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Using foliar applications of magnesium and potassium to improve yields and some qualitative parameters of vine grapes (*Vitis vinifera* L.)

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ABSTRACT

In a three-year field experiment (2011–2013) we assessed the effect of magnesium ($MgSO_4$) and potassium (K_2SO_4) applied as foliar applications both separately (3.86 kg Mg/ha or 12.44 kg K/ha) and in combination (1.93 kg Mg/ha + 6.22 kg K/ha) on yields of grapes of cv. Zweigelt and some qualitative parameters of the grapes. The applications were repeated 4 times in stages BBCH 15–19; 55; 75 and 83. The experiment was carried out on soil well supplied with Mg and K in the subsoil layer. In terms of average 3-year results the grape yields were by 11.2% ($MgSO_4$), 13.9% (K_2SO_4) and 6.6% ($MgSO_4$ + K_2SO_4) significantly higher than the untreated control. The sugar content of grapes (sum of glucose and fructose) was lower (mostly insignificantly) by 0.5–4.3% in all the fertilized treatments than in the untreated control. Fertilization had no significant impact on the pH of must (juice) and ranged between 3.02 and 3.25. The content of titratable acids in the must ranged insignificantly between 8.73 and 10.86 g/L, and average values were the highest in the untreated control. On the basis of these results it is evident that separate applications of Mg and K have a positive effect, in particular in that they stimulate grape yields, and at the same time the effect of the year is significant.

Keywords: fruit crop; macronutrient; deficiency; pH of grape must

Grapevine (*Vitis vinifera*) is a productive drought stress-adapted plant and one of the most economically important fruit crops (Zörb et al. 2014). Production of quality grapes suitable for wine-making depends on numerous factors (Gerendás and Führs 2013). Moretti (2002) stated that among intrinsic (degree of wood maturation, content of nutritive and nitrogenous compounds) and external factors (temperature, rain distribution, soil parameters) the quality of wine produced is also modulated by fertilization to a central degree.

Magnesium (Mg) is an important macronutrient with a number of physiological functions in the plant. The importance of magnesium in the plant

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is in many ways connected with photosynthesis. It is the central atom of chlorophyll and it activates enzymatic processes. Magnesium also favourably influences assimilation (Mengel and Kirkby 2001).

Magnesium deficiency reduces the content of chlorophyll in the leaves and changes the chlorophyll *a*:*b* ratio in favour of chlorophyll *b*. Visually it is seen as chlorosis of leaves, especially older ones and causes premature abscission. Chlorosis is caused either by Mg deficiency, high content of soil Ca (calcareous soils) or a combination of these factors (Marschner 2002, Ksouri et al. 2005, Gluhić et al. 2009). Magnesium uptake by the plant is also affected by the antagonistic effect of Ca and K and as was confirmed by Garcia et al. (1999) who discovered a marked reduction of Mg in grape berries on soils with high supply of Ca connected with an increase in the total acid content. Skinner and Matthews (1990) reported Mg deficiency also in low-soil-pH value and low-phosphorus-content vineyards. Magnesium deficit results not only in reduced yields but also in increased risk of tendril atrophy (Füri and Hajdú 1980, Májer 2004). Foliar spraying with Mg containing fertilizers is a common practice to correct nutrient imbalances in grape but Mg doses beyond those required for maximum yield rarely induce further improvement of product quality (Gerendás and Führs 2013).

Potassium (K) is an essential element for plant nutrition and its ability to influence meristem growth, water status, photosynthesis and long distance transport of assimilates is well established (Mengel and Kirkby 2001). Owing to its fundamental roles in turgor generation, primary metabolism, and long-distance transport, K plays a prominent role in crop resistance to drought, salinity, high light, or cold as well as resistance to pest and pathogens. In K-deficient crops, the supply of sink organs with photosynthates is impaired and sugars accumulate in source leaves. This not only affects yield formation, but also quality parameters, for example in grape (Zörb et al. 2014). Potassium accumulates primarily in the berry skin tissues during ripening as a result of K remobilization from mature leaves (Coombe 1992). Grape berries are a strong sink for K, particularly during ripening (Mpelasoka et al. 2003). The most abundant cation in grape berries is potassium which contributes to charge balance and may be involved in sugar transport (Spayd et al. 1993). Potassium reduces acid levels in berries and interacts with tartaric acid to form potassium bitartrate which has limited solubility (Lang 1983). Higher potassium supply increased the total soluble solids content and decreased the total acidity of berries (Martin et al. 2004). Adequate potassium nutrition helps to increase both the colouring and polyphenolic content of berries (Sommers 1977).

The occurrence of physiological disorders – shrivel of berries and stalk necrosis – is also associated with unbalanced magnesium and potassium nutrition of vine. These disorders appear as a loss of turgor and lower sugar content in the grape berries; at the same time increasing the content of acids (Bondada and Keller 2012). This causes degradation of the quality of grape production all over the world; nonetheless the cause of these disorders has not yet been fully clarified, yet (Knoll et al. 2010).

Fertilizing is imposed as a necessary measure since every year yields, the green and ripening mass of the vine plant take up large quantities of mineral substances (Duletić and Mijović 2014). Generally nutrients can be applied directly into the soil or sprayed on the leaves. Soil application is the ancient and normal fertilization practice; however it depends on many factors, from the soil type to the plant characteristics and physiological state and therefore cannot be generalized (Brataševec et al. 2013). Foliar fertilization does not completely replace soil fertilization (Kannan 2010). The application of foliar fertilization is increasing in order to reduce micro- and macronutrient deficiency (Kaya and Higgs 2002).

The aim of the present 3-year field trials on the soil with a good supply of magnesium and potassium was to compare the effect of foliar applications of magnesium and potassium applied both separately and in combination on grape yields and some qualitative parameters.

MATERIAL AND METHODS

The 3-year experiment was conducted in Nosislav, a village some 20 km south of Brno, south Moravia, Czech Republic. Table 1 gives the agrochemical characteristics of the soil prior to establishment of the trial (Mehlich 1984).

Most of the vineyards of the Czech Republic lie in this region. The region is dry and warm. Soil and climate conditions are as follows: altitude – 185 m a.s.l.,

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Table 1. Agrochemical characteristics of the soil prior to establishment of the trial (mg/kg)

Depth (m)	pH/$CaCl_2$	P	K	Mg
0–0.3	7.42 alkaline	46 low	485 high	385 high
0.3–0.6	7.58 strong alkaline	45 low	308 good	353 good

annual sum of precipitation 480 mm, average annual air temperature 9.2°C, soil – medium heavy Chernozem. The age of the vineyard with the blue cv. Zweigelt was 13 years, spacing 3 × 1 m (3333 plants/ha), 2-cordon system. Grass is grown between the rows.

Soil organic carbon content (C_{ox}) was low – 1.59% in the topsoil and 1.29% in the subsoil. Fertilization in all the treatments in the experiment was carried out in spring before budding with 60 kg N/ha and 37 kg P/ha as calcium ammonium nitrate (27% N) and ammonium phosphate (12% N and 22.7% P). Table 2 shows the individual treatments of the experiment.

Foliar applications were carried out 4 times during vegetation in the following stages: 15–19 BBCH (9 or more leaves unfolded); 55 BBCH (inflorescence swelling, flowers closely pressed together); 75 BBCH (berries pea-sized, bunches hanging) and 83 BBCH (berries developing colour); which approximately means depending on the year that the applications began in late May and were ended in mid to late August. The fertilizers were sprayed using the motor knapsack sprayer Stihl 430 (Weiblingen, Germany) with a dose of 400 L of the solution per ha. Table 2 shows the total amount of applied nutrients after 4 applications. In all the treatments we used the adjuvant Trend 90 (0.1%). During vegetation, pesticide control was conducted in the experimental treatments consistent with the rest of the vineyard without using S-fungicides.

Grapes were picked manually. In terms of quality the grapes were analysed for the content of sugars, titratable acids and pH.

HPLC estimation of glucose + fructose (sugars) in grape must (juice). Grape must samples were centrifuged (3000 × g; 6 min) and diluted with 10 × demineralized water. The estimation was performed by means of IC in the Shimadzu LC-10A system plus the thermostat (column oven) CTO-10ACvp set at 60°C. The manual injection Rheodyne valve had a loop of a volume of 20 μL. Separation was performed in an isocratic regime with the mobile phase of 2 mmol sulphuric acid at a flow rate of 0.75 mL/min in the column Watrex Polymer IEX H form 10 μm; 250 × 8 mm with 10 × 8 mm. Spectrophotometric detection was performed by the DAD detector SPD-MAvp (Kyoto, Japan). Sugar was measured at 190 nm. The quantification of the individual analyses was performed on the basis of external calibration.

Estimation of total titratable acidity (EEC No 2676/90). The content of total titratable acidity was estimated by titration in the automatic titrator Titroline Easy (manufacturer SI Analytics GmbH, Mainz, Germany). Titrations were performed with NaOH (0.1 mol/Lt) as the titration reagent. The total acidity of must or wine takes into account all types of acids, i.e. inorganic acids such as phosphoric acid, organic acids as well as amino acids whose contribution to titratable acidity is not very well known.

Estimation of the pH of grape must. An undiluted sample was used to estimate the pH value of must using a pH-meter WTW pH 526 and pH electrode SenTix 21 (both manufactured by the company WTW, Weilheim, Germany).

Statistical analysis. The measured values of grape yields, sugar content of grapes, titratable

Table 2. Treatments of the experiment

Treatment No.	Description	Fertilizer	Concentration of solution (%)	Total rate Mg or K (kg/ha)
1	control	–	–	–
2	Mg	$MgSO_4$	2.5	3.86
3	K	K_2SO_4	1.8	12.44
4	Mg + K	$MgSO_4$ + K_2SO_4	1.25 + 0.9	1.93 + 6.22

$MgSO_4$ – Epso Top (9.65% Mg, 13% S); K_2SO_4 – soluSOP 52 (43% K, 18% S)

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acidity and pH of grape must were analysed by the analysis of variance (ANOVA at level 0.05; two factors were always compared – differences between years and in each year) in combination with the Fisher *LSD* test. All data were analysed using Statistica 10 CZ software (Round Rock, USA) and processing of the measured data was performed in Microsoft Excel 2013 (Redmond, USA).

RESULTS AND DISCUSSION

Grape yields (Table 3) were significantly different in the individual years, in the 3rd year of the experiment the yields were twice as high as in the 1st year; the greatest effect of the year was the intensity and distribution of precipitation and the temperatures during the year. In the first 10 months of 2011 the average sum of precipitation was only 88.2% of the other years and 7 months were below average; extremely below average was February when precipitation was only 18.5% of the many years' average (1961–1990). At the same time the temperatures in April, August and September 2011 were considerably above the long-term average.

Separate applications of Mg and K had a positive impact on grape yields in all the years as compared with the untreated control (Table 3). In terms of 3-year averages the foliar application of Mg and K increased yields by 11.2% and 13.9%, respectively, above the control. The explanation for these better results after individual applications of Mg and K in comparison with joint application of both elements could be the antagonistic effect of Mg and K. In field trials with cv. Riesling italico Májer (2004) explored the effect of foliar applications (5% solution applied 3× after the fall of blossoms) of magnesium in the form of Bitter Salt (Epso Top) on yield and quality parameters of grapes. Zatloukalová et al. (2011) reported a 3.1–6.7% increase in yields of cv. Riesling italico after 5 times repeated 5% foliar nutrition to vine with the fertilizer Epso Top (9.65% Mg, 13% S) and Epso combitop (7.8% Mg, 13% S, 4% Mn and 1% Zn).

Combined application of both nutrients (Mg + K) significantly increased the yields as against the control only in 2013 and the average 3-year yield increase was 6.6% (Table 3). The cause may be the mutual antagonistic effect of both nutrients as described by Marschner (2002). Both fertilizers also contain the sulphate ion; sulphur supports nitrogen utilisation at the same time stimulating yields and reducing the risk of losses, e.g. such as the leaching of nitrates into groundwater (Mengel and Kirkby 2001). We can assume better environmental conditions for uptake, assimilation and utilization of both nutrients in 2013 which was resulted in the highest grape yield during three years of experiments.

However, whereas the importance of magnesium as an essential plant nutrient is well established, the impact of Mg nutrition on quality parameters has only been rarely addressed (Trolove et al. 2008, Gerendás and Führs 2013). Gerendás and Führs (2013) concluded that Mg doses beyond those required for maximum yield rarely induce a further improvement of product quality. Shin and Lee (1993) described the effect of foliar nutrition with potassium in the form of a 0.6% solution of K_2SO_4 on the qualitative parameters of grapes. The delicious and balanced taste of wine is the result of a directly proportional sugar/acid ratio, especially glucose + fructose and all titratable acids. In 2011 the sugar content in K fertilized grapes (treatment 3)

Table 3. Grape yields in 2011–2013

Treatment No.	Description	2011		2012		2013		3-year average (%)
		(kg/plant)	± SD	(kg/plant)	± SD	(kg/plant)	± SD	
1	control	2.91^{acA}	0.02	4.05^{aB}	0.03	5.90^{aC}	0.08	100.0
2	Mg	3.24^{bcA}	0.08	4.49^{bB}	0.09	6.56^{bC}	0.16	111.2
3	K	3.45^{bA}	0.18	4.43^{bB}	0.13	6.71^{bC}	0.15	113.9
4	Mg + K	3.05^{cA}	0.05	4.28^{abB}	0.09	6.43^{bC}	0.10	106.6

Mean values of grape yields in kg per plant ± standard error (SD) (n = 4). Different small letters indicate significant differences at the level of $P < 0.05$ among individual treatments within the same year and different uppercase letters indicate significant differences at the level of $P < 0.05$ among individual years

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Table 4. Content of sugar in grape must (glucose + fructose)

Treatment No.	Description	2011		2012		2013		3-year average (%)
		(g/L)	± SD	(g/L)	± SD	(g/L)	± SD	
1	control	208.50^{aA}	4.62	205.23^{aA}	6.72	170.18^{bB}	1.79	100.0
2	Mg	209.08^{aA}	6.43	208.70^{aA}	8.18	162.15^{bB}	1.20	99.5
3	K	187.18^{bA}	5.75	204.45^{aB}	3.43	164.58^{bC}	3.45	95.7
4	Mg + K	191.85^{abA,B}	8.58	205.60^{aA}	3.89	179.88^{aB}	2.01	99.3

Mean values of glucose and fructose content in g per one litre of grape must ± standard error (SD) (n = 4). Different small letters indicate significant differences at the level of P < 0.05 among individual treatments within the same year and different uppercase letters indicate significant differences at the level of P < 0.05 among individual years

was lower than in treatments 1 and 2 (Table 4). In 2012 no significant differences were discovered among the treatments. In 2013 the combined Mg + K application resulted in higher sugar content than in the other treatments. The 3rd year also showed a significant decrease in the sugar content compared with the other years (Table 4). The explanation could be unsuitable scheduling of precipitation amounts during the vegetation including rainfall deficiency during July (only 4.7 mm). Zatloukalová et al. (2011) detected insignificantly higher sugar content in cv. Riesling italico after 5 foliar applications of a 5% solution of Epso Top than in the untreated control. In two-year trials also Krempa et al. (2009) discovered minimal differences in the sugar content of the unfertilized cv. Muscatel yellow (22.65°NM) against the application of N, Mg (22.30°NM) and N, Mg, S (22.50°NM). In comparison Takacs et al. (2007) discovered that foliar application of Mg during the summer contributed (also preventively) to a higher Mg content in vine leaves, higher photosynthesis and a higher content of sugar in the grapes. Abd El-Razek et al. (2011) postulated that increasing K fertilization improved sugar transport into the berries. These findings are in parallel with findings stating that K enhances translocation of sugars and helps to retard crop diseases (Ramming et al. 1995).

Table 5 gives the pH of the must which was not (with one exception) affected by fertilization and ranged between 3.02 and 3.25. Zatloukalová et al. (2011) reached the same conclusions in cv. Riesling italico; after 5 foliar applications of a 5% solution of Epso Top the pH did not change as compared to the untreated control (3.07 and 3.11, respectively). Mpelasoka et al. (2003) discovered that excess K levels in grape berries may have a negative impact on wine quality, mainly because it decreases free tartaric acid resulting in an increase in the pH of grape juice and wine. In our 3-year experiments we did not draw the same conclusions. Poni et al. (2003) also reported the same pH value of must (i.e. 3.38) in the control and K_2SO_4 fertilized treatment.

The contents of titratable acids in grape must (Table 6) ranged between 8.73 and 10.86 g/L and the average values were the highest in the unfer-

Table 5. The pH of grape must (juice)

Treatment No.	Description	2011		2012		2013		3-year average (%)
		pH	± SD	pH	± SD	pH	± SD	
1	control	3.16^{aA}	0.04	3.17^{aA}	0.02	3.02^{aB}	0.02	100.0
2	Mg	3.25^{aA}	0.03	3.15^{aA}	0.01	3.11^{bB}	0.01	101.9
3	K	3.16^{aA}	0.09	3.13^{aA}	0.01	3.13^{bA}	0.02	100.9
4	Mg + K	3.14^{aA}	0.06	3.14^{aA}	0.01	3.16^{bA}	0.01	101.1

Mean values of pH in grape must ± standard error (SD) (n = 4). Different small letters indicate significant differences at the level of P < 0.05 among individual treatments within the same year and different uppercase letters indicate significant differences at the level of P < 0.05 among individual years

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Table 6. The content of titratable acids in grape must

Treatment No.	Description	2011		2012		2013		3-year average (%)
		(g/L)	± SD	(g/L)	± SD	(g/L)	± SD	
1	control	8.87^{aA}	0.16	9.10^{aA}	0.27	10.86^{aB}	0.32	100.0
2	Mg	8.73^{aA}	0.25	8.98^{aA}	0.31	10.31^{abB}	0.40	97.1
3	K	8.75^{aA}	0.32	9.16^{aA}	0.25	9.43^{bA}	0.51	95.4
4	Mg + K	8.85^{aA}	0.44	9.03^{aA}	0.32	9.48^{bA}	0.12	95.4

Mean values of titratable acids in g per one litre of grape must ± standard error (SD) (n = 4). Different small letters indicate significant differences at the level of $P < 0.05$ among individual treatments within the same year and different uppercase letters indicate significant differences at the level of $P < 0.05$ among individual years

tilized control treatment. Krempa et al. (2009) in two-year trials also found minimal differences in acid contents between the unfertilized cv. Muscatel yellow and Furmint (8.09 and 9.20 g/L, respectively) after the application of N, Mg (8.04 and 9.31 g/L, respectively) and N, Mg, S (8.22 and 9.26 g/L, respectively). Likewise Zatloukalová et al. (2011) detected that the acid content increased insignificantly after 5 foliar applications of 5% Epso Top solution (13.25 g/L) in contrast to the untreated control (13.15 g/L). Neither Poni et al. (2003) found any differences in the content of titratable acids between the treated control and treatment where K_2SO_4 was applied (6.1 and 6.4 g/L, respectively). On the other hand Abd El-Razek et al. (2011) discovered that the acid content in grape berries decreased after potassium fertilization. This finding was in accordance with our own results only in the last year of the experiment in treatments 3 and 4 as compared with the unfertilized control treatment (Table 6). Rupp et al. (2002) concluded that late Mg application (foliar sprays with $MgSO_4$ or MgO) is safe as regards wine quality.

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