Scientific Papers. Series B, Horticulture. Vol. LXVI, No. 1, 2022
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

CLIMATE VARIABILITY AND MAIN NUTRIENTS IN LEAF BLADE AND PETIOLE FOR DIAGNOSE THE GRAPEVINE NUTRITIONAL STATUS

Eleonora NISTOR[1], Alina DOBREI[1], Alin DOBREI[1], Giovanni MATTI[2]

[1]Banat University of Agricultural Sciences and Veterinary Medicine “King Michael I of Romania”, Faculty of Horticulture and Forestry, Calea Aradului 119, Timisoara, Romania;
[2]Universita degli Studi Firenze, Dipartimento Di Scienze Produzioni Agroalimentari E Dell'ambiente, Viale Delle Idee 30, 50019, Sesto Fiorentino, Italy

Correspondent author email: nisnoranisnora@gmail.com

Abstract

For monitoring the Cabernet Sauvignon nutritional status, leaf blade and petiole tissues collected in flowering and veraison from 2018-2019 growing seasons, were analysed for main macronutrients. Sampling in flowering or veraison, do not show significant differences in variables response. Rather than otherwise, the differences were observed between growing seasons, and the climate variability from 2019 with heavy rain in the spring correlated with low temperatures and the summer and autumn draught associated with hot weather, influenced the absorption of macronutrients, canopy development, and the relationship between leaf blade and petiole macronutrients concentration. Results indicate that leaf blade prevails over petiole for nitrogen (veraison) potassium (flowering) calcium (flowering) and magnesium (flowering) in predicting vine nutrients status while petiole is better indicator for phosphorus (flowering stage). Grape berry mineral main compounds are influence by dry weather and the degree of dehydration. Research results can be used as guide in main macronutrients nutritional status in Cabernet Sauvignon, for regions with similar terroir conditions.

Key words: *climate, Cabernet Sauvignon, juice, petiole, nutrients, quality.*

INTRODUCTION

The soil, a huge sink of nutrients, plays a major role in interaction with plants and grape production, amid continuous climate variability (Santos et al., 2020). Some studies from last decade, show that in summer growing season (June–August) in the soil first 50 cm, temperature was higher with about 6ºC than in autumn season (September-November) (Biasi et al., 2019). Heat stress is shortening the phenological stages, some starts earlier, other are delayed and grape berries composition is changed (Koufos et al., 2020). Higher temperature has large impact on organic matter mineralization, microbial communities and water availability (Pareek, 2017). Soil and climate influence the growth and fruiting processes, the quantity and quality of the wine, vineyard life, the resistance to diseases and pests (Celette & Gary, 2013). As grapevine develops large canopy and grape yield, the amount of nutrients absorbed from soil increase, with an inclined balance towards macronutrients (N, P, K, Ca, Mg) compared to micronutrients (Fe, Cu, Mg, Mn, etc.) (Fogaça et al., 2007). Therefore, the evaluation of soil nutrient supply is useful to establish the nutritional diagnoses for fertilization (Dobrei et al., 2016). However, testing soil samples to assess the nutrient supply is not always sufficient, especially for the grapevine which has many varieties and clones or rootstocks, with different growing stages and high consumption of nutrients (Benito et al., 2015). The supply of vines with nutrients from the soil can be assessed qualitatively depending on the symptoms from the leaves (especially on the older leaves for macronutrients and the younger leaves for micronutrients) and the vigour of the vine, or quantitatively by analyzing plant tissues (Costa et al., 2019). Samples composition is variable depending on the soil fertility and fertilization, on climate variability during the growing season, the time of day when samples were collected or growing stages (Dominguez et al., 2015).
Different fertilizers and the ratio achieved between the main macroelements (N, P, K, Ca, Mg) have great influence on grape production

with high impact on wine quality (Domagała-Świątkiewicz et al., 2019). The disruption of balance among macro and micro nutrients limits the performance of the vine (Dobrei et al., 2016). Climate variability and heat stress contribute to the increase of potassium levels accumulation according to de Orduña (2010).
In recent decades, abiotic stress has been associated with micronutrient deficiency that decreases production efficiency due to limited metabolism or biosynthesis (Bencke-Malato et al., 2019). The antagonism magnesium-potassium is aggravated by high soil pH.
The aim of the study was to diagnose the nutrient content of the leaf blade and petiole tissue, in two reliable growing stages - at flowering and veraison when diagnose is quite similar, in two different growing seasons (2018-2019) to can establish better fertilization management correlated with the soil nutrients supply and climate variability, and other complement observations including berry main minerals, in the Cabernet Sauvignon variety.

MATERIALS AND METHODS

Experimental site and climate

The research was carried on in Recas Vineyards, Timis County, east-side of Romania, region located on the same latitude as Bordeaux, which benefits from microclimate with gentle Mediterranean influence, mild winters, short springs, warm summers, long autumns and sudden transitions from winter to summer. During the last decade the annual average temperature in the area was 12.52°C and annual precipitation 547 mm. In last decade, summers were very hot (June-August, average 20.69 - 23.57°C). Climate data (Figure 1) were registered and collected from the Wireless Weather Station Wi-Fi Connection Solar Charging (Davis 6250) installed in the vineyard.

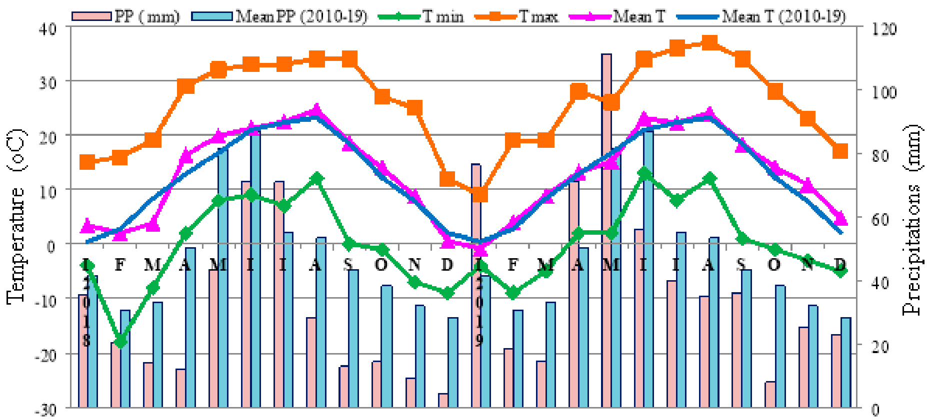

Figure 1. Climate variability during 2018-2019 growing seasons
(mean temperature and precipitations over 2010-2019 decade)

Precipitations show high variability during both the growing and dormant seasons. The weather in 2018 was versatile; in the last decade of April there was a late frost, next period, the rainfall prevented the timely accomplishment of some works in the vineyard, followed by a warm summer with high temperatures and a warm autumn during the day and cool nights. With large variability from month to month, in 2018 precipitations significantly decreased (336 mm), but the hailstorms and heavy rains from June decreased the grape production. In 2019 total precipitations accumulated 514.3 mm, close to the annual mean value in the area. The first growth stages, bud break and beginning of flowering were normal developed in 2019. From the last decade of May, throughout April, the last decade of June, as well as July, due to heavy long term rainfall, phytosanitary treatments could not be optimally applied. The temperature values were variable from one year to another. In 2018, weather favoured the fast grapes ripening, registering the earliest grape harvest in the last 40 years, considering that the harvesting period started 14-21 days earlier. However, the vines were not affected by the low temperatures of winter 2018-2019 or by late spring frosts. Warm nights and days with over 28-30 ºC, but also the draught greatly favoured the sugar and tannins accumulation.

Soil

The slope gradient for vineyard rows rank between 10 and 12% and altitude from 120 to 170 m. Distance was 1.2 m between vines and 2.2 interrows. Vines were double Guyot trained and shoots were cut back at 35 cm above the third/top trellis wire. In the fertilization programme was applied 100 kg nitrogen early in the spring before budburst, 40 kg phosphorus and 120 kg potassium for one hectare area in the dormant season (autumn).

The wine grape varieties were planted 12 years ago on sandy loam, and loam clay soils, medium supply of phosphorus, good in potassium, nitrogen, and organic matter, with pH average value around 6.28 (0-110 cm). Soil samples were analysed for total nitrogen phosphorus, potassium, calcium and magnesium supply level by spectrophotometer analysis, using different colour reagents. The analysis of the exchangeable bases (SB) was done by the Kappen method and the humus by the oxidimetric method.

Leaf blade and petiole sampling and analysis

The leaf blades with petiole were harvested from the shoot in position opposite to the bunch, at 80% flowering and during the veraison. Each year 100 leaf blades were harvested, but were selected only 40 for analyses. The samples were collected between 8 to 10 o'clock when the leaves had maximum turgidity and the soil moisture was optimal. The leaves on the same vine were placed in the same bag and then labelled for transfer to the laboratory. Samples were minimum handling to avoid the risk of contamination and transport in insulated and cool container. Leaf blade and petiole were washed, draught, milled, ashed, then dilute and main components analysed. The total plant nitrogen (N%) was determined by near infra-red spectroscopy (NIR) with wavelengths ranked between 780–2,500 nm, after calibration. Phosphorus and potassium concentration from petiole and leaf blades were measured by inductively couple plasma - optical emission spectrometry (ICP-OES), after was calibrated with standard solutions of a different concentration. No foliar spray or drip irrigation fertilizers were applied during research to avoid samples contamination. Copper fungicides and other treatments for fungal foliar diseases control were performed after berry set stage. Direct monitoring at flowering stage has the advantage of nutritional correction problems for the current crop. For juice sampling 100 berries were crushed and pressed. The minerals were determined by laboratory analysis spectrophotometry.

Statistical analysis

The data were statistically analysed by XLSTAT software version 2019.1.3 (Addinsoft, Inc. New York) for: the simple linear regression based on Ordinary Least Squares (OLS), R^2 (coefficient of determination), confidence interval (CI) and the analysis of variance. CV%, p-value and t-test (one-tailed) were calculated in GraphPad Prism Version 7.04.

RESULTS AND DISCUSSIONS

The analysis of leaf and petiole tissue allows the estimation of the nutritional status of the vine, and can provide information on the absorption and supply of soil with nutrients. The results from leaf blade and petiole samples analyses for macronutrients (N, P, K, Ca, Mg) during flowering and veraison, in 2018 and 2019 growing seasons are summarized in Figures 2, 3, 4, 5 and 6, respectively. Usually, leaf blade is a better indicator of nitrogen (N) status, while petiole gives more indications for potassium (K) deficiencies or toxicity. The significance level was established to $\alpha = .05$. Climate variability, grape variety, and soil type can influence the concentration of main macronutrients in petiole and leaf blade, which reflect the absorption of nutrients by the vines. The confidence interval (CI) is quite narrow, which reflect a good accuracy ($p < .0001$) of variables relationship for all macronutrients analysed (Figures 2, 3, 4, 5, 6). P-value is extremely low ($p < .0001$) compared to the $\alpha = .05$ risk threshold, and the differences between variables mean are extremely significant, conclusion also confirmed by the CI limits.

Nitrogen

Climate variability, grape variety, and soil type can influence the concentration of main macronutrients in petiole and leaf blade, which reflect the absorption of nutrients by the vines.

In grapevine, spring growing stages mainly depends on reserves stored in roots and wood in the previous growing seasons (Costa et al., 2019). Nitrogen has two main incorporation phases: before "pea-size" and during veraison. Cabernet Sauvignon is ranking as medium petiole nitrogen concentration during bloom-time, among grape varieties (Schreiner et al., 2013). In present study, leaf blade show in both flowering and veraison stages higher concentrations of nitrogen than petiole. However, petioles had higher concentrations in phosphorus and potassium regardless of growing season and stage of sampling.

Around 52% in 2018 and by 64% in 2019 growing seasons from leaf blade nitrogen variability is explained by the petiole nitrogen concentration. In veraison stage the nitrogen concentration in petiole explains nearly in the same rates (59.64% and 54.96%) the leaf blade nitrogen variability in 2018 and 2019 (Figure 2).

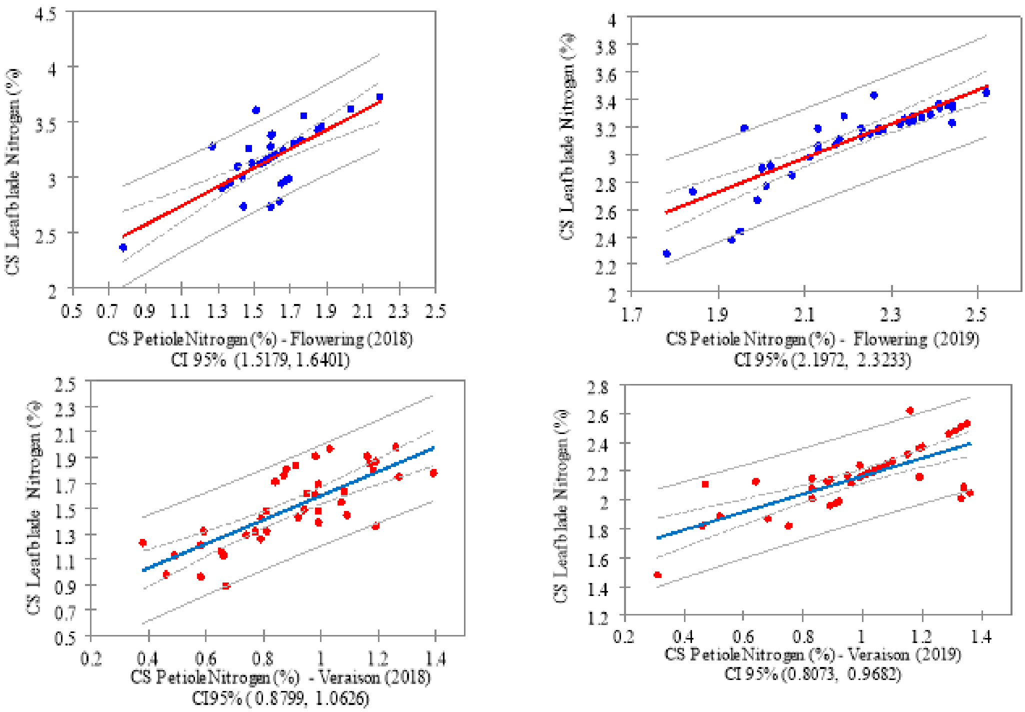

Figure 2. Nitrogen concentration in leaf blade and petiole, at flowering and veraison, for Cabernet Sauvignon (CS) during 2017-2018 growing seasons (CI = confidence interval; CV% = coefficient of variation; R^2 = coefficient of determination)

Phosphorus

During flowering stage in both growing seasons, phosphorus linear regression model explain in moderate rate the phosphorus from leaf blade (Figure 3). In the veraison stage the relationship between the variables is changed: the phosphorus concentration in the petiole explains moderately the phosphorus in the leaf (62.81%) in the first growing season and largely (78.54%) in the second. In 2018 growing season (flowering and veraison) the phosphorus concentration was lower compared with 2019 (leaf blade show lower variability than petiole). In 2019, excepting the veraison stage the variability of phosphorus concentration was higher in petiole than in leaf blade. Leaf blade and petiole phosphorus concentration is variable from flowering to veraison and higher in the first growing season than the second. Soil moisture due to heavy rainfall, correlated with lower temperatures from spring of second growing season (2019) decreased the ability of vines roots to uptake the phosphorus. Leaf blade phosphorus concentration was higher compared to petiole in veraison than in flowering stage.

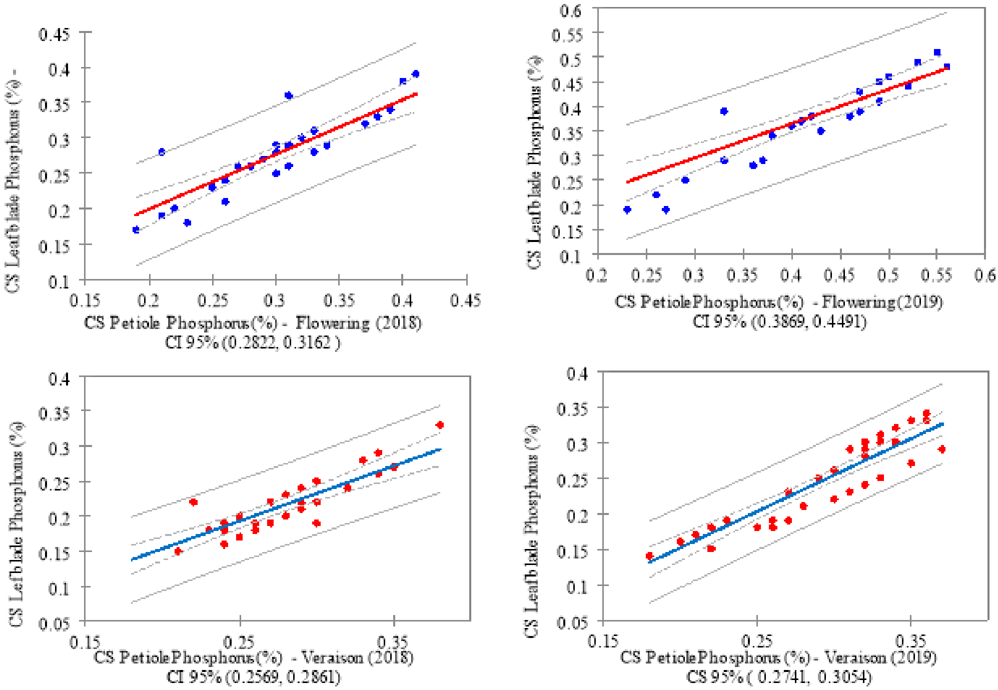

Figure 3. Phosphorus concentration in leaf blade and petiole, at flowering and veraison, for Cabernet Sauvignon (CS) during 2017-2018 growing seasons (CI = confidence interval; CV% = coefficient of variation; R^2 = coefficient of determination)

Potassium

According to Conradie (1981) potassium is the main mineral accumulated before and after veraison, with the highest rate during ripening, in grape berries. Potassium cation (K^+) accumulation is linked with the water availability and correlated with berry flesh weight and dry matter, and also contributes to the sap flow. In the present research, there were no differences between seasons in petiole and leaf blade potassium concentration relationship (Figure 4). The resulting variability rate accounting for petiole potassium was slightly larger in 2019 than in 2018 veraison stage. Potassium doesn't combine in organic compounds and therefore is easily leached from leaves to the soil, but has high mobility in plants tissues and the amount removed in grapes can be replaced from the soil sink.

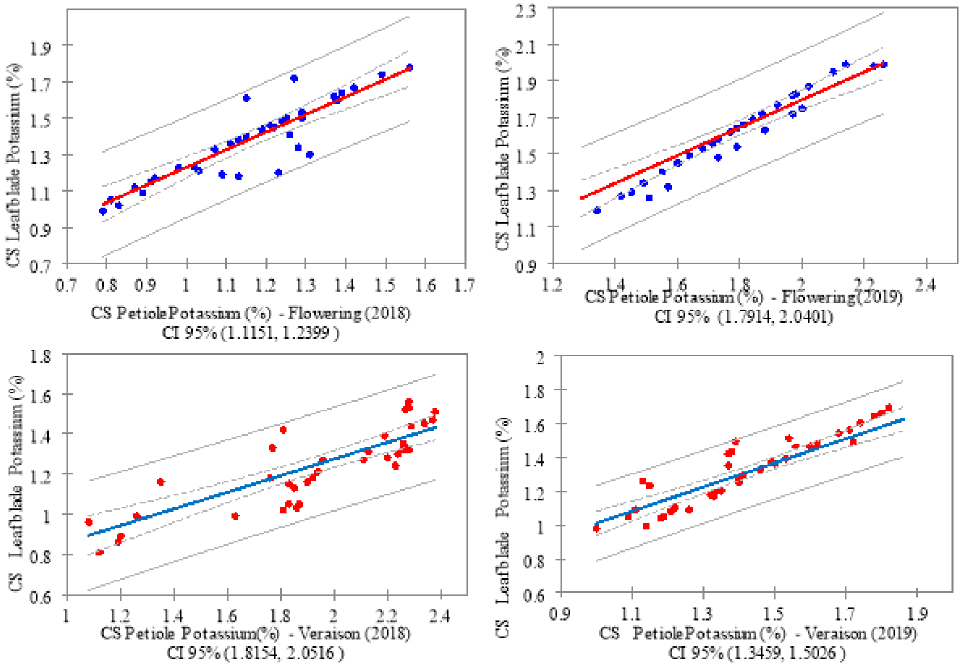

Figure 4. Potassium concentration in leaf blade and petiole, at flowering and veraison, for Cabernet Sauvignon during 2017-2018 growing season (CI= confidence interval; CV% = coefficient of variation; R^2 =coefficient of determination)

Calcium

In both years petiole calcium of Cabernet Sauvignon variety, explained in large ratios (81.98% and 83.12% respectively) the variability of these macronutrients in the leaf blade during flowering stage. Quite different was the situation for veraison, when higher calcium variability from petiole compared to leaf blade was found. In flowering stage (in both growing seasons), the calcium concentration variability was higher in petiole than leaf blade, while in veraison stage the limits of variability were narrow in both seasons (Figure 5). Calcium is presumably in antagonism with potassium and magnesium; therefore interactions between calcium and previous macronutrients have to be considered when nutrient programs are applied (Benito et al., 2013).

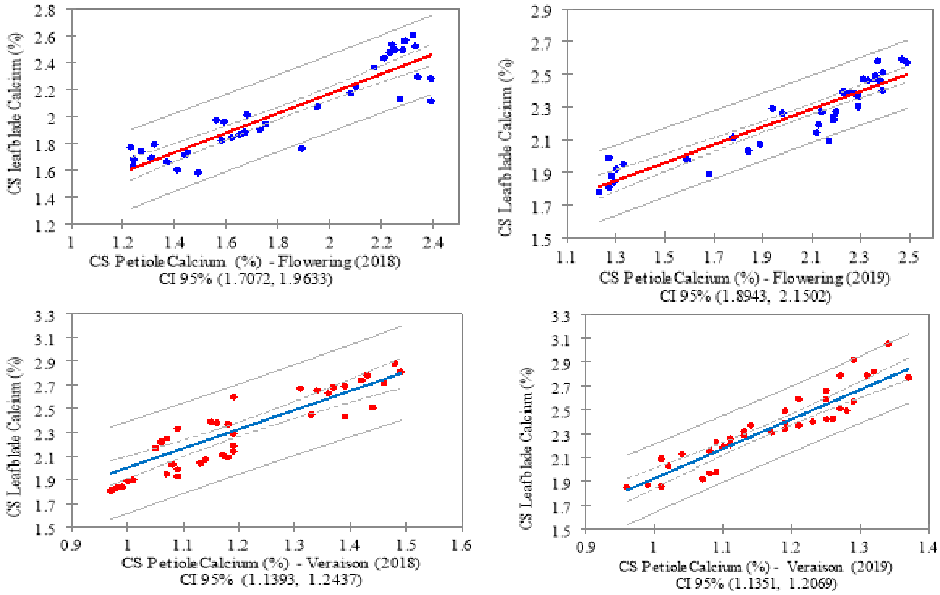

Figure 5. Calcium concentration in leaf blade and petiole, at flowering and veraison, for Cabernet Sauvignon during 2017-2018 growing seasons (CI = confidence interval; CV% = coefficient of variation; R^2 = coefficient of determination)

Magnesium

Medium influence of magnesium concentration from petiole was found in both growing seasons in samples from flowering stage. During veraison, linear regressions indicated that petiole magnesium had larger influence on leaf blade, and was quite similar across years. Regarding the variability of the magnesium concentration, was higher in the petiole compared to the leaf blade (Figure 6).

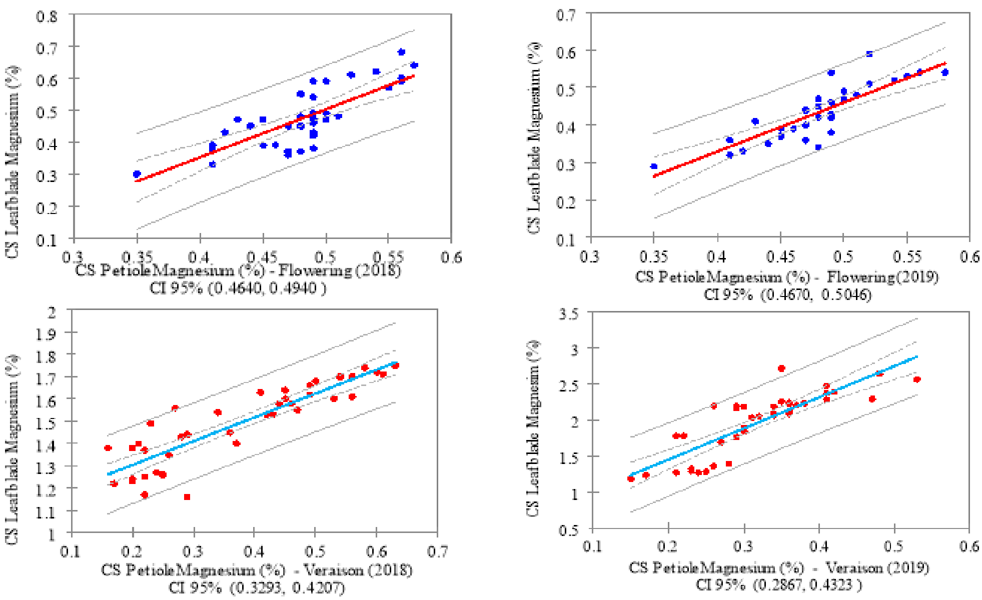

Figure 6. Magnesium concentration in leaf blade and petiole, at flowering and veraison, for Cabernet Sauvignon during 2017-2018 growing seasons (CI = confidence interval; CV% = coefficient of variation; R^2 = coefficient of determination)

Climate variability correlated with grapevine nutrition influence on grape yield and berry composition

Berry composition is important for both viticulturists and winemakers. Mineral status is influenced by many factors as soil, translocation from roots to canes and shoots, crop load, number of berries on cluster, cultural practices or vine vigour, climate variability and microclimate.

At ripening stage, berry composition was different during two growing seasons; berries from 2018 had higher level of anthocyanins than those from 2019.

Climate variability correlated with grapevine nutrition influenced the berry composition and yield. Rainfalls from the 2019 flowering season have positive influence on titratable acidity (TA) level (Table 1).

By contrary, soil moisture had little impact on TA level at grape maturity. In both growing seasons, TA level was negatively correlated with the temperature (variables involved diurnal and nocturnal temperature) from early growing season to ripening stage.

However, the higher pH berry juice at ripening was found in the warmer 2019 growing season, and was correlated with higher sugars concentration (Table 1).

Nitrogen

In 2018, the nitrogen in petiole and leaf blade show higher concentration in veraison compared to flowering stage, and was opposite in 2019. The variability of nitrogen concentration in petiole and leaf ranked to a large extent, being generally higher in petiole.

Table 1. Grape yield and main production parameters for Cabernet Sauvignon variety during 2018-2019 growing seasons

	Yield (kg/vine)	Cluster weight (g)	Berry weight (g)	Pruning weight (kg/vine)	°Brix	pH	TA (g/l)	Total anthocyanins mg/l
2018	4.8	106.55	1.30	1.38	22.14	3.54	7.76	66.75
2019	5.6	128.30	1.42	1.25	23.50	3.72	7.42	54.20

Table 2. Results for macro - and trace elements in Cabernet Sauvignon grape berries during 2018-2019 growing seasons

	N	K	P	Ca	Mg	B	Fe	Cu	Mn	Zn
	μg $berry^{-1}$									
2018	1472± 86.4	3842± 103.17	288 ± 39	471 ± 13	142 ± 6	14 ± 1.2	5.2 ± 0.4	2.6 ± 0.18	2.2 ± 0.18	1.1 ± 0.19
2019	1524 ±92.6	3925± 112.05	295 ± 42	475 ± 44	149 ± 8	12 ± 0.9	5.7 ± 0.6	2.9 ± 0.21	2.4 ± 0.3	1.4 ± 0.21

According to Vrignon-Brenas et al., (2019), the post harvest application has the same influence on petiole nitrogen concentration like that applied at flowering; in the present research, the first nitrogen application was before budburst. According to Costa et al. (2019) results, usually fertilization is positive correlated with nitrogen concentration in the petiole. Lower temperature and heavy rainfed in flowering stage in 2019 growing season, are correlated with the higher influence of petiole on leaf blade nitrogen concentration. The higher vigour of Cabernet Sauvignon facilitates more nitrogen accumulation, because large canopy need more nitrogen during budbrake and flowering stages.

More favourable climate during veraison stage from 2018 (Figure 1) and the availability of nitrogen from soil, facilitate the increase of nitrogen concentration in petiole and leaf blade; lower petiole and leaf blade nitrogen concentration during second growing season in veraison stage (2019) is correlated with less humidity from June and July.

Several researches demonstrated that draught can decrease the nutrients uptake from soil (due to nutrients mineralization or less nutrient diffusion in the soil) and the nitrogen concentration and phosphorus in tissues (Parker et al., 2011; Fila et al., 2014). Year to year variability of nitrogen concentration in petiole and leaf blade was reported by Benito et al. (2013) in Garnacha Tinta variety, Schreiner et al. (2013) in Pinot Noir or Romero et al. (2014) in Tempranillo variety. In present study, overall lower variability of nitrogen concentration recommends both leaf blade and petiole from veraison stage, for nitrogen status of the vine. Similar results were found in Garnacha Tinta (Benito et al., 2013) and Tempranillo (Romero et al., 2014). However, Conradie (1981) reported that petiole is better indicator of nitrogen status in vines than leaf blade, because is more sensitive to variation. Large doses of nitrogen applied in vineyards can influence the absorption and interact with other nutrients (Helwi et al., 2015).

Phosphorus

Phosphorus concentration in petiole was found to be higher than in leaf blade according to Klein et al. (2000) founding. Large variability in petiole phosphorus concentration in Red Grenache variety (Benito et al., 2013) indicate leaf blade to be more useful for phosphorus diagnose in wine grapes varieties. On contrary, phosphorus was the less abundant macronutrient in leaf petiole (4.0 g kg^{-1}) found by Arrobas et al. (2014) in cv. Viosinho Blanc. In present research, the higher phosphorus concentration in petiole compared to leaf blade and less variable in leaf blade flowering stage in the first growing season, recommends this macronutrient as phosphorus status in Cabernet Sauvignon.

Potassium

Cabernet sauvignon show lower variability from flowering to veraison and from year to year, compared with nitrogen. Lower variability is contrary to the observations of Romero et al. (2014) and Benito et al. (2013) which suggest that petioles are better indicators of potassium status from vines compared to leaf blade, due to better response after potassium supply. In present study, the regression model for potassium concentration indicates that petiole had medium or lower influence on leaf blade potassium. The draught from the last growing seasons and over cropping, can explain the lower levels of potassium in vines analysed tissues. According to Abbasi et al. (2016) less humidity in soil decrease potassium uptake due to lower mobility, transpiration rate and declined of roots membrane transporters. Potassium level has been found to be variable from one year to another by Christensen (2000) and his research results confirm limits variability from 30 to 50% in the same vines from the same vineyard, depending on rootstock, variety and soil moisture. Therefore, Cabernet Sauvignon leaf blade (flowering stage) lower variability during both growing seasons can be a better predictor of potassium status.

Calcium

Calcium commonly range between 1.0-2.0% and can increase to 3.5% in petioles when potassium and magnesium are lower, according to Christensen (2000) findings. In preset study, some calcium uptake over 2% in leaf blade and petiole can be partly explained by the new roots which usually start to grow after bloom stage and the balanced soil pH.

This statement is according with de Herralde et al. (2010) findings, which indicates that roots main functions are nutrient and water uptake, and those with Ø < 2 mm, are often mycorrhized. Higher calcium concentration (25.7 g kg^{-1}) in petiole samples collected at veraison was found by Arrobas et al. (2014) in cv. Viosinho Blanc from Portugal.

Conradie (1981) research results in Chenin Blanc show that little amount of calcium is accumulated before and after budburst due to the reserves used for new growth from vines roots. However, Cabanne and Doneche (2003) after studying the calcium accumulation in Cabernet Sauvignon, Merlot, Semillon and Sauvignon Blanc varieties from Bordeaux vineyards concluded that calcium concentration increased from flowering to veraison.

Overall low variability of potassium from one year to another in both leaf blade and petiole (flowering and veraison) from Cabernet Sauvignon, recommends this macronutrient for wine grape varieties in study nutrient status.

Magnesium

The negative correlation between magnesium and potassium concentration was documented by other researchers (Gransee & Führs 2013; Domagała-Świątkiewicz et al., 2019). However, magnesium concentration is positive influenced by phosphorus application according to Skinner and Matthews (1990). Leaf blade in both flowering and veraison in first growing season show less variability, therefore can be used for magnesium status for future nutrition with the macronutrient in the vineyard. In Shiraz variety from Riverina (Australia), while phosphorus concentration decline from spring to the end of growing season similar to nitrogen, calcium and magnesium increased in substantially amounts in leaves, with the highest calcium concentration in flowering stage and magnesium at berry set stage (Benito et al., 2013). Conradie (1981) research results show that in Chenin Blanc variety, magnesium absorption was not significant three weeks before budburst and after one month; instead, magnesium increased in leaves during flowering stage till veraison.

Climate variability correlated with grapevine nutrition

Nitrogen berries content at harvest can offer the plant status for this macronutrient for the whole season; nitrogen accumulates during berries development with a considerable dropping in the first stage of veraison (50% in the skin and seeds), but higher amounts of nitrogen decrease the grape production (Amiri & Fallahi, 2007). According to Satyanarayana (1972) the nitrogen level from leaves is a major indicator in grape yield. The more dry vintage 2018 decreased the nitrogen content in Cabernet Sauvignon berries at harvest and was less altered in fruits the next vintage year (Table 2). Potassium is one of the most necessary nutrient in grapevine and large amounts are removed with grape yield (Kodur, 2011). It is absorbed by vines during all stages, but mainly after veraison, with a sharp increase during ripening and has greatly influence on grape juice pH. Leaf potassium concentration was not significantly different between the two growing seasons but less humidity during veraison and ripening in 2018 season, decreased potassium uptake by roots; the content in berries was lower compared to 2019 season. On contrary, Etchebarne et al. (2009) doesn't found in ripened berries potassium concentration modified by water availability for plants. Component of the nucleic acids and ATP, phosphorus accumulate in grape berries during the whole growing season but mainly after veraison; translocation from leaves increase phosphorus into bunches to almost 300 μg $berry^{-1}$ in both growing seasons. Structural role of the calcium in berries cell wall and membranes increases until veraison (decreased after). The calcium accumulation depends of vine water status and was lower in 2018 growing season. Magnesium which is involved in photosynthesis and can be found mainly in leaves is absorbed in small quantities in grape berries especially in seeds (before, during and after veraison) was also influenced by vine water status; magnesium concentration in berries reached 142 in the first growing season and 149 μg $berry^{-1}$ respectively in the second; the magnesium from petiole doesn't show any link with berry quality (Table 2). Research results of Panceri et al. (2013) for calcium and magnesium content in grape berries during dry weather, confirm the concentration increase of both minerals in grape juice. Boron deficiency - which is associated with draught stress, decrease pollen tube growth and pollen germination is limited, resulting hen and chick syndrome – was observed in June-July 2019 vintage. No significant differences were found in grape juice between growing seasons for Fe, Mn and Zn which accumulates mainly in berry pulp and skin, and their concentration is associated with the migration from the skin to pulp and positively influence by dehydration; Galgano et al. (2008) found similar results. The presence of Cu in grape juice is influenced mainly by copper fungicides treatments and was higher in more dehydrated berries during 2019 vintage (Table 2).

CONCLUSIONS

The comparison with other results is difficult because terroir is different within the same region; however, most of the petiole and leaf blade concentrations found ranked around those reported in the literature which signifies that the vineyard area nutritional status is adequate for Cabernet Sauvignon growing. The higher temperature from 2019 growing season (the highest from 1960), negatively influenced the macronutrients accumulation in leaf blade and petiole both in flowering and veraison stages, comparing to more balance growing season of 2018. Leaf blade macronutrients concentration was more uniform excepting phosphorus which is better predicted by petiole. Flowering stage was more reliable for predicting nutritional status of the vines excepting nitrogen. Results can be useful as guide for Cabernet Sauvignon grape growers in similar terroir. Climate change but especially climate variability influence on grapevine nutrition requires further research not only on this variety but also on others, as well as for the essential microelements for vines. Dry weather, lower water activity and water loss from berry during development, veraison and ripening, induces changes in the soluble solids and mineral composition and is related with their concentration which is positive correlated with the degree of dehydration.

REFERENCES

Abbasi, H., Jamil, M., Haq, A., Ali, S., Ahmad, R. & Malik Z. (2016). Salt stress manifestation on plants, mechanism of salt tolerance and potassium role in alleviating it: a review. *Zemdirbyste-Agriculture*, 103, pp. 229-238. DOI: 10.13080/z-a.2016.103.030.

Amiri, M.E. & Fallahi E. (2007). Influence of mineral nutrients on growth, yield, berry quality, and petiole mineral nutrient concentrations of table grape. *J. Plant Nutr*. 30, 463-470.

Arrobas, M., Ferreira, I.Q., Freitas, S., Verdial, J.& Rodrigues M.Â. (2014). Guidelines for fertilizer use in vineyards based on nutrient content of grapevine parts, *Scientia Horticulturae* 172 191–198. DOI: 10.1016/j.scienta.2014.04.016.

Bencke-Malato, M., De Souza, A.P., Ribeiro-Alves, M., Schmitz, J.F., Buckeridge, M.S. & Alves-Ferreira M. (2019). Short-term responses of soybean roots to individual and combinatorial effects of elevated (CO_2) and water deficit. *Plant Science* 280:283–296. DOI:10.1016/j.plantsci.2018.12.021.

Benito, A., Romero, I., Domínguez, N., García-Escudero, E. & Martín I. (2013). Leaf blade and petiole analysis for nutrient diagnosis in *Vitis vinifera L*. cv. Garnacha tinta. *Australian Journal of Grape and Wine Research*, 19, 285–298. DOI: 10.1111/ajgw.12022.

Benito, A., García-Escudero, E., Romero, I., Domínguez, N. & Martín I. (2015). Sufficiency ranges (sr) and deviation from optimum percentage (dop) references for leaf blade and petiole analysis in 'Red Grenache' grapevines. *OENO One*, 49(1), 47–58. DOI: 10.20870/oeno-one.2015.49.1.94.

Biasi, R., Brunori, E., Ferrara, C. & Salvati L. (2019). Assessing Impacts of Climate Change on Phenology and Quality Traits of *Vitis vinifera* L. The Contribution of Local Knowledge. *Plants (Basel).* 8(5): 121. DOI: 10.3390/plants8050121.

Cabanne, C. & Doneche, B. (2003). Calcium accumulation and redistribution during the development of grape berry. *Vitis.* 42(1), pp.19-21. DOI: 10.1111/j.1755-0238.2010.00118.x.

Celette, F. & Gary, C. (2013). Dynamics of water and nitrogen stress along the grapevine cycle as affected by cover cropping. *European Journal of Agronomy,* 45, 142–152. DOI: 10.1016/j.eja.2012.10.001.

Christensen, P. (2000). Use of tissue analysis in viticulture. University of California Cooperative *Extension Tulare County, Publication NG10-00***.**

Conradie, W.J. (1981). Seasonal uptake of nutrients by Chenin blanc in sand culture II. Phosphorous, potassium, calcium and magnesium. *South African Journal of Enology and Viticulture.* 2 (1), pp. 7-13. DOI: 10.21548/2-1-2403.

Costa, R., Fraga, H., Fonseca, A., García, de Cortázar-Atauri I., Val M.C., Carlos C., Reis S., Santos J.A. (2019). Grapevine Phenology of cv. Touriga Franca and Touriga Nacional in the Douro Wine Region: Modelling and Climate Change Projections. *Agronomy*, 9(4):210. DOI: 10.3390/agronomy9040210.

Dobrei A., Dobrei A.G., Posta Gh., Danci M., Nistor E., Camen D., Malaescu M., Sala F. (2016). Research concerning the correlation between crop load, leaf area and grape yield in few grapevine varieties. *Agriculture and Agricultural Science Procedia,* vol. 10, pp. 222-232. DOI: 10.1016/j.aaspro.2016.09.056.

Domagała-Świątkiewicz I., Gąstoł M., Kiszka A. (2019). Effect of nitrogen and potassium fertilization on the magnesium content in vineyard soil, and in the leaves and berries of Bianca and Sibera grapevine cultivars*, Journal of Elementology,* 24(2): 755-769. DOI: 10.5601/jelem.2018.23.3.1714.

Dominguez N., García-Escudero E., Romero I., Benito A., Martín I. (2015). Leaf blade and petiole nutritional evolution and variability throughout the crop season for *Vitis vinifera L.* cv. Graciano. *Spanish Journal of Agricultural Research* 13(3), p. 17. DOI: 10.5424/sjar/2015133-5142.

Etchebarne F., Ojeda H., Deloire A. (2009). Grape berry mineral composition in relation to vine water status and leaf area/fruit ratio. In book: *Grapevine Molecular Physiology & Biotechnology*. Pp. 53- 72. DOI: 10.1007/978-90-481-2305-6_3.

Fogaça A.O., Daudt C.E., Dorneles F. (2007). Potassium in grapes II – analysis of petioles and their correlation with the potassium content of wine grapes. *Ciência e Tecnologia de Alimentos Campinas,* 27(3) 597–601. DOI: 10.1590/S0101-20612007000300026.

Fila G., Gardiman M., Belvini P., Meggio F., Pitacco A. (2014). A comparison of different modelling solutions for studying grapevine phenology under present and future climate scenarios. *Agricultural and Forest Meteorology*, vol. 195, pp.192–205. doi: 10.1016/j.agrformet.2014.05.011.

Galgano F., Favati F., Caruso M., Scarpa T., Palma A. (2008). Analysis of trace elements in southern Italian wines and their classification according to provenance, *LWT - Food Science and Technology*, Vol. 41, Issue 10, pp. 1808-1815. https://doi.org/10.1016/j.lwt.2008.01.015.

Gransee A., Führs H. (2013). Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. *Plant and Soil*, 368: 5-21. DOI: 10.1007/s11104-012-1567-y.

de Herralde F., Savé R., Aranda X., Biel C. (2010). Grapevine Roots and Soil Environment: Growth, Distribution and Function, In book: *Methodologies and Results in Grapevine Research*. DOI: 10.1007/978-90-481-9283-0_1.

Klein I., Strime M., Faberstein L., Mani Y. (2000). Irrigation and fertigation effects on phosphorus and potassium nutrition of wine grapes. *Vitis* 39(2):55–62. doi: 10.5073/vitis.2000.39.55-62.

Kodur S. (2011). Effects of juice pH and potassium on juice and wine quality, and regulation of potassium in grapevines through rootstocks (Vitis): a short review. *Vitis*, Siebeldingen, v.50, p.1-6.

Koufos G.C., Mavromatis T., Koundouras S., Jones G.V. (2020). Adaptive capacity of winegrape varieties cultivated in Greece to climate change: current trends and future projections. *OENO One* 54(4) 1201–1219. DOI: 10.20870/oeno-one.2020.54.4.3129.

de Orduña M.R. (2010). Climate change associated effects on grape and wine quality and production. *Food Research International*, 43, 1844–1855. DOI: 10.1016/j.foodres.2010.05.001.

Panceri C.P., Gomes T.M., De Gois J.S., Borges D.L.G., Bordignon-Luiz M.T. (2013). Effect of dehydration process on mineral content, phenolic compounds and antioxidant activity of Cabernet Sauvignon and Merlot grapes, *Food Research International*, Vol. 54, Issue 2, pp. 1343-1350,ISSN 0963-9969, https://doi.org/10.1016/j.foodres.2013.10.016.

Pareek N. (2017). Climate change impact on soils: adaptation and mitigation. *MOJ Ecology & Environmental Sciences*, 2(3):136-139. doi: 10.15406/mojes.2017.02.00026.

Parker A.K., García de Cortázar-Atauri I., van Leeuwen C., Chuine I. (2011). General phenological model to characterise the timing of flowering and veraison of *Vitis vinifera L. Australian Journal of Grape and Wine Research* 17, 206–216. DOI: 10.1111/j.1755-0238.2011.00140.x.

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. *Spanish Journal of Agricultural Research* (S.l.) 12(1), p. 206-214. DOI: org/10.5424/sjar/2014121-4308.

Santos J.A., Fraga H., Malheiro A.C., Moutinho-Pereira J., Dinis L.-T., Correia C., Moriondo M., Leolini L., Dibari C., Costafreda-Aumedes S., Kartschall T., Menz Ch., Molitor D., Junk J., Beyer M., Schultz H.R. (2020). A Review of the potential climate change impacts and adaptation options for European viticulture. *Applied Sciences* 10(9) 3092. DOI: 10.3390/app10093092.

Satyanarayana G. (1972). Studies on nutritioual requirements of Anab-e-Shahi grape. Abstract of Int. Symp. Sub-tropical and Tropical Horticulture, *Ind. Soc. Hort.*, 188.

Schreiner R.P., Lee J., Skinkis P.A. (2013). N, P, and K supply to Pinot noir grapevines: Impact on vine nutrient status, growth, physiology and yield. *American Journal of Enology and Viticulture*, 64:26–38. DOI: 10.5344/ajev.2012.12064.

Skinner P.W., Matthews M.A. (1990). A novel interaction of magnesium translocation with the supply of phosphorous to root of grapevine (*Vitis vinifera L.*). *Plant, Cell and Environment*. 13(8) pp. 821-826. DOI: 10.1111/j.1365-3040.1990.tb01098.x.

Vrignon-Brenas S., Aurélie M., Romain L., Shiva G., Alana F., Myriam D., Gaëlle R., Anne P. (2019). Gradual responses of grapevine yield components and carbon status to nitrogen supply: This article is published in cooperation with the 21th GIESCO International Meeting, June 23-28 2019, Thessaloniki, Greece. Guests editors: Stefanos Koundouras and Laurent Torregrosa. *OENO One* 53(2). DOI: 10.20870/oeno-one.2019.53.2.2431.