentrations of nutrients (Ca, Fe, & Mn) were affected by the genotype and season, with the highest concentration of the elements in April (Spring in North Hemisphere).

Considering that most fertilization is normally performed in the flowering and fruiting period, foliar sampling in winter favors the recommendation for the period of greatest demand by plants. However, knowing the nutritional status of the plant at harvest or in the fruit set is important to sustain adequate levels of the nutrients in leaves when fruits are a major sink. Thus, the recommendation to perform foliar sampling in olive trees twice a year seems quite reasonable. Regardless of the recommended sampling time in each system, the most important is to have support material for the correct recommendation, calibrated based on scientific results obtained at the same collection time that producers and technicians will use.

Considering the characteristic of the olive tree to have roots that can reach 1.5 m deep in soils without limitations (Navarro García et al. 2012) and the naturally acidic characteristic of southern Brazilian soils, it is important to analyze the 20-40 cm layer, even if sporadically, to monitor the acidification of the profile and guide the liming of the orchards in the medium and long term, although the best to correct subsoil acidity is the lime incorporation before the implementation of the orchard.

Studies of correlation are the base for the fine adjustment of a system for recommendation of fertilization. For future studies, we suggest to replicate the evaluations in different locations, with other types of cultivar (as we conducted only with Arbequina), soil, orchard managements and years, in order to expand the representativeness. However, due to the high spatial variability among the trees in the same orchard, the attributes should be quantified individually by tree, in order to refine the correlations among chemical characteristics of soil and leaf, as well as olive fruit yield. As the regional databank increases, new techniques for olive nutrition should be used (i.e. DRIS, CND, among others).

5. Conclusion

Most of the orchards present favorable nutritional conditions for the development of olive trees. However, some orchards may be restricted by P scarcity, as even in the surface layer the levels of this element are low. Also, in orchards with sandy soil, B levels are less than ideal for cultivation.

In some orchards, there is concern about the excess of Al^{3+} in depth associated with the acid pH of the soil, which may be hindering the absorption of water and nutrients by plants. For this reason, chemical analysis of deeper layers of soil (20-40 cm) are recommended. However, in orchards where subsoil pH was adequately corrected, soil sampling at 0-20 cm in routine sampling is enough to represent the soil fertility conditions for olives.

According to the data obtained in Pearson's Correlation analysis, excessive N may be causing limitations in production.

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