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ORIGINAL PAPER

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*

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ABSTRACT

During a three-year study, an impact of different levels of nitrogen and potassium fertilization was investigated on the magnesium content in vineyard soil and in grapevine plants grown in a cool climate condition. Three levels of K: 0, 50 and 100 kg K ha^{-1} and three levels of N: 0, 50, and 100 kg N ha^{-1} were applied. Two white grape cultivars were used as model plants: cv. Bianca and cv. Sibera (*Vitis vinifera*). Apart from soil analyses, plant tissues (leaf blades, leaf petioles and grapes) were assessed each year for Mg using the ICP-OES technique. Potassium concentrations in the soil solution as well as EC and the concentration of sulphates increased proportionally to the K fertilizer doses in every year of the study. Reverse relationships appeared for Mg and Ca. The soil Mg levels, despite significant reserves of Mg in the topsoils, were slowly depleted due to the absence of fertilizer Mg inputs and progressive soil acidification. A high level of K fertilization decreased the Mg concentration in soil, especially in the 3rd year of the trial. Seasonal variety in the Mg content of petioles and blades was found. The leaf Mg concentrations ranged from 0.23% to 0.27% in blades and from 0.29% to 0.39% in petioles for cv. Sibera and cv. Bianca, respectively. The cultivar Bianca had higher Mg concentrations than cv. Sibera in both analyzed leaf parts. Furthermore, petioles were characterized by a higher Mg concentration than blades. The mean K:Mg ratio was 6.7 in cv. Bianca leaves and 9.6 in cv. Sibera leaves. The cultivar Bianca was characterized by a low concentration of magnesium in berries compared to berries of the cv. Sibera plants. The Mg concentration in grape must was significantly correlated with the Mg level in leaf blades (r = 0.50) and leaf petioles (r = 0.40) as well as with the available Mg concentration in soil (r = 0.37).

Keywords: nutrient interactions, leaf blade and petiole, K:Mg ratio.

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INTRODUCTION

Magnesium ions are the second most abundant cations in plant cells, involved in numerous processes such as photosynthesis, enzyme catalysis, and nucleic acid synthesis (Tanoi, Kobayashi 2015). A sufficient Mg level is required for maximizing the carbohydrate transport into sink organs (such as roots and seeds) so as to promote high yields (Cakmak, Yazici 2010).

Schreiner and Scagel (2006) demonstrated that less than 5% of grapevine canopy Mg came from the stored pool. Consequently, magnesium supplied to the canopy mostly comes from soil uptake. The amount of total Mg uptake per vine in the study of Pradubsuk and Davenport (2010) was in a range 3.3 to 7.9 g, depending on the growing season. Similar results were found by Schreiner and Scagel (2006), who demonstrated that the uptake of Mg per vine during the plant growing season was 4.5 g of Mg. The total amount of Mg which Arrobas et al. (2014) found in the aerial parts of grapevine was 27.0 kg Mg ha^{-1}, while in leaves it equalled 11.4 kg Mg, compared to 13.2 kg in the trunk/cordons plus canes and 2.5 kg Mg ha^{-1} in the grape clusters. The concentration of Mg in grape leaves increased throughout the growing season and the highest accumulation of magnesium in plants occurred between the blooming and *veraison* stages, and continued until harvest but at a slower rate (Pradubsuk, Davenport 2010).

The nutritional status of grapevine is commonly reflected in the concentration of elements in leaves collected in two phenological stages of a plant: blooming and *veraison*. Nutrient concentrations may differ considerably between plant organs and parts of a leaf such as a blade and petiole (Romero et al. 2010, Assimakopoulou et al. 2012, García-Escudero et al. 2013, Romero et al. 2014). Benito et al. (2013) demonstrated that the diagnosis of magnesium at blooming or *veraison* showed similar reliability for both leaf petioles and blades. According to Robinson (2005), adequate levels of Mg should be >0.4% in petioles and 0.3 - 0.6% in leaf blades of grapevine cultivated in Australia vineyards. It is thought that the Mg content in grapevine leaves depends on a rootstock (Garcia et al. 2001, Toumi et al. 2016).

Magnesium deficiency symptoms are easy to distinguish and can be observed from the *veraison* period, first on older leaves and later on younger ones, where chlorosis may occur (Christensen, Peacock 2000). Its intensity increases towards leaf veins, and hence the earliest visible symptoms are observed as interveinal yellowing (Grzebisz 2011). Cukmak and Yazici (2010) showed pronounced inhibition of root growth before any noticeable change in shoot growth and chlorophyll concentration can be detected, but Hermans et al. (2013) reported the excessive sucrose and starch accumulation in fully developed leaves. Latent Mg deficiency is already yield important. Low availability of magnesium in soil vineyards may lead to a decrease in the yield of berries, which follows the appearance of Mg-deficient symptoms (Májer 2004). Van Leeuwen et al. (2004) found a significant correlation between petiole Mg in three cultivars of grape and berry sugar content.

The concentration of elements in plant tissues depends basically on three processes: ion absorption, ion transport through the symplast or apoplast system, and ion accumulation in biomass. The presence of favourable ionic proportions and absence of harmful components in soil-plant systems are significant for the plant growth and mineral composition. Magnesium, calcium and potassium interact or compete with one another in the soil solution and cation exchange, and they compete for entry into plants and within a plant (HERMANS et al. 2013). FAGERIA (2001, 2014) indicated that nutrient interactions in crops are probably one of the most important factors affecting yields of crop. Cation-cation interactions, especially between divalent cations, are very important for relationships that influence yield and yield quality. HERMANS et al. (2013) showed antagonism between divalent cations such as manganese (Mn), but also iron (Fe) in leaves and calcium (Ca) and zinc (Zn) in roots. Considering their similarity in terms of chemical properties, Mn^{2+} and Mg^{2+} can compete for membrane transport and substitute one another in activating a number of enzymes. The uptake of Mg can be depressed strongly by potassium. Application of K fertilizer often induces Mg deficiency in plants (RIETRA et al. 2015). Competition between K and Mg at the cellular level may lead to K-induced Mg deficiency. Potassium/magnesium antagonism was shown by HOWELL and CONRADI (2012) in their experiment on different fertilization strategies for drip irrigated table grapes. The same was evidenced by TOUMI et al. (2016), who observed the growth and mineral nutrition of grapevine in a hydroponic culture. A negative correlation between grape petiole Mg and K was found by VAN LEEUWEN et al. (2004) in a study on the influence of climate, soil and a cultivar on *terroir*.

Magnesium deficiency in crop plants can be expected to become more common in the future, particularly in soils overfertilized with N, P and K (GRZEBISZ 2011). GRANSEE and FÜHRS (2013) indicate the role of Mg in raising the crop tolerance to various stresses, and point out that little attention has been paid to this mineral nutrient, compared to other nutrients, by agronomists and scientists in the last decades. GRZEBISZ (2011) demonstrated that fast growing plants require a high supply of magnesium, mainly *via* externally applied fertilizers, which will sustain their rate of growth.

ZHANG et al. (2010) indicated that nitrogen - potassium interactions are currently a topic of interest in numerous studies. However, the effect of applying different levels of both K and N on the nutrient Mg status in grapevine is not well known, especially under the cool climate conditions. Additionally, in white wine production (cv. Bianca and Sibera) the nitrogen supply to vines should be at least moderate, because N deficit stress can negatively affect grape aroma potential. Therefore, we have undertaken to investigate the effect of increasing N and K supply on the vineyard soil Mg level and on Mg concentrations in grapevine tissues.

MATERIAL AND METHODS

This study was carried out from 2010 through 2013, in Garlica Murowana vineyards located near Kraków, Poland. The site lies at the following coordinates: 50°8′25″N 19°55′39″E.

Soil properties

Some properties of the soil are listed in Table 1. Soil samples from the site of the experiment were collected at 20 random locations. The samples were separated into the following profile depths: 0-20, and 20-40 cm. The vineyard soil was characterized as silty clay loam with the total organic matter of 1.68%.

Table 1

Soil properties of the experimental vineyard

Soil layer	pH_{H_2O}	pH_{KCl}	(%) soil fraction			Cation exchange capacity cmol(+) kg^{-1}				TOC (%)	Available nutrients (mg dm^{-3})			
			sand	silt	clay	Ca^{2+}	K^+	Mg^{2+}	CEC		P	K	Mg	Ca
0-20	6.38	5.24	18	43	39	3.35	0.97	0.56	7.14	0.99	37	159	75	558
20-40	6.30	4.94	-	-	-	3.45	0.74	0.57	6.49	0.57	30	90	56	509

TOC – total organic carbon

Three levels of K: 0, 50 and 100 kg K ha^{-1}, as potassium sulphate (50% K_2O), and the three levels of N: 0, 50, and 100 kg N ha^{-1}, as ammonium nitrate (34% N), were applied. Treatments were replicated three times and arranged in a randomized complete block design. The N and K treatments were carried out 2 weeks after grapevine blooming.

Climatic conditions

The climatic conditions varied noticeably during the three vintages studied (Figure 1). The site of the experimental vineyard had a long-term average annual precipitation of 576 mm with an average minimum temp. of -2.9°C (in January) and maximum temp. of 17.8°C (in July). In 2010, the temperatures in the plant growing season were near the average, while the rainfalls recorded for 2010 were heavy, especially in May and September. This vintage was warmer, as the average temperature recorded from April to September was 14.7°C compared to 12.9°C recorded in 2011. Higher precipitation (757 mm and 346 mm 2010 and 2011, respectively) was also noted. The year 2011 was dry, except for May, and colder compared to multi-annual temperatures. The year 2013 had an annual precipitation of 577 mm and maximum rainfall in June/July, which was beneficial for flowering and fruit setting. Favourable climatic conditions (low precipitation and relatively high temperatures) were recorded before the harvest. The calculated sums of

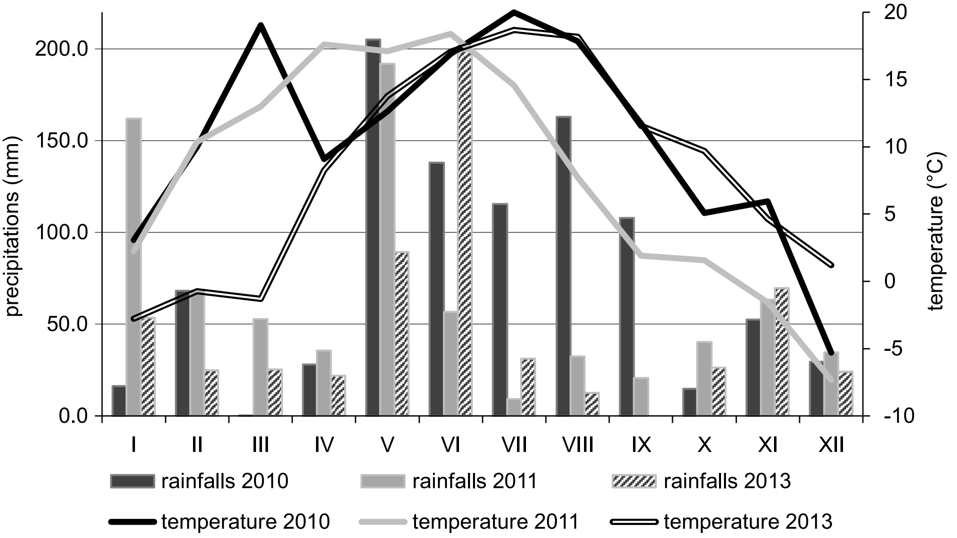

Fig. 1. Climatic conditions during the experiment
(Note: the year 2012 was excluded because of frost injuries)

active temperatures (SAT) were: 2755°C, 2481°C and 2764°C for the 2010, 2011 and 2013 vintage, respectively.

Plant material

The study was performed on mature (7-year-old) vines of two cultivars: Bianca and Sibera, grafted on SO4 rootstock. Both cultivars are classified as inter-intraspecific hybrids belonging to *Vitis vinifera* L. according to taxonomy. Grapevine rows were oriented north-south, with 3.5 m spacing between rows and 0.9 m in-row spacing (3200 vines ha^{-1}). The vineyard management complied with the recommendations for commercial vineyards in Poland.

Tissues analysis

Leaf petioles, leaf blades and fruit were sampled for nutrient analyses. Ten mature, full-sized leaves per plant were sampled from each side of the cordon, both from inner and outer canopy layers. Petioles were separated from blades and dry matter of those tissues was measured (PN-R-04013:1988). Plant samples were washed in distilled water, dried at 60°C in a forced-air oven (Venticell 111, BMT) and ground (Pulverisette 14, Fritsch). Afterwards, they were mineralized in 65% v/v, Suprapur HNO_3 (Merck) in a MARS-5 Xpress microwave oven (CEM) according to PASŁAWSKI and MIGASZEWSKI (2006) with some modifications. The concentrations of Mg were determined using the ICP-OES technique (Prodigy spectrometer, Teledyne Leeman Labs). The intra-laboratory validation studies (precision, trueness, robustness) were performed. We measured standard deviation or half-width of an interval at a stated level of confidence. The sample signal was fitted to the calibration function obtained using the calibration standards, mostly based on the least square linear regression. The *r* parameter studied during the analytical method validation estimated the method's accuracy. In the present paper, the recovery estimation was made for spiked samples, as an appropriate CRM was unavailable.

Moreover, 20 randomly chosen bunches of grapes were taken from each plot for pressing. Juice samples were wet-mineralized and analyzed as above.

Analysis of data

Analysis of variance was used to compare means of treatments using Statistica 12.5 software. The Pearson correlation analysis was used to link the mean foliar and must Mg concentrations with the available Mg in soil.

RESULTS AND DISCUSSION

Data on the available nutrient concentrations in vineyard soil are collated in Table 2. The pH of the soil solution was affected by the treatments in every year of the study and generally decreased during the experiment. The potassium concentration in the soil solution as well as EC and the sulphate concentration increased proportionally to K fertilizer doses in every year of the study. The reverse was true for Mg and Ca (Table 2). The soil Mg levels, despite a significant pool of Mg in the topsoil (Table 1), were slowly depleted due to the absence of fertilizer Mg inputs and progressive soil acidification. There is considerable evidence in the literature that acidification and salt accumulation are results of N and K fertilization, particularly on light soils. Similarly, the effect of the soil solution pH on nutrients' availability is well documented. In Poland, according to the sufficiency level concept (specified levels of individual nutrients in the soil below which crops will respond to added fertilizers), the optimal concentration for K, Mg and Ca in heavy soil should be within the limits: 150-250 mg, 60-120 mg and 1000-2000 mg dm^{-3}, respectively (Nowosielski 1988). The present study demonstrated low concentrations of available calcium (extractable 0.03 mol dm^{-3} CH_3COOH) in every year, and a low concentration of magnesium in the third year of the study. The potassium concentration was below the optimal range in soil in 2010, irrespective of the N/K fertilization regime, and in the control treatment in every year of the soil examinations.

The high level of K fertilization decreased the Mg concentration in soil, especially in the third year of the trial. In 2013, the K/Mg ratio in soil for the highest level of K (100K) was 11.0, 14.5 and 17.7 respectively for 0N, 50N and 100N supply. For the control treatment, this ratio was 1.6, 1.2 and 2.1 in the years 2010, 2011 and 2013, respectively. This is in accordance with

Table 2

Soil chemical properties as influenced by different N and K fertilization regimes

Year	N level	K level	pH_{H_2O}	EC (μS cm^{-1})	Ca (mg dm^{-3})	K (mg dm^{-3})	Mg (mg dm^{-3})	S (mg dm^{-3})	K/Mg
2010	0N	0K	6.39*b*	63*a*	501	85	54.7	4.5*a*	1.6
		50K	6.20*b*	84*ab*	578	118	66.8	11.0*ab*	1.8
		100K	5.95*ab*	97*ab*	476	144	55.5	15.9*ab*	2.6
	50N	0K	6.16*ab*	75*ab*	645	82	71.1	9.3*ab*	1.2
		50K	6.17*ab*	73*ab*	590	121	64.3	10.7*ab*	1.9
		100K	5.96*ab*	80*ab*	450	109	47.9	13.8*ab*	2.3
	100N	0K	5.91*ab*	90*ab*	476	86	56.3	4.9*a*	1.5
		50K	5.5*a*	115*ab*	446	121	49.4	13.0*ab*	2.4
		100K	5.75*ab*	125*b*	464	111	53.6	18.5*b*	2.1
2011	0N	0K	6.13*b*	53*a*	507*b*	85*a*	71.7*c*	6.4*a*	1.2
		50K	5.92*ab*	67*ab*	443*ab*	141*ab*	61.7*abc*	18.5*bc*	2.3
		100K	5.95*ab*	67*ab*	442*ab*	153*ab*	70.1*c*	23.5*cd*	2.2
	50N	0K	5.88*ab*	57*a*	513*b*	89*a*	66.7*bc*	6.8*a*	1.3
		50K	5.85*ab*	70*ab*	458*ab*	127*a*	62.9*abc*	12.3*ab*	2.0
		100K	5.53*ab*	94*ab*	393*ab*	214*b*	53.1*ab*	28.4*cd*	4.0
	100N	0K	5.08*a*	122*b*	371*ab*	86*a*	54.4*ab*	5.6*a*	1.6
		50K	5.29*ab*	97*ab*	425*ab*	112*a*	61.3*abc*	12.4*ab*	1.8
		100K	5.17*ab*	122*b*	321*a*	156*ab*	48.1*a*	22.0*cd*	3.2
2013	0N	0K	5.84*c*	160*a*	520*b*	129*a*	62.1*c*	8.7*a*	2.1
		50K	5.92*c*	220*a*	500*b*	354*bc*	59.4*bc*	35.4*bc*	6.0
		100K	5.89*c*	219*a*	351*ab*	475*d*	43.1*abc*	28.7*b*	11.0
	50N	0K	4.91*ab*	186*a*	389*ab*	148*a*	45.6*abc*	8.4*a*	3.2
		50K	5.07*b*	194*a*	312*ab*	277*b*	34.6*ab*	20.8*ab*	8.0
		100K	5.14*b*	245*a*	267*a*	408*cd*	28.1*a*	31.1*bc*	14.5
	100N	0K	4.39*a*	286*ab*	277*a*	133*a*	32.6*a*	9.1*a*	4.1
		50K	4.48*ab*	274*a*	239*a*	237*ab*	27.2*a*	20.6*ab*	8.7
		100K	4.31*a*	439*b*	219*a*	406*cd*	23.0*a*	49.1*c*	17.7

the conclusion reached by GRZEBISZ (2011) and EDMEADES (2004), who demonstrated that magnesium losses were significantly related to increasing NPK doses and lime application. EDMEADES (2004) concluded that a balanced state of soil Mg was achieved by applying 5-20 kg Mg ha^{-1} year^{-1} in strategies of soil management, plant (pasture) and animal Mg nutrition. CUKMAK and YAZICI (2010) confirmed that Mg deficiency was of critical concern in light and acid soils due to its potential for leaching and the interaction with Al.

The grapevine leaf nutrient concentration depends on a wide range of factors, such as environmental conditions, cultural practices, plant genetics (cultivar) and rootstock (Van Leeuwen et al. 2004). Not surprisingly, seasonal variety in the magnesium content of petioles and blades was found. Generally, the lowest values were recorded in 2013 (0.24%) in comparison to 2010 and 2011 (mean 0.30% for both years). Leaf Mg concentrations in this study ranged from 0.23% to 0.27% in blades and from 0.29% to 0.39% in petioles for cv. Sibera and Bianca, respectively (Table 3). Generally, mean concentrations of Mg in plant petioles and blades were in accordance with some previous reports (Robinson 2005, Christensen, Peacock 2000). The cultivar Bianca had higher Mg concentrations in both analyzed parts of the leaf as compared to cv. Sibera (Figure 2). Furthermore, petioles were characterized by a higher Mg concentration than blades (Table 3, Figure 3). We also assessed the K:Mg ratio for the tested grape tissues. Christensen and Peacock (2000) reported that Mg deficiency was more commonly associated with the K:Mg ratios of >10:1 with petiole Mg levels at <0.2%. The mean K:Mg ratio was 6.7 for cv. Bianca leaves and 9.6 for cv. Sibera (Table 3).

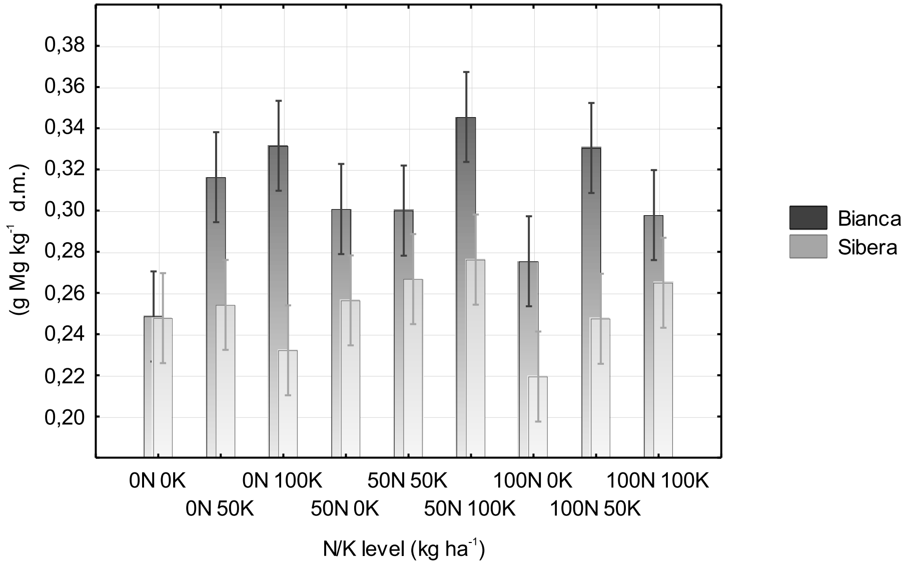

Fig. 2. Effect of nitrogen-potassium fertilization on the magnesium content (g Mg kg^{-1} d.m.) in leaves of Bianca and Sibera cultivars (mean of years and leaf organ)

Significant interactions between the cultivars and plant tissues were noted. Higher values of the K/Mg ratio were in cv. Sibera petioles in each year of the experiment (14.3, 12.4, and 11.1, respectively) than in cv. Bianca (6.9, 7.4, 9.0). Pettigrew (2008) indicated genotypic variation in potassium response of crops. Genotypes more responsive to K fertilization were able to take up K at a greater rate or more efficiently because of a larger root system. In our study, leaves of cv. Bianca accumulated more nutrients and trace elements than those of cv. Sibera, except for K (data not presented).

Table 3

The magnesium content in petioles and blades (g Mg kg^{-1} d.m.) of two cultivars (Bianca and Sibera) of grapevine affected by nitrogen-potassium fertilization (2010-2013)

Factor	Mg (g kg^{-1} d.m.)			Mean	K/Mg ratio
	2010	2011	2013		
Bianca	3.6*b*	3.3*b*	2.3*a*	3.1*b*	6.7*a*
Sibera	2.4*a*	2.7*a*	2.5*b*	2.5*a*	9.6*b*
Blades	2.4*a*	2.7*a*	1.9*a*	2.3*a*	6.1*a*
Petioles	3.6*b*	3.3*b*	2.9*b*	3.3*b*	10.2*b*
0N 0K	2.8*a*	2.7*ab*	2.3*a*	2.5*a*	10.3*c*
0N50K	3.0*a*	3.1*bc*	1.9*a*	2.9*c*	7.7*ab*
0N100K	2.8*a*	3.0*bc*	2.5*bc*	2.8*abc*	8.1*b*
50N 0K	32*a*	3.0*bc*	2.6*bc*	2.8*abc*	7.9*b*
50N 50K	31*a*	3.0*bc*	2.1*ab*	2.8*ab*	7.6*ab*
50N 100K	32*a*	3.4*c*	2.4*abc*	3.1*c*	6.6*a*
100N 0K	31*a*	2.4*a*	2.7*c*	2.5*ab*	10.3*c*
100N 50K	30*a*	3.2*bc*	2.0*a*	2.9*c*	7.3*ab*
100N 100K	29*a*	3.0*bc*	2.5*bc*	2.8*c*	7.4*ab*

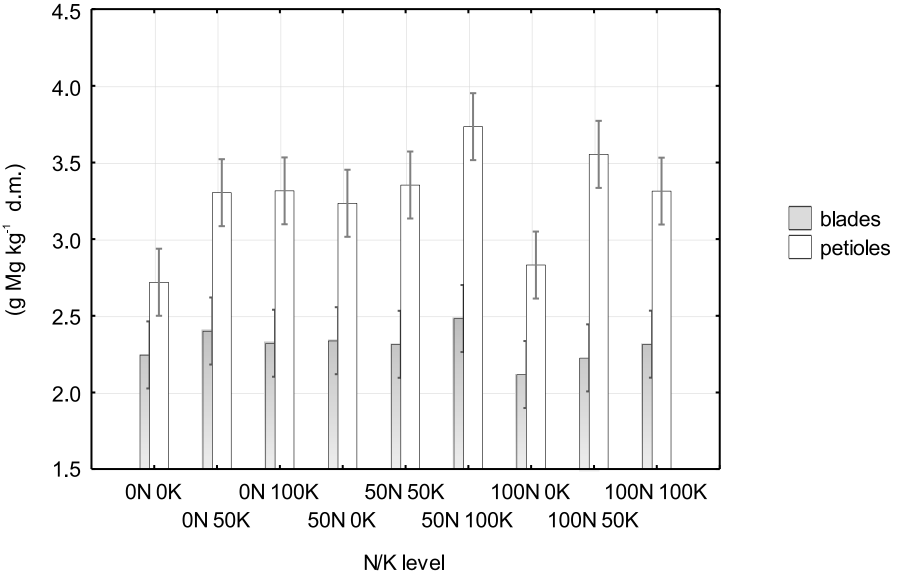

Fig. 3. Effect of nitrogen-potassium fertilization on the magnesium content (g Mg kg^{-1} d.m.) in blades and petioles of grapevine (mean of years and cultivars)

An analysis of grape tissues provides information on the nutrient ions available to the plant in the soil (ARROBAS et al. 2014). The mean foliar magnesium concentration for the grape cultivars was significantly correlated to the Mg available concentration in the soil but only for leaf blades ($r = 0.37$) – Figure 4. The lack of correlation between Mg in soil and in leaf petioles was determined. However, petioles were a more sensitive indicator of the Mg/K competition than blades. The mean petiole Mg concentration was nega-

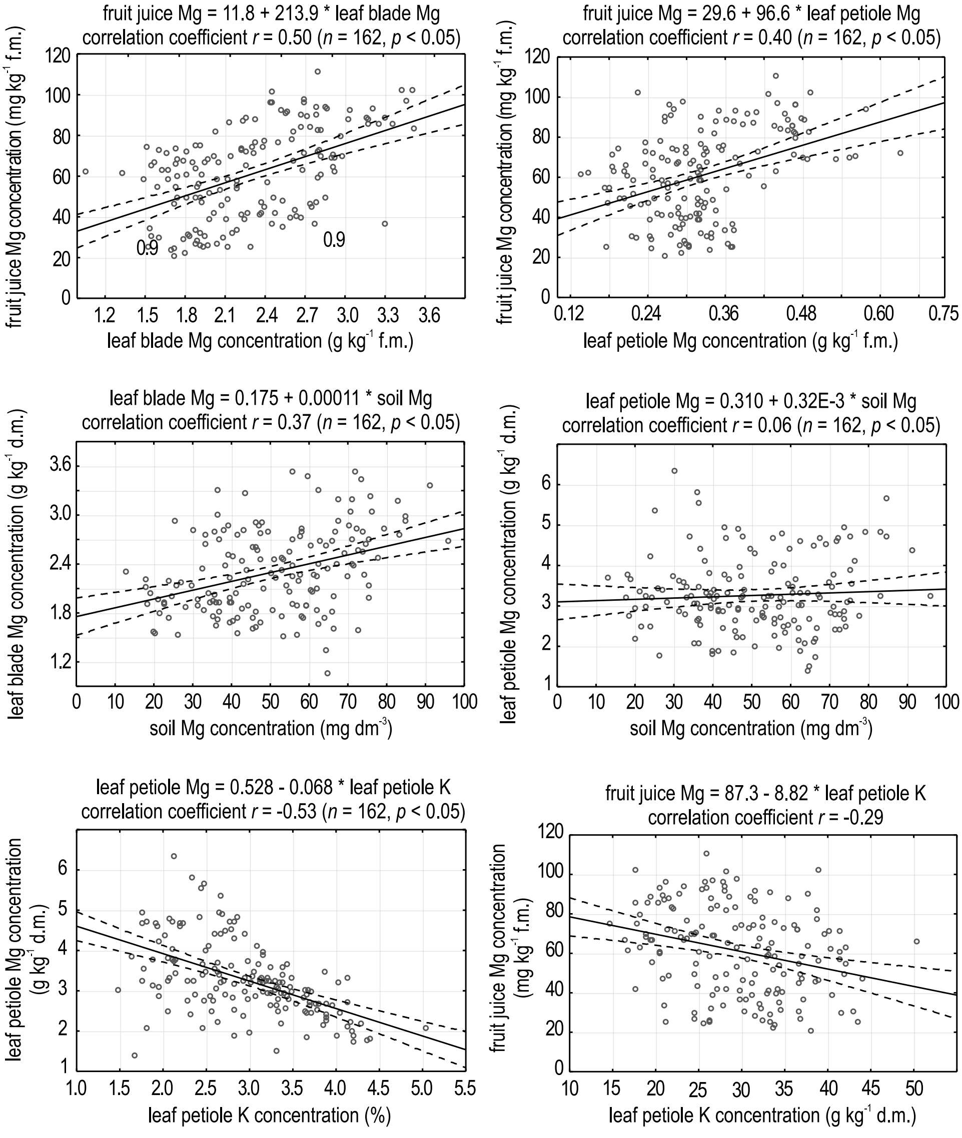

Fig. 4. Correlation coefficients (r) for the magnesium concentration in grape leaf, berries and soil available Mg content (significant for $p < 0.05$)

tively correlated to the mean petiole K concentration (*r* = -0.53). These results are supported by the study of Van Leeuwen et al. (2004), who found a negative correlation between Mg and K in petioles. A significant but weak negative correlation was observed for leaf petiole K and must Mg concentration (*r* = -0.29). The effect of K in reducing leaf and must Mg is probably caused by its competition with Mg in the distribution of Mg ions in either the xylem or phloem transport.

Cation competition is a result of nutrient imbalances in soil, and Mg uptake is strongly influenced by ions such as NH_4^+, Ca^{2+} and K^+ (Gransee, Führs 2013). Moreover, cation competition is an extremely complex issue because nutrients can interact either within the soil or in the plant to affect nutrient absorption or utilization (Rietra et al. 2015). Surprisingly, the foliar magnesium concentration in cv. Bianca and cv. Sibera grape increased under the influence of applied K (Table 3, Figure 2). A probable explanation might be the high mobility of Mg ions in soil due to hydrated ions being less strongly bound to soil charges compared to other cations (Gransee, Führs 2013). Edmendes (2004) indicated that high doses of K fertilizer change cation ratios in the soil solution and ratios of exchangeable cations change as well. Magnesium is “forced” off the exchange complex into the soil solution, thus increasing the risk of Mg leaching. On the other hand, this improves magnesium phytoavailability. Grzebisz (2011) indicated a high contribution of mass flow to plant Mg nutrition. However, under drought stress (which in our study occurred from July to October in 2013), this system of plant nutrient delivery could have been unfavourable. There is much evidence that an increasing concentration of K^+ in the soil decreases plants’ Mg uptake due to the competitive inhibition for entrance into plants (Jacobsen 1993). On the other hand, nitrogen stimulates magnesium uptake and this synergism can be used by synchronized application N and K in fertilization practice (Rietra et al. 2015). Data from our experiment indicate that the highest Mg concentration in grapevine leaves in the dry year 2011 was recorded for 50N 100K, 100N 50K and 100N 100K fertilization levels. In 2013, an increase in N supply increased the foliar Mg concentration. A significant correlation was observed between the cultivars and treatments (Figure 2). Generally, nitrogen supply altered the potassium response in grapevine leaves. The highest level of nitrogen decreased the magnesium concentration in cv. Sibera leaves much more than in cv. Bianca tissues, especially for 0K treatments. The best NK treatments for the Mg content in leaves of the tested cultivars was 50N 100K.

The magnesium concentration in grape must was affected by the growing season, cultivar and the level of N/K supply, but only in 2013 (Table 4). The lowest Mg concentrations in fruits were detected in 2013, irrespective of a cultivar. The cultivar Bianca was characterized by a low concentration of magnesium in berries compared with cv. Sibera (Figure 5). Moreover, the highest yield of cv. Sibera grapes was harvested in 2013, whereas the total

Table 4

The magnesium content in grape must (mg Mg kg^{-1} f.m.) of two grapevine cultivars (Bianca and Sibera) as affected by nitrogen-potassium fertilization (2010-2013)

Factor	Mg (mg kg^{-1} f.m.)			Mean
	2010	2011	2013	
Bianca	60.7*a*	45.3*a*	28.5*a*	44.8*a*
Sibera	82.3*b*	87.7*b*	62.3*b*	77.4*b*
0N 0K	79.0*a*	66.7*a*	48.0*bc*	64.6*b*
0N 50K	69.4*a*	65.2*a*	48.2*bc*	60.9*ab*
0N 100K	73.3*a*	65.5*a*	48.1*bc*	62.3*ab*
50N 0K	67.8*a*	67.7*a*	42.5*ab*	59.3*ab*
50N 50K	70.5*a*	67.9*a*	41.6*ab*	60.0*ab*
50N 100K	73.3*a*	66.2*a*	47.4*bc*	62.3*ab*
100N 0K	69.4*a*	61.1*a*	36.9*a*	55.8*a*
100N 50K	67.1*a*	68.1*a*	43.6*abc*	59.6*ab*
100N 100K	73.6*a*	70.1*a*	52.5*c*	65.4*b*

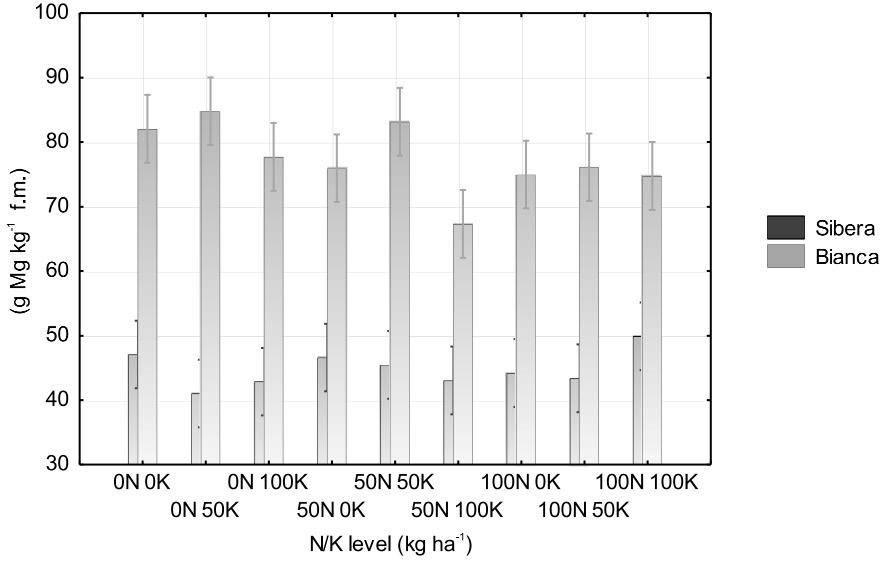

Fig. 5. Effect of nitrogen-potassium fertilization on the magnesium content (mg Mg kg^{-1} f.m.) in grape juice of Bianca and Sibera cultivars (mean of 2010-2013, cultivar x NK level, p = 0.009)

yield of cv. Bianca berries was independent of a growing season. The increase mentioned above was caused by the lack of fruiting in 2012 due to heavy flower frost damage (data not presented). The effect of K treatments on the Mg concentration in grape must was modified somewhat by the level of N.

In 2013, the greatest relative difference in the fruit Mg concentration resulting from levels of N/K was in the 100 N 100 K (52.5 mg Mg kg^{-1} f.m.) and 100 N 0 K (36.4 mg Mg kg^{-1} f.m.) treatments. A significant cultivar × treatment interaction was observed for the Mg concentration in grape must (Figure 5). For cv. Bianca, treatments 0 N and 50 N along with a low potassium supply (50 K) increased the Mg concentration in fruits, but the 100 K treatment decreased the Mg content in must. It was revealed that an increase in N supply decreased the cv. Bianca fruit Mg concentration but increased its berry yield (data not shown). The well-known dilution effect is a possible explanation of why Mg declines in cv. Bianca grape must in parallel with an increase in the yield of berries. In the case of cv. Sibera, increasing K in the soil solution for zero and a low N treatment reduced the Mg concentration in must. The reverse was true for the 100 N treatment.

The magnesium concentration in grape must was significantly correlated with the Mg concentration in leaf blades ($r = 0.50$) and leaf petioles ($r = 0.40$) as well as with the available Mg concentration in the soil ($r = 0.37$) – Figure 4. There is no doubt that magnesium is a phloem-mobile element and is easily translocated to fruits and seeds. However, Hermans et al. (2013) reported that Mg homeostasis in plants is still a poorly understood mechanism compared to the homeostasis of other elements, and it has not been recognized yet which transport systems control Mg acquisition, distribution and reallocation.

CONCLUSIONS

Potassium and nitrogen fertilization is a viticultural technique with a great effect on the grapevine yield and the quality of wine. However, interactions between nutrients should be considered in a complete nutrient management program in vineyards. A mineral fertilization plan should take into account the related changes in nutrient solubility, nutrient resupply from the solid phase and the resulting bioavailability to plants.

The field fertilizer trials showed the effect of nutrient availability on foliar Mg concentrations in cv. Bianca and Sibera grapevine. If an NK fertilization plan in a vineyard neglects Mg, magnesium losses from soil may occur. Fertilization modifies soil fertility also by alterations of the phytoavailability of nutrients present in the soil solution. Potassium fertilization increases the concentration of K but also decreased the soil content of Mg. These interactions highlight the importance of balanced fertilization and regular monitoring of the soil Mg level, plant nutrient status and nutrient budgeting in vineyards.

The effect of K treatments on the Mg concentration in grape leaves and must was modified by the level of N. At all levels of the N/K ratio, the highest leaf Mg concentrations tended to occur at the intermediate level of nitrogen (50 N) and potassium (50 K). The magnesium concentration of leaf blades collected at *veraison* was correlated with the soil available Mg concentration better than that of leaf petioles. Furthermore, we found a negative correlation between Mg and K in grapevine petioles. Positive correlations between the grape must Mg concentration and leaf Mg concentration as well as with the soil available Mg concentration were found.

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