Influence of Soil Reaction on Phosphorus, Potassium, Calcium and Magnesium Dynamics in Grapevine (*Vitis vinifera* L.)

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Summary

Influence of soil reaction on phosphorus, potassium, calcium and magnesium dynamics in grapevine was studied on the variety Sauvignon Blanc in 2007, in the Plešivica wine-growing region. Investigations were conducted on three vitisol subtypes: dystric cambisol (pH_{KCl} 3.73-3.76), pseudogley (pH_{KCl} 4.67-4.69) and rendzina on marl (pH_{KCl} 7.21-7.27). To establish the amount and dynamics of P, K, Ca and Mg in plant material, leaf samples were taken three times during the growing period: at the flowering and veraison stages and at the end of the growing period. At all sampling times, significantly higher leaf contents of P, Ca and Mg were found on alkaline soil compared to acid soils, while differences in K levels were not statistically significant. Differences in P contents may be explained by better solubility and thereby better availability of P from Ca-phosphates compared to Al, Mn and Fe-phosphates in acid soils. In addition, the cation ratio K/(Ca+Mg) that has a significant influence on grape quality, was also determined in leaves. Compared to optimal values (0.30–0.40), the least favourable ratio K/(Ca+Mg) was recorded at flowering on acid soils (0.38–0.77) and at harvest on calcareous soil (0.12–0.27). Differences in the content of sugar and total acids in must indicate a positive correlation between leaf contents of P, Ca and Mg and sugar content of must, and a negative correlation between leaf contents of P, Ca and Mg and the total acid content of must.

Key words

grapevine, soil reaction, leaf, must

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Introduction

Soil reaction is the most important factor influencing the solubility and plant availability of phosphorus (P), calcium (Ca), magnesium (Mg) and potassium (K). Availability of these nutrients to plants may be reduced both on acid and on alkaline, calcareous, soils. In very acid soils deposition of phosphate ion occurs due to a high concentration of aluminium, iron and manganese ions. Aluminium phosphates, variscites $Al(OH)_2H_2PO_4$, and iron phosphates, strengites $Fe(OH)_2H_2PO_4$, are predominantly formed. Besides P ion, concentrations of Ca, Mg and K ions are also reduced in acid soils (Jemo et al., 2007). High concentration of Ca-ions in calcareous soil causes formation of less soluble diCa to octoCa phosphates and apatite. Owing to somewhat higher solubility of Ca phosphate, the phosphate ion from Ca phosphate is more available to plants compared to Al, Mn and Fe phosphates (Füleky, 2006). Mg and K availability is also reduced in calcareous soil due to antagonistic relations between Ca and Mg as well as Ca and K. Inadequate soil fertilization, that is, intensified application of K fertilizers, can also cause reduced Mg uptake due to K and Mg antagonism. However, to fully evaluate grapevine supply of P, K, Ca and Mg, it is necessary to know the optimal values for individual elements as well as the cation ratio K/(Ca+Mg) in leaves. Very broad limits of optimal contents of particular elements are reported in literature, however without specifying the variety and vineyard age, or agroclimatic conditions of specific vine-growing positions. According to Fregoni (1998), optimal contents of the studied elements at flowering in leaves dry matter are: 0.15–0.38 % P, 0.65–1.70 % K, 1.70–3.80 % Ca and 0.18–0.45 % Mg; at veraison: 0.12–0.28 % P, 0.50–1.60 % K, 2.20–4.50 % Ca and 0.17–0.60 % Mg. According to Vercesi et al. (1993), critical values for deficiency of particular elements in leaves dry matter are: < 0.11 % P, < 0.57 % K, < 1.41 % Ca and < 0.47 % Mg. With regard to absolute values of individual elements in leaves, Fregoni (1998) maintains that the grape and must quality is more affected by the K/(Ca+Mg) ratio, which should range from 0.30-0.40, than by the contents of individual elements.

Leaf contents of individual elements are not a constant, they keep changing during the growing period. Besides, element contents depend on the variety, soil chemical properties, weather conditions as well as on the anthropogenic impact (fertilization). According to Petek et al. (2008), P and N contents decrease towards the end of the growing period, those of Ca and Mg increase, while changes in K content are negligible. The K/(Ca+Mg) ratio changes accordingly. According to the same authors, the K/(Ca+Mg) ratio in leaves of the variety Sauvignon Blanc grown on calcareous soil is much higher at flowering (0.73) to drop to 0.25 at the end of the growing period. The authors think that the established cation ratio is unfavourable and should be corrected by application of Mg fertilizers. For these reasons, the main aim of these investigations was to find out to which extent soil reaction affects the availability of P, Ca, Mg and K, and the cation ratio K/(Ca+Mg). Thus investigations were conducted on the variety Sauvignon Blanc grown on soils of different reactions (very acid, acid and alkaline reaction).

Material and methods

Influence of soil reaction on P, K, Ca and Mg dynamics in grapevine was monitored in eight years old vineyard on the variety Sauvignon Blanc (planted on SO4 rootstock) in the Plešivica wine-growing region in 2007. The trial was set up on three vitisol subtypes: dystric cambisol (very acid soil), pseudogley (acid soil) and rendzina on marl (calcareous soil). The trial was laid out according to the strip-plot design with three replications. Major chemical properties of the soil were determined in layers at 0-30 and 30-60 cm depths before the trial was set up (after the harvest) in 2006 (Table 1) using the standard methods (JDPZ, 1966). Identical standard agricultural management practices were applied in all the three vineyards. Basic tillage was performed on 28.02.2007 with 500 kg ha^{-1} of Hydrocomplex NPK 12:11:18.

Grapevine leaf samples were taken three times during the growing period: at flowering[1] and veraison[2] stages and at the end of the growing period (harvest[3]). Average samples were formed from 120 healthy, fully developed and undamaged leaves, taken opposite to clusters from all 40 vine plants (3 leaves x 40 plants) that made up the trial plot.

After leaf digestion with concentrated HNO_3 (Milestone 1200 Mega Microwave Digester) P was determined spectrophotometrically (AOAC, 1995), K was determined with a flame photometer and Mg and Ca were determined by the atomic adsorption technique. Must sugar content was determined using a digital Refractrometer PR-101, Atago, and the values are expressed as Brix percent. Total acids (TA) in must were determined by the titration method (EEC, 1990).

Statistical analysis included modelling of leaf P, K, Ca, and Mg concentration, as well as leaf K/(Ca+Mg) ratio, using soil

Table 1. Chemical properties of investigated soils

Soil type	Depth (cm)	pH (KCl)	Humus (%)	Total N (%)	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})	Al^{3+} (mg kg^{-1})	CaO (%)	Mg (mg kg^{-1})
Dystric cambisol	0-30	3.73	1.34	0.11	168.90	322.60	304.00	–	173.0
	30-60	3.76	0.92	0.08	24.50	164.60	229.50	–	160.0
Pseudogley	0-30	4.67	1.31	0.13	162.00	333.30	5.60	–	188.0
	30-60	4.69	0.86	0.09	19.50	141.30	5.30	–	199.0
Rendzina on marl	0-30	7.24	2.01	0.17	74.70	316.60	–	21.50	168.0
	30-60	7.27	1.26	0.13	37.40	146.60	–	20.50	162.0

– analysis was not preformed

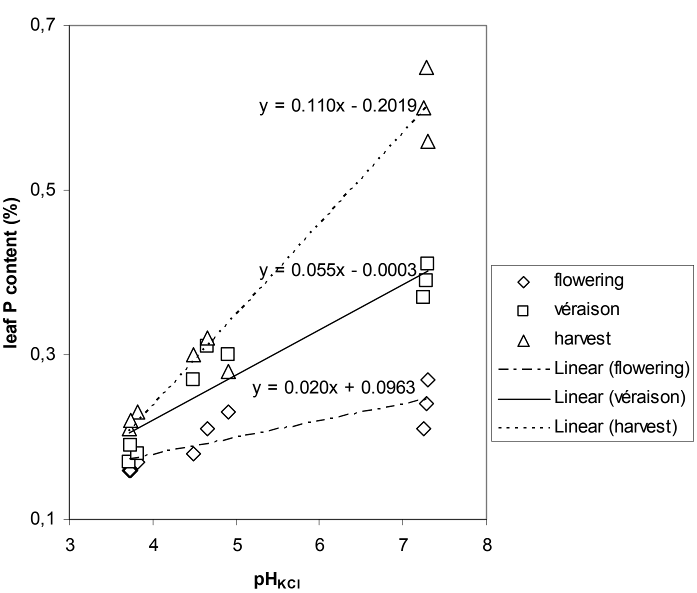
pH as the predictor variable with added effects of the physiological phase, and as phase by pH interaction (allowing for the differential response to pH level in different phases). After fitting the described full model, non-significant terms at P=5% were dropped out, and obtained reduced models refitted to the data. The relationships between leaf variables listed above, must sugar and acid contents were investigated using simple correlation analysis. All statistical analyses were performed using SAS (SAS Institute Inc., 2007) procedures CORR and GLM.

Results and discussion

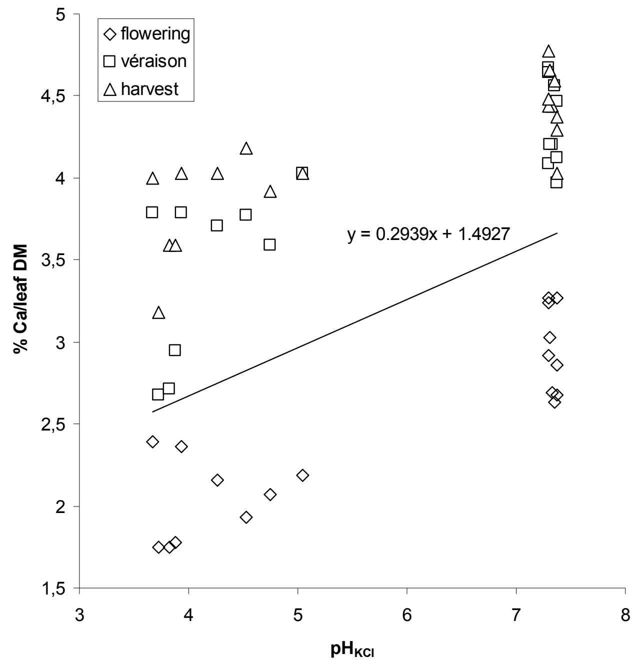
Amounts and dynamics of P, Ca and Mg in vine leaves greatly depended on soil reaction (pH) as well as on vine development phenophases (Graphs 1, 2 and 3). Soil reaction influence on K content in vine leaves was negligible in all phenophases (Graph 4), which was also reported by Petek et al. (2008).

In all three phenophases, higher P, Ca and Mg contents were detected in vine leaves on calcareous soil compared to acid soils; while there where no differences in K content. The highest P, Ca and Mg contents in vine leaves were determined at harvest and the lowest at flowering on all three soil types; for P this differs from the findings of Petek et al. (2008) who found 0.20-0.42 % P.

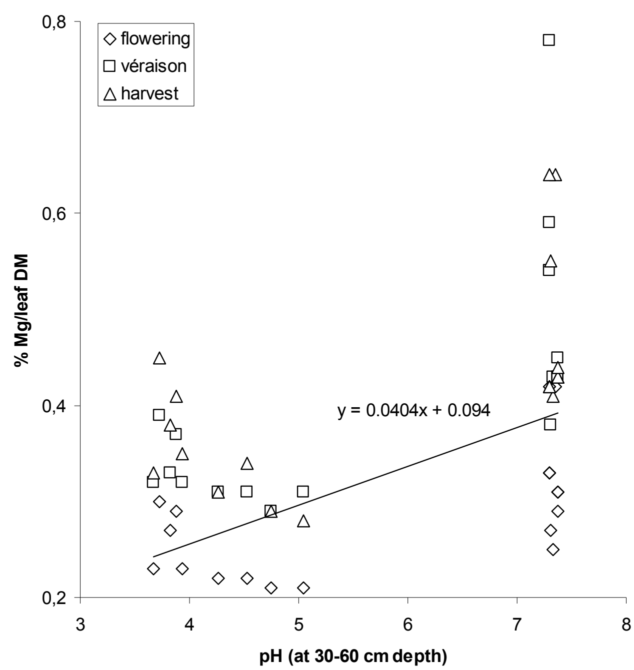
Regression of P content in vine leaves on soil pH was dependent on physiological phase; starting with minimal slope of 0.02 % for each pH unit at flowering and reaching the steepest value of 0.11 % at harvest (Graph 1). These differences can be attributed to better solubility and availability of P from Ca phosphates in calcareous soil compared to aluminium and iron phosphates in very acid soils (Marschner, 1995; Füleky, 2006). The highest P content in vine leaves (0.60 % P/DM*) was recorded on calcareous soil at harvest and the lowest (0.16 % P/DM) at flowering on very acid soil. Values determined for P in vine leaves on dystric cambisol



Graph 1. Influence of soil reaction on phosphorus content and dynamics in vine leaves

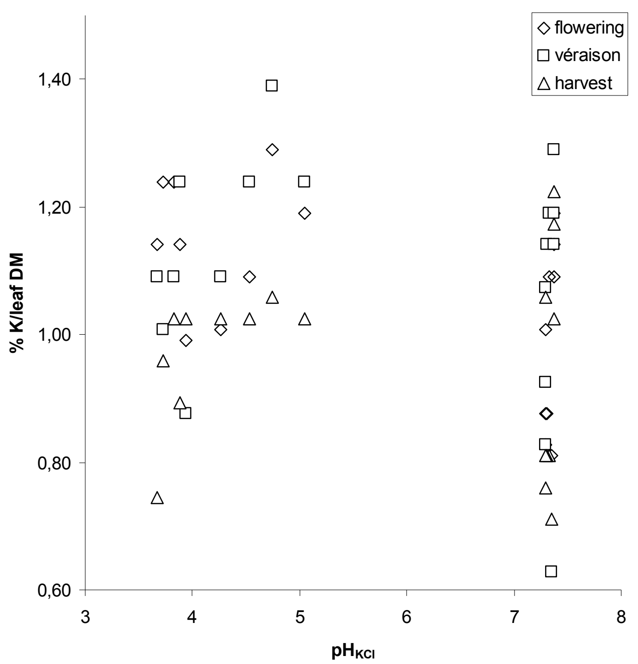


Graph 2. Influence of soil reaction on calcium content and dynamics in vine leaves

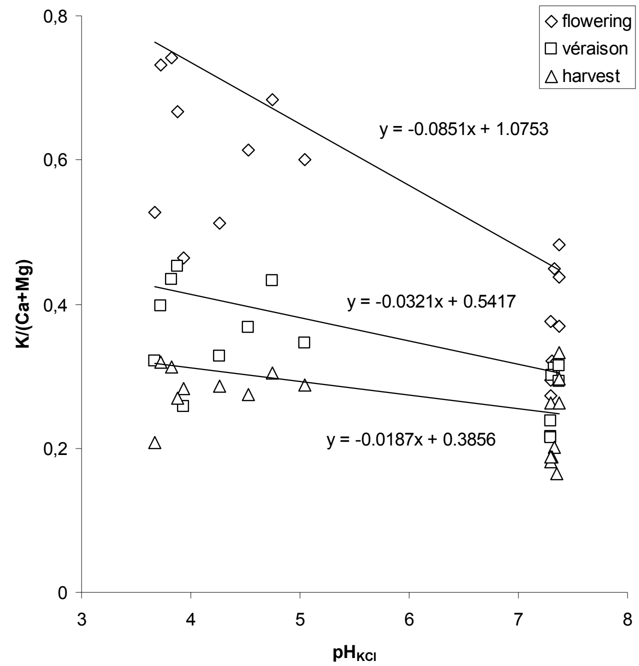


Graph 3. Influence of soil reaction on magnesium content and dynamics in vine leaves

* DM – Dry Matter



Graph 4. Influence of soil reaction on potassium content and dynamics in vine leaves



Graph 5. Influence of soil reaction on the dynamics of K/(Ca + Mg) ratio in vine leaves

(0.16[1], 0.18[2] and 0.22[3] % P/DM) and pseudogley (0.21[1], 0.29[2] and 0.30[3] % P/DM) are lower than optimal values (0.25-0.45 % P/DM) reported by Bergman (1992) and are in agreement with those reported by Fregoni (1998). P supply to grapevine on rendzina (0.24[1], 0.39[2] and 0.60[3] % P/DM) can be allotted to the category of optimal to rich supply even though that initial soil content of P in upper layer on rendzina was lower than in other soil types.

A trend of Ca and Mg increase with the soil acidity decrease was uniform across phases (Graphs 2 and 3). Compared to the trends of P accumulation in leaves, absorption of Ca and Mg was not blocked by high soil acidity, so increase of Ca and Mg content from initial to the final phenophase was equal at different soil pH levels. Highest contents of Ca (4.77 % Ca/DM) and Mg (0.64 % Mg/DM) were found in vine leaves at harvest on calcareous soil, and the lowest (1.75 % Ca/DM and 0.21 % Mg/DM) at flowering on dystric cambisol. These Ca and Mg values are similar to those determined by Gluhić et al. (2007) on calcareous soils of Plešivica. According to Fregoni (1998), Ca and Mg contents determined in vine leaves of our experiment were optimal on calcareous soil, while Ca and Mg contents determined in vine leaves on acid soils, at the flowering stage, are at the lower threshold of optimal values (1.70-3.80 % Ca/DM and 0.18-0.45 % Mg/DM).

Trend of cation ratio K/(Ca+Mg) in leaves was generally decreasing towards higher soil pH values, but response differed across phases (Graph 5). It was steepest at the initial phase – flowering (this ratio K/(Ca+Mg) on acid soils ranged from 0.38 to 0.77), and decreased towards the end of the growing period. Lowest values of the K/(Ca + Mg) ratio (0.12-0.27) were determined at harvest on calcareous soil.

According to Fregoni (1988), the values calculated for the cation ratio K/(Ca+Mg) significantly deviate from optimal values (0.30-0.40) both on acid and calcareous soils. Highest aberrations were determined at flowering (widest ratio) on acid soils. As K values changed negligibly over the growing period, the reason for the unfavourable cation ratio should be looked for in lower Ca and Mg contents at flowering. Cation imbalance in vine leaves on acid soils can be solved by raising the soil reaction (pH) by liming. Also, attempts should be made to lower the pH of calcareous soils through application of acid organic and mineral fertilizers. Due to large amounts of Ca and Mg ions in calcareous soil, uptake of K ions is reduced, resulting in a cation ratio lower than optimal. Very low K/(Ca+Mg) ratio was recorded on calcareous soil at the end of the growing period, ranging from 0.14 to 0.27 (Graph 5). Regulation of the K/(Ca+Mg) ratio is of the utmost importance because, according to a number of authors (Fregoni, 1998; Marschner, 1995, etc.), it has the significant influence on the quality of grapes, must and wine.

These investigations have also shown that there is a relationship between the contents of P, Ca and Mg in leaves and the amount of total sugar and total acids (TA) in must. Higher contents of sugar were recorded on calcareous soil in Borička (23.6 – 26.5 % Brix) compared to acid soils in Rečki gaj (21.6 – 24.1 % Brix). Must content of total acids (TA) ranged from 6.3 to 7.1 g l^{-1} on acid soil, and from 5.4 to 6.0 g l^{-1} on calcareous soil (Table 2).

Very strong correlation was found between the contents of sugar (R=0.90) and TA (R = - 0.89) in must and leaf P content. Also, a positive but not so strong correlation was established between sugar content in must and leaf contents of Ca

Table 2. Must sugar and total acid concentrations on acid and calcareous soils

Sample	Sugar (% Brix)		Total acid ($g\ l^{-1}$)	
	Rečki gaj	Borička	Rečki gaj	Borička
1	24.1	25.3	6.6	5.5
2	23.4	24.7	7.0	5.8
3	21.7	24.7	6.3	5.4
4	21.6	24.5	7.0	5.7
5	22.6	26.5	7.1	6.0
6	23.7	26.5	6.9	5.5
7	22.9	25.1	7.0	5.7
8	23.9	23.6	7.0	5.9
9	22.4	23.9	7.0	5.7
Average	22.9	25.0	6.9	5.7

(R=0.44) and Mg (R=0.61). Negative correlation was found between the cation ratio K/(Ca+Mg) in leaves and sugar content in must (R= -0.41).

Conclusions

These investigations have shown that soil reaction has a significant influence on the contents of P, Ca and Mg in vine leaves whereas its influence on K content was not recorded. Significantly higher values of P, Ca and Mg were determined at all growth stages (flowering, veraison and harvest) on calcareous soil (rendzina) compared to acid soils (pseudogley and dystric cambisol). Leaf contents of P, Ca and Mg increased towards the end of the growing period while changes in K content were negligible. The K/(Ca+Mg) ratio varied significantly during the growing period in dependence on the soil and vine growth stage. The widest ratio was determined at flowering on acid soil (0.77) and the narrowest (0.14) at harvest on calcareous soil. Differences in sugar and total acid contents in must indicate a positive correlation between leaf contents of P, Ca and Mg and sugar content in must and a negative correlation between the K/(Ca+Mg) ratio and must sugar content.

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