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ORIGINAL ARTICLE

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SOIL – TO – LEAF RELATIONSHIP IN MICRO AND MACROELEMENTS CONTENT ON THE VINEYARD MICROLOCATION

ABSTRACT: The conducted research aims to ascertain the variations in macro and microelement content within the soil-to-leaf relationship in small vineyards. The vineyard block (1.2 ha), located in Sremski Karlovci, Serbia, planted with Grašac (Riesling Italico), was divided into 20 subplots. Each subplot served as an individual location for soil and leaf sampling. Soil samples were collected at three depths, while leaf sampling occurred at two phenophase (end of flowering and at ripening), with separation into petiole and blade parts. Variability of soil physico-chemical characteristics between subplots was determinate, with the greatest variability in the 30–60 cm soil layer. The soil generally displayed low levels of organic matter and available P, K, Zn and B. Erosion processes were indicated by the spatial distribution of physico-chemical parameters. Differences in nutrient contents were noted among leaf parts and phenophases, aligning with existing literature. Comparing leaf nutrient status to optimal values from literature, N and P content was found at lower limits, confirming K and B deficiencies. Identically, fertilization recommendations can be inferred from soil and foliar analyses, primarily for N, K and B. Additionally, based on soil analysis, a slight increase in P and Zn application is advisable. Established correlations among all observed variables revealed connections between soil parameters, across all depths, and nutrients in the leaf blade at the end of flowering. It is notable to say that nutrient content in soil, particularly N, K, Mn and Zn, exhibited statistically significant positive correlations with its content in the leaf blade, respectively. Further research is necessary to lay the foundation for the development of accurate and reliable criteria for diagnosing nutrition, not only for the whole species but also among grapevine leading varieties. Given the significant variations in nutrient requirements and accumulation among these genotypes, this research will be instrumental in ensuring optimal nutrient supply while minimizing deficiencies or excesses.

KEYWORDS: vineyard soil, foliar analysis, Grašac (Riesling Italico) variety

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INTRODUCTION

In viticulture, there exists a greater potential for anthropogenic influence on soil improvement, compared to the possibility of improvement intervention on other abiotic factors, such as climate. Therefore, soil management should be approached systematically, already during the establishment of the vineyard (Ninkov et al., 2017). The transfer of nutrients from soil to plants has a significant impact on yield and, more importantly, on the quality of grapes, particularly in high-quality varieties that are used for winemaking. Both nutrient deficiencies and sufficiency have a crucial influence on the quality and yield of grapes. For example, it has been found that a low level of potassium can reduce sugar content and the amount of colour-giving compounds in grapes, while a high K level can decrease must acidity. Elevated nitrogen levels can delay ripening, resulting in lower levels of anthocyanins, increased acidity, reduced sugar and phenolic compound content, and lower colour intensity in grapes (García-Escudero et al., 2013).

It is well known that nutrient status in plants is influenced by numerous factors, ranging from complex soil processes (such as pH, carbonates, physical characteristics of the soil, among others), to climatic conditions, and the plant itself (species, age, phenological stage, etc.). In viticulture, this complexity is even more pronounced due to the influence of grape variety, rootstock and clones, as well as the ongoing impact of climate changes. After extensive soil analysis and soil improvement during vineyard establishment, it is advisable in viticulture to perform soil analysis every four years, while foliar analysis should be conducted every season. Foliar analysis is essential for fine-tuning nutrient management since soil status does not fully reflect the actual nutrient composition in the plant, as it is influenced by complex nutrient uptake processes from the soil. Several methods of nutritional plant analysis have been proposed; however, mineral content analysis of leaf blade and petiole are still the most widely used determination methods (García-Escudero et al., 2013; Hickey et al., 2021), while in the past, the entire leaf was analysed (Paprić et al., 2009). In addition, grapevine nutrient guidelines have mostly been developed for two phenological (growth) stages: bloom and veraison (ripening) (AWRI 2010, NSA 2011; Hickey et al., 2021).

Different parts of the leaf contain varying contents of nutrients, and it is important to compare them with appropriate criteria (Melo et al., 2018). When deciding between leaf petiole or leaf blade analysis, there are several advantages and disadvantages to consider. Generally, leaf petiole is easier to sample as a representative sample and has a longer history of application. However, as a transport tissue, it has lower accuracy and exhibits large diurnal and yearly fluctuations in nutrient contents. Additionally, it may fail to diagnose certain nutrient deficiencies, such as Mg, and has a small dynamic range for N. On the other hand, leaf blade analysis provides higher accuracy and wider ranges for nutrient dynamics. However, it requires careful sampling and thorough washing before analysis, as it is prone to sample contamination from dust and chemicals (Hickey et al., 2021). Based on their extensive research, Schreiner and Scagel (2017) recommend using leaf blades, as opposed to petioles, for diagnosing the N, P, and K status of Pinot noir grapevines.

The interpretation of foliar analysis results and the establishment of reference values is a particularly demanding and extensive work, requiring multi-year comprehensive trials. Such research has always been of interest for vineyard management and remains relevant due to ongoing climate and numerous other changes. Extensive studies presenting values by grape varieties, growth periods, various nutrient levels, and the combination of multiple elements are documented in the works of Bergmann and Neubert (1976). Nowadays, several methods have been proposed for interpreting foliar analysis results, including the sufficiency ranges (SR) method, critical values method, DRIS (diagnosis and recommendation integrated system), and DOP (deviation from optimum percentage) (Romero et al., 2014). These methodologies consider different ranges of values and aim to classify each nutrient content as deficient, low, adequate, high or excessive. Establishing these criteria requires extensive surveys of basic data and nutrient contents within a specific region. This process involves the compilation of a comprehensive database over time, which includes various factors such as climate, topography, soil properties, genetics, grapevine varieties and cultivation practices, including irrigation techniques (Romero et al., 2014). Research in Serbia on this topic has experienced periods of vigour in the past, followed by a hiatus. However, there is a renewed focus on these studies, making them highly relevant and deserving of continued attention.

The aim of this study is to highlight the variations in the content of macro and microelements in the soil – grapevine leaf relation in a small-sized vineyard, and additionally, to examine the variations in grapevine leaves based on leaf part and season.

MATERIALS AND METHODS

Location of investigation and sampling

The research was conducted during the vegetation period of 2020 at the Experimental Field of the Faculty of Agriculture, University of Novi Sad in Sremski Karlovci. The observed research plot covers an area of 1.2 hectares planted with the Grašac (Riesling Italico) variety grafted on Keber 5 bb rootstock, clone SK-54. The vineyard was established in 1994, with rows oriented in a north-south direction. The planting distance is 2.8 x 1.6 m and grafts are planted in pair. The vine training system is modified Karlovci training system (one cane and one spur with 12 and 2 buds respectively). The relative elevation difference of the vineyard between the northern highest point bordering the nearby forest and the south-eastern point adjacent to the road is 12 m.

In order to spatially characterize the variability of the soil, the vineyard block was divided into a grid of 20 subplots (Figure 1), each subplot covering an area of approximately 600 m^2 and containing 7 rows. Each individual subplot was then observed as a single sampling location/unit for soil and grapevine leaf. Soil sampling was carried out at three depths (0–30, 30–60, and 60–90 cm) using an agrochemical auger, with one representative sample per subplot consisting of 10–15 individual samples (following the methodology for soil fertility control). This way, a total of 60 soil samples were collected on April 21, 2020.

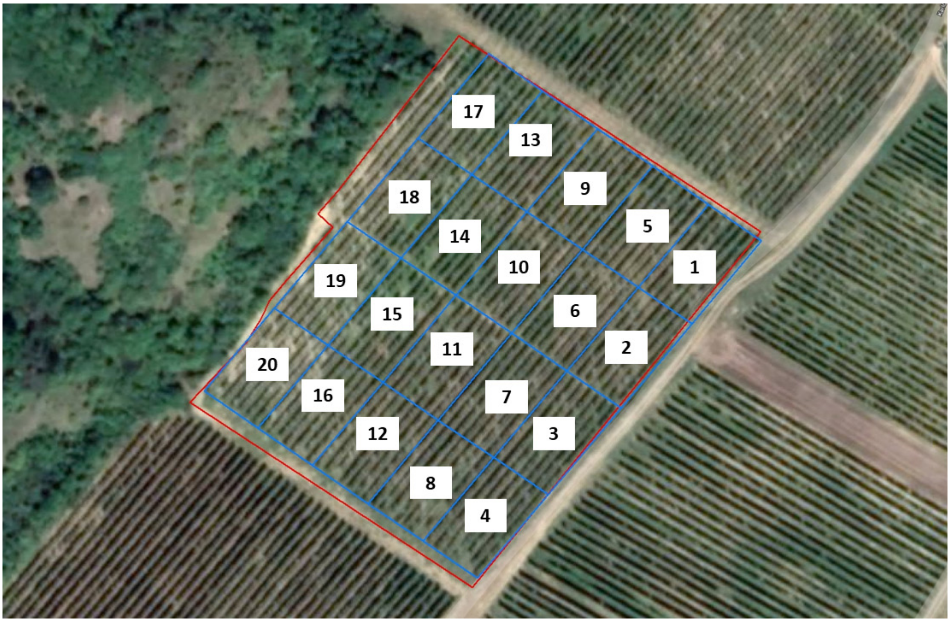

Figure 1. Layout of divided subplots of observed vineyard block

Grapevine leaf sampling was performed during two phenophases of the grapevine life cycle: flowering (with 80% of plants in this phase) on June 10, 2020, and onset of ripening on August 17, 2020. Sampling was done in the early morning hours, following the methodology for leaf sampling for foliar analysis of macronutrient status. For each grape cluster, an opposite leaf was picked together with its petiole. From each of the 20 subplots, 30 individual leaves were taken evenly as one composite sample. Samples were stored in a paper bag and kept cool during transportation to the laboratory.

Laboratory analysis

The laboratory analyses of collected soil and grape leaf samples were conducted at the Laboratory for Soil and Agroecology of the Institute for Field and Vegetable Crops. The laboratory is accredited according to the SRPS ISO/IEC 17025:2017.

The total of 60 soil samples were air-dried and sieved to a particle size of <2 mm, in accordance with ISO 11464:2006. The pH value in 1:2.5 (v/v) suspension of soil in 1 M KCl was determined upon the ISO method 10390:2005. The free $CaCO_3$ content was determined by volumetric method ISO 10693:1995. Organic matter content was measured by sulfochromic oxidation method (Tyurin's method). Total organic carbon (TOC) and total nitrogen were determined by elementary analysis (CHNSO VarioEL III) after dry combustion in accordance with the ISO 10694:1995 and AOAC Official Method 972.43:2006, respectively. Readily available phosphorus and potassium were extracted by ammonium lactate extraction, and measured by the means of spectrophotometry and flame photometry, respectively (Egnér et al., 1960). Particle size distribution was determined in the <2 mm fraction by the pipette method (Van Reeuwijk, 2002). The size fractions were defined as clay (<2 µm), silt (2–20 µm), fine sand (20–200 µm) and coarse sand (200–2,000 µm). Cation exchange capacity (CEC) was determined by ammonium acetate (Chapman, 1965). The content of available microelements was determined by soil extraction using DTPA according to the ISO 14870:2001 method. The determination of available Boron content was performed after soil extraction in hot water. The detection of Cu, Zn, Fe, Mn and B from prepared solutions was carried out using the ICP-OES Vista Pro Axial instrument, Varian, following the US EPA 200.7:2001 method.

For the purpose of foliar analysis, the collected leaf samples were thoroughly rinsed with distilled water and air-dried. Subsequently, the leaf petiole was separated from the leaf blade. In this manner, a total of 80 individual plant material samples were analysed: 20 samples from each observed subplot at two time intervals, consisting of both leaf blade and leaf petiole for each sample. The samples were ground using a plant material mill. Prior to further sample analysis, the moisture content was determined gravimetrically and the presented results are based on dry weight. Total nitrogen was analysed using the elemental analysis on the CHNSO VarioEl. III following the AOAC 972.43:2006 method. The determination of P, K, Mg, Ca, B, Mn and Zn content was conducted after microwave wet digestion of the samples in a mixture of ccHNO_3 and H_2O_2 with gradual heating up to 180 °C using the Milestone ETHOS1 instrument with a digestion time of 35 minutes. The detection of elements was performed using the ICP-OES Vista Pro Axial instrument, Varian, following the US EPA 200.7:2001 method.

Statistical data processing

Data were statistically processed by analysis of the main descriptive parameters and correlations between examined parameters. All statistical analyses were performed using STATISTICA for Windows version 13 (TIBCO, 2018). Statistical parameters were shown in tables 1 and 5.

RESULTS AND DISCUSSION

Soil properties and variability

According to the analysis of physical soil properties, the particle size distribution indicates that the observed area primarily falls into two texture classes clay loam and light clay based on the IUSS classification. However, there is one sample from the higher part of the plot (sample ordinal number 18) (Figure 1) that belongs to the class of rough sandy loam (30–60 cm), characterized by a high sand content. On observed plot, in the upper soil layer (0–30 cm), the texture classes of clay loam and light clay are relatively equally distributed, while in deeper soil layers, the dominant texture class is light clay. Based on the conducted descriptive statistics (Table 1), the greatest variation in data is observed in the soil layer at 30–60 cm depth. Overall, the largest differences were found in the sand content, primarily due to the presence of one sample (No. 18) with a high sand content of 89.52%.

According to the determined pH values, the tested samples range from 7.08 to 7.79, indicating a variation from neutral to slightly alkaline soil class (Table 1). Based on the average pH values, the pH reaction decreases with depth, and in terms of spatial distribution, the eastern and southern edges of the plot exhibit higher pH values. The content of free carbonates expressed as $CaCO_3$, according to the average values, exceeds the threshold for highly carbonate soils (>10%) and remains relatively consistent with depth (Table 1). However, individual samples exhibit a wide range of variation, encompassing all classes from non-carbonate to highly carbonate soils. The carbonate content shows the least variation in the surface layer of the soil, while the variability among samples increases with depth. The spatial distribution of carbonate content aligns with the pH distribution. The variability of Cation exchange capacity (CEC) is relatively consistent within each soil layer (Table 1). Generally, higher CEC values were observed in the western part of the plot. The organic matter (humus) content is very low in all tested samples, falling within the class of very low to low humus soil. As expected, it decreases with depth, with the highest value recorded as 1.53 in the upper soil layer (Table 1). The western and upper parts of the plot exhibit the lowest humus content.

Table 1. Descriptive statistics of soil properties at three depths (20 subplots of 1.2 hectare)

Parameter	Depth [cm]	Average	Min.	Max.	Percen-tile 25	Percen-tile 75	Variance	Std. dev.*
Sand [%]	0–30	47.59	37.61	70.45	42.84	50.89	39.63	8.27
	30–60	46.46	33.02	89.52	40.36	46.95	101.94	12.84
	60–90	44.48	33.11	65.53	39.39	47.39	33.28	7.86
Silt [%]	0–30	27.88	20.32	33.40	26.32	28.64	8.28	2.88
	30–60	28.10	12.20	36.60	26.54	31.12	25.29	5.03
	60–90	29.07	21.88	35.60	26.98	30.30	13.00	3.61

Clay [%]	0–30	24.53	17.64	29.00	22.88	26.90	9.39	3.06
	30–60	25.44	12.88	30.24	23.46	28.36	19.07	4.37
	60–90	26.45	18.48	34.04	24.38	29.80	17.79	4.22
pH in KCl	0–30	7.43	7.24	7.67	7.35	7.52	0.01	0.12
	30–60	7.40	7.14	7.79	7.26	7.54	0.03	0.17
	60–90	7.38	7.08	7.77	7.26	7.54	0.04	0.19
CEC [meq/100g]	0–30	16.81	12.27	19.35	15.77	18.49	4.54	2.13
	30–60	17.24	11.85	21.13	15.10	19.15	7.65	2.77
	60–90	17.63	12.42	21.49	15.99	19.27	6.59	2.57
$CaCO_3$ [%]	0–30	11.09	4.20	21.46	6.52	14.30	22.89	4.78
	30–60	11.15	4.21	29.45	6.31	11.78	61.66	7.85
	60–90	11.47	1.40	31.13	6.31	13.04	59.30	7.70
OM [%]	0–30	1.15	0.75	1.53	0.98	1.30	0.05	0.22
	30–60	0.82	0.25	1.40	0.63	0.98	0.08	0.28
	60–90	0.66	0.13	1.12	0.44	0.83	0.08	0.27
P_2O_5 [mg/100g]	0–30	18.27	6.44	28.48	12.28	24.41	51.19	7.15
	30–60	7.64	1.81	13.70	4.84	10.78	11.04	3.32
	60–90	5.16	2.46	14.26	3.54	5.55	8.46	2.91
K_2O [mg/100g]	0–30	18.79	8.50	28.36	17.04	21.43	21.40	4.63
	30–60	12.22	4.59	18.72	11.20	13.49	10.15	3.19
	60–90	11.48	5.02	29.95	9.17	12.56	26.05	5.10
Cu-DTPA [mg/kg]	0–30	7.38	2.36	21.64	5.43	7.98	15.44	3.93
	30–60	2.77	0.61	6.57	1.47	3.71	2.66	1.63
	60–90	1.41	0.33	3.76	0.84	1.72	0.76	0.87
Fe-DTPA [mg/kg]	0–30	9.91	6.27	16.20	8.34	10.63	5.59	2.36
	30–60	11.09	5.17	18.05	9.42	13.10	10.39	3.22
	60–90	12.33	6.46	21.86	10.43	13.77	15.36	3.92
Mn-DTPA [mg/kg]	0–30	6.22	4.99	7.98	5.34	7.22	1.13	1.06
	30–60	6.95	5.37	9.21	5.79	8.27	1.75	1.32
	60–90	7.80	5.28	13.32	6.79	8.68	3.09	1.76
Zn-DTPA [mg/kg]	0–30	2.16	0.95	9.11	1.48	2.31	2.88	1.70
	30–60	0.80	0.21	1.65	0.62	0.97	0.13	0.36
	60–90	0.64	0.24	1.43	0.37	0.90	0.11	0.33
B-H_2O [mg/kg]	0–30	0.37	0.14	1.04	0.25	0.42	0.04	0.19
	30–60	0.28	0.08	0.72	0.20	0.33	0.02	0.13
	60–90	0.26	0.06	0.51	0.18	0.35	0.01	0.11

* Standard deviation

The content of readily available phosphorus, expressed as P_2O_5, shows significant variation in the upper soil layer (Table 1). In the soil layer at 30–60 cm, where the root activity of grapevines is highest, phosphorus levels are generally low. The optimal phosphorus content was determined in only four out of the 60 tested samples. Half of the samples fall into the class of very low and low content, while one-fifth (12 samples) belong to the class of medium content. Additionally, nine samples exhibit high phosphorus content, all of which originate from the surface soil layer. In general, higher phosphorus content is found in the lower parts of the observed plot. Based on the average value of available potassium content, expressed as K_2O, the soil is classified as low to medium in terms of potassium content. Regarding the soil depths, the potassium content shows the highest variation in the surface (0–30 cm) and deepest layers (60–90 cm), ranging from very low to optimal classes. There are no excesses of potassium observed. In the soil layer at 30–60 cm, where the root activity of grapevines is highest, none of the samples reach the optimal level. Out of the 20 observed samples in the 30–60 cm soil layer, 16 belong to the low content class (7–15 mg / 100g), while two samples fall into the very low (<7 mg / 100g) and medium content (15–20 mg / 100g) classes, respectively. Similar to the spatial distribution of phosphorus, potassium content is higher in the lower parts of the observed plot.

Regarding accessible microelements in the soil, copper deficiency is not expected in vineyards due to the intensive use of copper-based fungicides. The copper content is the highest in the surface layer of the soil, where the highest variance and standard deviation of results are present as well, indicating its anthropogenic origin and it decreases with depth. The observed soil is generally adequately supplied with copper in deeper layers (Table 1 and Table 2). However, in two specific parts of the vineyard (sample No. 4 and No. 17), the copper content in the surface layer reaches notably high contents of 21.64 and 10.84 mg/kg, respectively. In contrast, other areas of the vineyard's surface layer have copper contents below 10 mg/kg. Content above 10 mg/kg suggest an anthropogenic origin and may potentially have phytotoxic effects on the vigour of young plants.

The observed soil is generally well supplied with available iron, and its content is consistent throughout the soil profile, with all recorded contents above the minimum values (Table 1 and Table 2). The lowest iron content was found in the parts of the vineyard covered by samples No. 12, 18 and 19. The iron content varies the most in the deepest layer of the soil. The content of available manganese is the most consistent among all observed elements, indicating that the soil is generally well supplied with this micronutrient values (Table 1 and Table 2).

The content of available zinc generally decreases with depth and is at a low level values (Table 1 and Table 2). Below the minimum threshold of 0.6 mg/kg, there are 15 samples in the deeper soil layers, specifically four sections of the vineyard located in the 30–60 cm soil layer (samples No. 9, 16, 18, and 19). The determined zinc contents highlight the necessity of implementing additional zinc fertilization to address the observed deficiency.

The content of available boron is very low. Out of the 60 analysed samples, 42 have values below the minimum threshold of 0.35 mg/kg (Table 2). In the 30–60 cm soil layer, where the root activity of grapevines is highest, only four sections of the vineyard have boron content exceeding 0.3 mg/kg (samples No. 12, 12, 13 and 17). When applying boron fertilizers to the soil, extreme caution should be exercised. It is necessary to determine the precise amount of fertilizer, as there is a fine line between optimal quantities (1.5–2.0 mg/kg) and amounts that can have toxic effects (5 mg/kg) (Ubavić et al., 2008).

Table 2. Minimum and optimal values of microelements in the soil for grapevines (Lanyon et al., 2004; Ubavić et al., 2008; Ninkov et al., 2019)

Assessment of the level of provision	Cu	Fe	Mn	Zn	B
			[mg/kg]		
Minimum values	0.2	2.5–4.5	2.0	0.6	0.35
Optimal values	1.2–2.4	11–21	10–20	3–6	1.5–2.0

Overall, the tested 20 subplots exhibit variation in the physico-chemical characteristics of the soil, with the highest variability observed in the 30–60 cm soil layer, where grapevine root activity is the greatest. The soil generally exhibits low levels of organic matter, macronutrients such as phosphorus and potassium, as well as micronutrients like zinc and boron. The spatial distribution of the physicochemical parameters of the soil indicates the presence of erosion processes at the investigated microlocation.

Foliar analysis, content and seasonal dynamics of nutrients

Based on the analysis of two parts of grapevine leaves (blade and petiole) during two phenophases (flowering and ripening), differences in nutrient content have been observed both among leaf parts and across seasons (Table 3). Nitrogen, boron and manganese are found in higher contents in the leaf blade, specifically during the flowering (sampling in June), compared to the second sampling in August during the ripening. Phosphorus and potassium are found in higher contents in the leaf petiole, while the content of P remains relatively consistent across the two seasons. The content of K is higher in the petiole during the flowering phase (sampling in June). It has been determined that there are higher levels of magnesium and calcium in the leaf petiole, particularly during the ripening phase in August (Table 3). Finally, zinc shows seasonal variation, with higher contents observed in the leaf blade during June, while higher contents are found in the leaf petiole during August (Table 3). These findings are broadly consistent with previous research and the established nutrient dynamics, where the content of N and K is highest in leaves during spring and decreases throughout the season. The content of P in leaves is highest before flowering, and additionally, the content of Ca and Mg is higher in older leaves (Burić, 1979).

Table 3. Nutrients content in grape leaves (mean value) according to leaf part and sampling time

Leaf part	Sampling time	N	P	K	Mg	Ca	B	Mn	Zn
				[%]				[mg/kg]	
Blade	June	2.77	0.21	0.62	0.35	2.48	35.50	218.93	32.79
	St. Dev.	0.11	0.03	0.04	0.03	0.20	7.86	35.19	5.89
	August	2.16	0.17	0.40	0.46	3.42	33.28	209.31	28.47
	St. Dev.	0.09	0.02	0.03	0.06	0.18	7.44	32.32	3.28
Petiole	June	0.84	0.28	0.78	0.81	2.07	24.39	63.17	26.82
	St. Dev.	0.08	0.08	0.14	0.08	0.19	3.13	15.15	8.18
	August	0.64	0.24	0.57	1.69	3.30	29.05	205.92	42.16
	St. Dev.	0.08	0.12	0.22	0.19	0.30	1.76	86.74	15.71

According to literature (Goldspink et al., 2000; Verdenal et al., 2021) N content in the leaf blade is very different to that in the petiole: petiole N content is more sensitive to variations in N nutrition than leaf blade N content, which is more constant. Consequently, the chosen analysis (i.e., on either the leaf blade or petiole, or both together) will greatly affect the results and require adapted interpretation thresholds (Verdenal et al., 2021).

In European vineyards, leaf blades are the standard tissue for diagnosing vine nutrients (OIV, 1996). On the other hand, the petioles are the tissue of choice for routine diagnosis of vineyard nutrient status in United States and Australia (Robinson et al., 1978; Christensen, 1984). Benito et al. (2013) suggest that diagnosis of nitrogen, phosphorus, potassium, manganese and zinc is preferable in the blade at complete cap-fall, fruitset and veraison, while the petiole is a better choice for iron and boron at both complete cap-fall and fruitset, and for boron at veraison. Calcium and magnesium are likely to be found at flowering or veraison, and iron at veraison, independently of sampling tissues.

Table 4 presents optimal nutrient content thresholds in grapevine leaves based on various literature sources, illustrating variations influenced by factors such as authorship, season, leaf segment, and research location. It is important to note that Table 4 offers a foundational overview. However, there are additional studies establishing optimal values, deficiencies, excesses, etc. Furthermore, some studies even provide insights into grapevine varieties and specific rootstocks. The production guidelines, based on ranges of nutrient status from the literature, are indicative for grape producers and testing laboratories (Schreiner and Scagel, 2017). The benefit for them will be if production guidelines take into account the effects of nutrients on vine productivity and must quality.

Comparing the outcomes of our spring foliar analysis (Table 3) with the reference values detailed in Table 4 (despite their variations attributed to different authors), it is deduced that the content of N and P in grapevine leaves is at the lower optimal threshold. Potassium content is notably deficient, in both the blade and petiole. In contrast, Mg and Ca contents are satisfactory, with Ca even reaching the upper limit of sufficiency. Distinct thresholds for Mn and Zn are presented, placing their content within the upper sufficiency optimal limit and well within the sufficiency range, respectively. Despite these distinct threshold levels, the content of B is notably deficient, particularly in the petiole.

The stated findings based on foliar analysis of deficiencies in certain elements are in complete alignment with soil analyses, except in the case of Zn. Soil analysis revealed low levels of organic matter, P, K, and B. The Zn content in grapevine leaves is sufficient, while specific parts of the observed plot are characterized by low levels of this element.

It is important to emphasize that a synchronized fertilization recommendation can be deduced from both soil and foliar analyses, especially concerning nutrients N, K and B. Nonetheless, according to soil analysis, a slightly elevated application of P and zinc Zn could be contemplated within the scope of fertilizer management. Importantly, with leaf P content at the lower threshold and Zn content well within the optimal range, increased quantities of P and Zn would not adversely affect the vineyard's ecosystem.

Based on the results of the entire study, correlations between all observed parameters were determined. The strongest correlations were obtained between soil parameters from all three depths and nutrients in the leaf blade sampled in flowering phase (Table 5).

The nutrient content in the soil, specifically nitrogen, potassium, manganese, and zinc, showed a positive statistically significant correlation with the respective nutrient content in the leaf blade. However, this relationship was not observed for phosphorus and boron.

The soil pH and carbonate content exhibited a negative and statistically significant correlation with the content of P, K and B in the leaf blade. The influence of high soil carbonate content, and consequently elevated pH levels, on nutrient uptake inhibition has been the subject of thorough investigation (Cambrollé et al., 2015). On the other hand, soil carbonate showed a positive correlation with the content of Mg and Mn in the grapevine leaf blade. However, the negative correlation between carbonate content in soil and Ca uptake and is unexpected. On the other hand, soil available phosphorus showed a statistically significant positive correlation only with the Ca content in the leaf blade. The complex process of calcium uptake, involving various transport pathways, remains a subject of ongoing debate in research studies (Duan et al., 2022; Nistor et al., 2022) and influenced by a many of factors, including water stress. It is widely acknowledged that mature leaves typically exhibit elevated calcium content what is also found in present study (Table 3).

Table 4. Optimal values for the interpretation of grapevine leaf nutrient content according to literature, on dray mass

	Source	Location	Leaf part	Season		N	P	K	Mg	Ca	B	Mn	Zn	Fe
						[%]					[mg/kg]			
1	Bergmann, 1986		whole leaf	flowering	LL	2.30	0.25	1.20	0.25	1.5	30	30	20	
					UL	2.80	0.45	1.60	0.60	2.5	60	100	70	
2	Paprić et al., 2009		whole leaf		LL	2.50	0.22	1.3	0.25					
					UL	2.75	0.24	1.4						
3	Melo et al., 2018	Brazil	whole leaf		LL	2.40	0.29	1.1	0.26	1.2	26	390	150	89
					UL	3.00	0.39	1.4	0.33	1.6	39	578	256	140
4	Verdenal et al., 2021		whole leaf		LL	2.00								
					UL	2.30								
5	AWRI, 2010	Australia	blade	flowering	LL	3.00	0.25	1.0	0.3	1.2	30	25	30	
					UL	5.00	0.40	1.8	0.6	2.8	200	200	60	
6	García-Escudero et al., 2013	Spain	blade	flowering	LL	3.13	0.27	0.9	0.3	2.1	58	68	18	105
					UL	3.28	0.31	1.0	0.4	2.3	67	87	20	131
7	Verdenal et al., 2021		petiole		LL	0.40								
					UL	0.60								
8	AWRI, 2010	Australia	petiole		LL	0.80	0.25	1.8	>0.4	1.2	35	30	>26	>30
					UL	1.10	0.50	3.0		2.5	70	60		
9	NSA, 2011	Canada	petiole	flowering	LL	1.60	0.16	1.5	0.2	0.4	25	20	20	40
					UL	2.50	0.60	4.0	0.4	1.5	50	150	100	180
10	García-Escudero et al., 2013	Spain	petiole	flowering	LL	0.94	0.27	1.3	0.6	1.4	40	23	14	22
					UL	1.10	0.34	1.8	0.7	1.5	42	29	17	25
11	Goldspink et al., 2000	Australia	petiole	flowering	LL	0.9	0.30	1.3	>0.4	1.2	30	25	15	
					UL	1.2	0.49	3.0		2.5	70	500	25	

LL = lower limit of optimal content
UL = upper limit of optimal content

Table 5. Correlation coefficients between soil parameters at three depths and leaf nutrient status of leaf blade sampled in June (flowering)

	Leaf blade, flowering							
Soil	N	P	K	Mg	Ca	B	Mn	Zn
pH-KCl	-0.162	-0.421*	0.032	0.326*	-0.407*	-0.556*	0.372*	-0.230
$CaCO_3$	-0.236	-0.522*	-0.173	0.315*	-0.460*	-0.491*	0.562*	-0.026
OM	0.271*	0.444*	0.316*	-0.132	0.485*	0.471*	-0.272*	-0.094
TOC	-0.058	-0.018	0.116	0.283*	0.033	-0.004	0.178	-0.108
N-Total	0.310*	0.437*	0.259*	-0.088	0.487*	0.518*	-0.282*	-0.072
P_2O_5	0.174	0.215	0.201	0.029	0.293*	0.251	-0.155	-0.100
K_2O	0.262*	0.292*	0.335*	-0.047	0.386*	0.278*	-0.243	-0.070
Coarse sand	-0.156	-0.273*	-0.040	0.058	-0.281*	-0.466*	0.085	-0.027

Fine sand	0.433*	0.333*	0.197	0.167	0.358*	0.501*	-0.210	-0.308*
Silt	-0.121	-0.261*	-0.162	0.075	-0.168	-0.094	0.370*	0.148
Clay	0.073	0.496*	0.085	-0.303*	0.398*	0.547*	-0.362*	0.132
CEC	0.227	0.542*	0.023	-0.322*	0.480*	0.688*	-0.406*	0.168
Cu-DTPA	0.201	0.195	0.235	-0.024	0.272*	0.141	-0.101	-0.077
Fe-DTPA	-0.073	0.031	-0.090	-0.421*	0.007	0.039	0.172	0.287*
Mn-DTPA	-0.195	-0.267*	-0.276*	-0.347*	-0.264*	-0.304*	0.472*	0.335*
Zn-DTPA	0.003	-0.006	0.058	0.017	0.195	0.040	0.116	0.287*
B-H$_2$O	0.060	-0.124	-0.042	-0.024	0.123	0.160	-0.029	0.094

* Significantly correlated p=0.95

Soil organic matter, total nitrogen, and available potassium content are significantly positively correlated with the major nutrients in the leaf blade: N, P, K, as well as with the content of B and Ca, which indicates importance of applying good fertilizer management. Total nitrogen is negatively correlated with the content of Mn, while total organic carbon is positively correlated only with the content of Mg in the leaf blade. The cation exchange capacity (CEC) of the soil showed a statistically significant positive correlation with the content P, Ca and B in the leaf blade. However, CEC exhibited a negative correlation with the content of Mg and Mn in the leaf blade. Stated findings indicated antagonistic interactions between elements. The influence of soil particle distribution on nutrient content has been determined, particularly on the phosphorus content in the leaf blade. However, the obtained correlations are not logical for drawing a general conclusion.

CONCLUSION

The tested 20 subplots of the small sized plot of 1.2 ha exhibit variation in the physico-chemical characteristics of the soil, with the highest variability observed in the 30–60 cm soil layer. The soil generally exhibits high pH reaction, low levels of organic matter, available P, K, as well as low levels of micronutrients Zn and B. The spatial distribution of the physico-chemical parameters of the soil indicates the presence of erosion processes at the investigated microlocation.

Based on the analysis of two parts of grapevine leaves (blade and petiole) during two phenophases (flowering and ripening), differences in nutrient content have been observed among leaf parts and across seasons, which broadly aligns with established nutrient dynamics described in the literature. Based on foliar analysis and by comparing nutrient levels in the leaves during the flowering phase with various literature sources' threshold values, it was found that the content of N and P is at the lower limit, while the deficiency of K and B is clearly confirmed. Synchronized fertilization recommendations can be inferred from both soil and foliar analyses, particularly for nutrients N, K, and B. However, based on soil analysis, a slightly increased application of P and Zn would be recommended for fertilization.

Based on the established correlations among all observed variables, the highest correlations were determined between soil parameters across all three depths and nutrients in the leaf blade sampled during the flowering phase. The nutrient content in the soil, specifically N, K, Mn, and Zn, showed a positive statistically significant correlation with the respective nutrient content in the leaf blade. However, this relationship was not observed for P and B. The identified correlations indicate the influence of pH and carbonates on reduced uptake of certain elements, as well as the presence of nutrient uptake antagonism in the grape leaves depending on the physicochemical soil parameters.

Further research is necessary to lay the foundation for the development of accurate and reliable criteria for diagnosing nutrition, not only for the whole species but also among grapevine leading varieties. Given the significant variations in nutrient requirements and accumulation among these genotypes, this research will be instrumental in ensuring optimal nutrient supply while minimizing deficiencies or excesses.

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REFERENCES

AWRI (2010): The Australian Wine Research Institute, Grapevine nutrition. Petiole analysis. AWRI 2010. RTP 0032. Available from: https://www.awri.com.au/wp-content/uploads/5_nutrition_petiole_analysis.pdf. Accessed: 3. 7. 2023.

Benito A, Romero I, Dominguez N, Garcia-Escudero E, Martin I (2013): Leaf blade and petiole analysis for nutrient diagnosis in *Vitis Vinifera* L. Cv. Granacha tinta. *Aust. J. Grape Wine Res.* 19: 285–298.

Bergmann W, Neubert P (1976): *Pflanzendiagnose und Pflanzenanalyse*. Jena: Verlag VEB Gustav Fischer.

Bergmann W (1986): *Farbatlas. Ernährungsstörungen bei Kulturpflanzen*. Visuelle und Diagnose. Jena: Verlag VEB Gustav Fischer.

Burić DP (1979): *Vinogradarstvo II*. Novi Sad: Radnički univerzitet “Radivoj Ćirpanov”.

Cambrollé J, García JL, Ocete R, Figueroa ME, Cantos M (2015): Evaluating tolerance to calcareous soils in *Vitis vinifera* ssp. *sylvestris*. *Plant Soil* 396: 97–107. [DOI: 10.1007/s11104-015-2576-4]

Chapman HD (1965): Cation-exchange capacity. In: C. A. Black (ed.), *Methods of soil analysis – Chemical and microbiological properties*. Agronomy 9: 891–901.

Christensen P (1984): Nutrient level comparisons of leaf petioles and blades in twenty-six grape cultivars over three years (1979 through 1981). *Amer. J. Enol. Viticult.* 35: 124–133.

Duan S, Zhang C, Song S, Ma C, Zhang C, Xu W, Bondada B, Wang L, Wang S (2022): Understanding calcium functionality by examining growth characteristics and structural aspects in calcium-deficient grapevine. *Sci. Rep.* 12, 3233. [DOI: 10.1038/s41598-022-06867-4]

Egnér H, Riehm H, Domingo WR (1960): Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. Chemische Extraktionsmethoden zur Phosphor – and Kaliumbestimmung. *Kungl. Lantbrukshoegsk. Ann*. 26: 199–215.

García-Escudero E, Romero I, Benito A, Dominguez N, Martín I (2013): Reference levels for leaf nutrient diagnosis of cv. 'Tempranillo' grapevine in the Rioja Appellation. *Commun. Soil Sci. Plant Anal*. 44: 645–654. [DOI: 10.1080/00103624.2013.745385]

Goldspink BH, Lantzke N, Paulin B, Fisher DL, Gordon C, Cross N, Campbell-Clause J M (2000): *Fertilisers for wine grapes: an information package to promote efficient fertiliser practices*. Department of Primary Industries and Regional Development, Western Australia, Perth. Bulletin 4421.

Hickey C, Breeden S, MacAllister C, Lessl J, Schreiner RP (2021): The Fundamentals of Grapevine Tissue Sampling for Nutrient Analysis. Penn State Extension Horticulture, The Pennsylvania State University. Available from: https://extension.psu.edu/the-fundamentals-of-grapevine-tissue-sampling-for-nutrient-analysis. Accessed: 4. 7. 2023.

Lanyon DM, Cass A, Hansen D (2004): The effect of soil properties on vine performance. *CSIRO Land and Water*, Technical Report 34/04.

Melo GW, Rozane DE, Brunetto G (2018): Identification of the critical levels, sufficiency ranges and potential response to nutrient fertilization in vineyards by the DRIS method. *Acta Horticulturae* 1217: 423–430. [DOI:10.17660/ActaHortic.2018.1217.55]

Ninkov J, Jakšić D, Vasin J, Perović V, Jakšić S, Banjac D, Živanov M, Marinković J, Bjelić D, Milić S, Tomić N, Marković S, Vasiljević S, Milošević B (2017): *Karakteristike zemljišta niškog vinogradarskog rejona*. Novi Sad: Institut za ratarstvo i povrtarstvo.

Ninkov J, Jakšić D, Vasin J, Jakšić S, Banjac D, Živanov M, Marinković J, Bjelić D, Milić S, Tomić N, Marković S, Perović V, Stanivuković I (2019): *Karakteristike zemljišta pocersko-valjevskog vinogradarskog rejona*. Novi Sad: Institut za ratarstvo i povrtarstvo.

Nistor E, Dobrei AG, Mattii GB, Dobrei A (2022): Calcium and potassium accumulation during the growing season in Cabernet Sauvignon and Merlot grape varieties. *Plants* 11: 1536. [DOI: 10.3390/plants11121536]

NSA (2011): Nova Scotia Canada Agriculture, Fruit Crop Tissue Sampling Guide. Available from: https://novascotia.ca/agri/documents/lab-services/analytical-lab-fruitcroptissue.pdf. Accessed: 3. 7. 2023.

OIV (1996): Resolution Viti 5/95. Diagnostic foliaire. Une methode harmonise. *Bull. OIV* 68: 35–40.

Paprić Đ, Korać N, Kuljančić I, Medić M (2009): Rezultati folijarne analize kod klonova sorte italijanski rizling na različitim loznim podlogama. *Letop. Naučn. Rad.* 33: 43–49.

Robinson JB, Nicholas PR, McCarthy JR (1978): A comparison of three methods of tissue analysis for assessing the nutrient status of plantings of *Vitis vinifera* in an irrigated area of South Australia. *Austral. J. Exp. Agr. Anim. Husb.* 18: 294–300.

Romero I, Benito A, Dominguez N, Garcia-Escudero E, Martin I (2014): Leaf blade and petiole nutritional diagnosis for *Vitis vinifera* L. cv. Tempranillo by deviation from optimum percentage method. *Span. J. Agric. Res.* 12: 206–214. [DOI: 10.5424/sjar/2014121-4308]

Schreiner RP, Scagel CF (2017): Leaf blade versus petiole nutrient tests as predictors of nitrogen, phosphorus, and potassium status of "Pinot Noir" grapevines. *HortScience* 52: 174–184. [DOI: 10.21273/HORTSCI11405-16]

Tibco Software Inc (2018): Statistica (data analysis software system), version 13. http://tibco.com.

Ubavić M, Marković M, Oljača R (2008): *Mikroelementi i mikrođubriva i njihova primena u praksi*. Banja Luka: Univrezitet u Banjoj Luci, Poljoprivredi fakultet.

Van Reeuwijk LP (ed.) (2002): *Procedures for soil analysis*. Sixth edition. ISRIC FAO Technical Paper vol. 9. International Soil Reference and Information Centre Wageningen, 12–16.

Verdenal T, Dienes-Nagy Á, Spangenberg JE, Zufferey V, Spring, J-L, Viret O, Marin-Carbonne J, Van Leeuwen C (2021): Understanding and managing nitrogen nutrition in grapevine: a review. *OENO One* 55: 1–43. [DOI: 10.20870/oeno-one.2021.55.1.3866]

ОРИГИНАЛНИ РАД

ОДНОС САДРЖАЈА МИКРО И МАКРОЕЛЕМЕНАТА У ЗЕМЉИШТУ И ЛИСТОВИМА НА МИКРОЛОКАЦИЈИ ВИНОГРАДА

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РЕЗИМЕ: Спроведено истраживање има за циљ да утврди варијације у садржају макро- и микроелемената у односу земљиште–лист у малим виноградима. Парцела величине 1,2 хектара у Сремским Карловцима (Србија), са сортом *грашац* (Riesling Italico), подељена је на 20 делова, под парцела. Свака под парцела служила је као појединачна локација за узорковање земљишта и листова. Узорци земљишта су сакупљани на три дубине, док је узорковање листова обављено у две фенофазе (фаза цветања и фаза сазревања), са раздвајањем дршке и лиске. Варијације у физичко-хемијским карактеристикама земљишта су потврђене међу посматраних 20 под парцела, са највећом варијабилношћу у слоју земљишта од 30–60 cm. Земљиште генерално показује низак садржај органске материје и приступачног фосфора (P), калијума (K), цинка (Zn) и бора (B). Просторна дистрибуција физичко-хемијских параметара указује на присутне процесе ерозије. Добијене разлике у садржају хранљивих материја међу деловима листа и фенофазама су у складу са постојећом литературом. При упоређивању садржаја хранљивих материја у листовима са оптималним вредностима из литературе, утврђено је да је садржај азота (N) и фосфора (P) на доњој граници, и потврђен је недостатак калијума (K) и бора (B). Идентичне препоруке за ђубрење могу се донети на основу анализе земљишта и фолијарне анализе, пре свега за азот (N), калијум (K) и бор (B). Додатно, на основу анализе земљишта, препоручује се благо повећање примене фосфора (P) и цинка (Zn) за ђубрење. Утврђене корелације између свих посматраних промењљивих откриле су везе између параметара земљишта на све три дубине и хранљивих материја у листу током фазе цветања. Садржај хранљивих материја у земљишту, нарочито азота (N), калијума (K), мангана (Mn) и цинка (Zn), показује статистички значајне позитивне корелације са садржајем одговарајућег елемента у листу током фазе цветања. Неопходна су даља истраживања како би се поставили темељи за развој тачних и поузданих критеријума за дијагнозу исхране винове лозе, не само за целу врсту него и међу њеним водећим сортама. С обзиром на значајне варијације у захтевима за хранљивим материјама и акумулацији међу овим генотиповима, оваква истраживања би била од кључног значаја за достизање оптималног снабдевања винове лозе хранљивим материјама, избегавајући њихов недостатак или сувишак.

КЉУЧНЕ РЕЧИ: земљиште винограда, фолијарна анализа, винска сорта *грашац*