The Content of Mg, K and Ca Ions in Vine Leaf under Foliar Application of Magnesium on Calcareous Soils

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Summary

Chlorosis frequently occurs in vine production on calcareous soils, which is usually attributed to high calcium concentrations in soil. If symptoms appear on older leaves, it is taken that chlorosis is caused by a deficit of Mg^{2+} ions. A method of preventing chlorosis is foliar application of magnesium; however, uncontrolled application can lead to imbalance with potassium and calcium ions. The research objective was to find out whether foliar application of magnesium could solve the problem of chlorosis, and whether magnesium affects ion interactions with potassium and calcium. The fertilizing trial was set up in vineyards, on anthropogenized rigosols, with different contents of available lime in soil (< 20, 25 and 30 % CaO). Fertilizer was applied three times during the growing period, in a total amount of 2500 g Mg/ha. According to the results, foliar application of magnesium can solve the problem of chlorosis only on soils with a lower lime content (< 20 % CaO). Magnesium concentrations in dry leaf ranged from 0.25 % (beginning of growing period) to 0.64 % (post harvest), which is in agreement with literature data. On soils with a high lime content, negative correlation was determined between Mg and K ions in the leaf (r = -0.78). Although correlation between Mg and Ca in plant was positive (r = +0.61 to +0.90) during whole grape vine vegetative period, determined high ratios between Ca and Mg, especially during summer (12.4), indicated that Ca was dominant ion in plant disturbing K and Mg physiological roles.

Key words

grapevine, magnesium, potassium, calcium, calcareous soils

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Introduction

Grapevine chlorosis is a physiological disorder often caused by insufficient quantity or imbalance of certain cations in plant physiological processes. This may be due to a high calcium content in soil (calcareous soils), which is commonly bound to calcite ($CaCO_3$), a relatively insoluble calcium mineral, but in the presence of CO_2 and H_2O it turns into its soluble form calcium bicarbonate ($Ca(HCO_3)_2$) whose dissociation forms HCO_3^- and Ca^{2+} , buffering the soil pH value in a range from 7.5 to 8.5 (Imas, 2000; Ksouri et al., 2005). In calcareous soils, calcium accounts for more than 80 % of the total sum of exchangeable cations while there is less than 4 % of exchangeable magnesium that often leads to magnesium deficiency in plants (Hagin and Tucker, 1982). On the example of grapevine, Garcia et al. (1999) concluded that high calcium content has an antagonistic effect upon Mg and K uptake, leading to a reduction of these elements in berries and an increase in total acids. Soil application of magnesium does not often give satisfactory results. In foliar application of magnesium salts, attention should be paid to solution concentration to avoid possible toxicity (Bavaresco, 2001; Imas, 2000). 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 (Fregoni, 1998). Most of the calcareous soils of Croatia are found in the central part of the Istrian Peninsula and in north-western Croatia (Plešivica wine-growing region); it is in these positions that grapevine is mostly grown (Gluhić, 2005; Racz, 2003).

Material and methods

Investigations were conducted in four vineyards in different locations in the Plešivica wine-growing region (Jastrebarsko, Croatia) in 2006. The variety studied was Sauvignon Blanc, grafted on SO_4 stock and planted at 2.20 m x 1.00 m spacing. The soil type of all vineyards was anthropogenized rigosol of P-C horizon structure and with rather high carbonate content. Besides standard NPK fertilization (500 kg/ha NPK 10-30-20), foliar treatment of vineyards with Mg (Magnesiogreen) was applied three times: 1st treatment (four weeks prior to flowering) with 500 g Mg/ha, 2nd treatment (two weeks prior to flowering) with 1000 g Mg/ha, and 3rd treatment (two weeks after flowering) with 1000 g Mg/ha. Total annual amount of pure Mg added was 2500 g/ha. Investigations were carried out according to the fully randomized scheme with four factors in each vineyard in four repetitions:

Factor 1: Mg fertilization (control and magnesium application)

Factor 2: active lime content in the soil {low (LV) 20 %, medium (MV) 25 % and high (HV) 30 %; according to preliminary chemical investigation were chosen vineyards with different active lime content}

Factor 3: vine plant chlorosis area (healthy and chlorotic plants were chosen and marked according to preliminary visual control)

Factor 4: time of whole leaf sampling (four dates: four weeks prior to flowering, two weeks prior to flowering, three weeks after flowering and immediately after harvest; fully developed and undamaged leaves opposite to cluster were taken).

Leaves were analyzed using standard analytical methods: potassium by flame photometry (AOAC, 1995) and magnesium and calcium by atomic absorption spectrometry on an AAS instrument (AOAC, 1995). Statistical data analyses (ANOVA; Student-Newmann-Keulse test) were performed using the Costat statistical program (2005).

Results and discussion

Magnesium application had a significant effect on leaf magnesium content whereas no effect on potassium and calcium levels was recorded (Table 1). The average dry leaf magnesium content of 0.32 %, with a high coefficient of variation, was probably a consequence of magnesium application. Comparison of fertilized and control treatments showed that foliar application of magnesium brought about an increase in the leaf magnesium content by almost 30 % (Table 2). Active lime content in the soil and chlorosis area had no influence on leaf magnesium content (Tables 1, 3 and 4). A significantly higher content of Mg was found at the 4th sampling (after harvest) in comparison with previous samplings, probably due to multiple applications of magnesium fertilizers in the growing period (Table 5). Magnesium content in dry leaf was low up to the ripening stage (ca 0.2 %) to grow to a post-harvest average of 0.6 %, though the 4th sampling was done about

Table 1. The ANOVA tests for Mg, K and Ca content in dry grapevine leaf

Source of variability		Mg	K	Ca
	Significance			
Mg fertilization	(A)	**	n.s.	n.s.
Soil lime content	(B)	n.s.	n.s.	***
Chlorosis area	(C)	n.s.	n.s.	n.s.
Sampling time	(D)	***	*	***
	Interaction			
A x D		**	-	-
Other interaction		n.s.	n.s.	n.s.
Average value		0.32 %	1.17 %	2.71 %
Coefficient of variability		40.80%	27.31%	21.67%

*, ** and *** - significantly different at the 95.0, 99.0 and 99.9 % confidence level, respectively; n.s. – not significant

Table 2. The comparison of average values of Mg, K and Ca in dry grapevine leaf for Mg fertilization

Treatment	Mg (%)	K (%)	Ca (%)
Control	0.26 b	1.13	2.63
Magnesium	0.37 a	1.20	2.79
Significance	**	n.s.	n.s.
LSD (0.05)	0.07	0.17	0.31

*, ** and *** - significantly different at the 95.0, 99.0 and 99.9 % confidence level, respectively; n.s. – not significant

Table 3. The comparison of average values of Mg, K and Ca in dry grapevine leaf for soil lime content

Treatment	Mg (%)	K (%)	Ca (%)
Low lime	0.32	1.19	3.07 a
Moderate lime	0.35	1.17	2.07 b
High lime	0.30	1.15	2.85 a
Significance	n.s.	n.s.	***
LSD (0.05)	0.09	0.23	0.44

*, ** and *** - significantly different at the 95.0, 99.0 and 99.9 % confidence level, respectively; n.s. – not significant

Table 4. The comparison of average values of Mg, K and Ca in dry grapevine leaf for chlorosis area factor

Treatment	Mg (%)	K (%)	Ca (%)
Nonchlorosis area	0.32	1.13	2.64
Chlorosis area	0.31	1.20	2.78
Significance	n.s.	n.s.	n.s.
LSD (0.05)	0.06	0.16	0.31

*, ** and *** - significantly different at the 95.0, 99.0 and 99.9 % confidence level, respectively; n.s. – not significant

Table 5. The comparison of average values of Mg, K and Ca in dry grapevine leaf for sampling time

Treatment	Mg (%)	K (%)	Ca (%)
I sampling	0.25 b	1.23 ab	1.66 c
II sampling	0.17 b	1.20 bc	2.02 bc
III sampling	0.21 b	1.26 a	2.61 b
IV sampling	0.64 a	0.98 c	4.85 a
Significance	***	*	***
LSD (0.05)	0.09	0.24	0.44

*, ** and *** - significantly different at the 95.0, 99.0 and 99.9 % confidence level, respectively; n.s. – not significant

Table 6. Correlation of Mg-K pair and Mg-Ca pair (fertilization and chlorosis area)

Fertilization	Chlorosis area	Pair Mg-K	Pair Mg-Ca
Control	Chlorosis area	-0.45	0.86
	Nonchlorosis area	-0.40	0.90
Magnesium	Chlorosis area	-0.60	0.74
	Nonchlorosis area	-0.49	0.77

70 days after the last fertilizer application. According to the data reported by Marshner (1995), these values are toxic for the majority of agricultural crops; however, no magnesium phytotoxicity was observed in our vineyards. Although an upward trend of both Ca^{2+} and Mg^{2+} ions was recorded in grapevine leaf, their unfavourable ratios were also determined in the course of the growing period, ranging from 6.64 (initial development stage) to 12.4 (beginning of summer and water deficit in the soil), to lower value to 7.57 (after grape harvest). It seems that, in the conditions of soil water deficit, strong competition of $Ca^{2+}\leftrightarrow Mg^{2+}$ ions occurs, leading to very poor Mg^{2+} uptake from soil. As one of the most important roles of Mg^{2+} ions in plants is their inclusion into the central atom of the chlorophyll molecule (Marshner, 1995; Takasc et al., 2007), it may be assumed that foliar application of magnesium during summer months (owing to high insulation) on calcareous soils may increase the leaf magnesium content and directly influence a more productive process of photosynthesis. A more intensive process of photosynthesis is certainly likely to lead to higher sugar concentration in grapes. This assumption, however, might hold only for the soils with low or moderate lime contents, since the Mg/Ca correlations are high and positive on soils containing much lime (Table 7). The amount of Mg^{2+} that can be bound to a chlorophyll molecule depends on several factors, such as the rate of magnesium added with fertilization (Scott and Robson, 1990), light conditions (Dorenstouter et al., 1985) and soil type (Marshner, 1995).

Table 7. Correlation of Mg-K pair and Mg-Ca pair (soil lime content and sampling time)

Soil lime content	Sampling time	Pair Mg-K	Pair Mg-Ca
Low lime	I	0.90	0.65
	II	0.45	0.94
	III	0.51	0.04
	IV	0.21	0.05
Moderate lime	I	0.69	0.33
	II	-0.88	0.60
	III	-0.79	-0.15
	IV	-0.70	0.97
High lime	I	-0.78	0.61
	II	-0.50	0.90
	III	-0.65	0.86
	IV	-0.35	0.86

Leaf potassium content changed only as a result of different times of plant material sampling whereas other factors studied had no statistically significant influence on potassium levels (Table 1). Literature data show frequent competition between magnesium and potassium. In our investigations, high negative correlations between magnesium and potassium were determined in soils with moderate or high lime contents (Table 7). Positive correlations were determined in soils with low lime contents. Also, negative correlations between Mg and K were recorded for healthy and chlorotic vine plants under magnesium application (Table 6).

In grapevine leaf calcium content depended on lime levels in soil and on the time of plant material sampling (Table 1). Although calcium was not applied foliarly, its content, similarly to magnesium, increased towards the end of the growing period and reached very high values (Table 5). From the initial 1.66 % (1^{st} sampling), the content of Ca^{2+} ions in dry leaf grew to 4.85 % (4^{th} sampling), which is nearly a 300 % increase. According to data provided by Marshner (1995), excess Ca^{2+} ions in plant cells can be bound to vacuoles, thereby maintaining its low level in the cell cytosol. Through this self-protection mechanism, the overall amount of Ca^{2+} ions can be as high as 10 % of total dry matter without occurrence of phytotoxicity symptoms, which does not reduce its antagonistic action towards other ions, especially magnesium and potassium.

Important findings of these investigations are the unfavourable ratios between Mg, K and Ca in the leaf, which may be attributed to poor characteristics of soils in the studied vineyards. The Mg^{2+}/K^{+} ratio was 1:3.6, Mg^{2+}/Ca^{2+} ratio was 1:8.5 and the $(Mg^{2+}+Ca^{2+})/K^{+}$ ratio was 1:0.38. All this indicates that Ca^{2+} is the dominant cation in grapevine leaf during whole vegetation (Table 5).

Conclusions

Foliar application of magnesium on calcareous soils could, under certain agroecological conditions (soil moisture and temperature), solve the problem of grapevine chlorosis on calcareous soils. However, as can be seen from our research results, the content of Ca^{2+} ions in plants significantly depends on the soil lime content, the excess of which disturbs the physiological roles of magnesium and potassium in the plant.

To estimate the potentials of foliar application of magnesium on calcareous soils, investigations should be extended in two directions – application of different forms and rates of magnesium fertilizers, and forms and functions of magnesium, potassium and calcium in grapevine.

Such an approach could provide evidence-based applicable solutions for the practice.

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