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Effect of soil fertilization on the incidence of berry shrivel and the quality of resulting wine

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Summary

Berry shrivel is becoming an increasing concern for winegrowers all over the world. Until today, no single factor causing this physiological disorder has been determined. Studies concerning berry shrivel conducted in Austria have shown that an unbalanced ratio of K and Mg in the soil is a likely factor contributing to the disorder. The aims of the present study were to establish a better understanding of the causes and consequences of berry shrivel and observe the effects of K and Mg fertilization *via* the soil on the incidence of berry shrivel, the mineral composition of affected berries and the resulting wine quality. A two-year fertilization trial was conducted on two sites located within southern Germany with the varieties 'Zweigelt' and 'Pinot Blanc'. Different amounts of K and Mg were applied each year at both locations in order to generate different ratios of K and Mg in the soil. Before harvest, the incidences of berry shrivel of the different treatments were determined. In addition, macronutrients including K, Mg and Ca that were translocated in healthy berries and berries affected by berry shrivel were determined at harvest. To compare the quality of wine influenced by berry shrivel, different wines were produced consisting of shrivelled berries, berries affected by bunch stem necrosis and healthy berries.

In the soil fertilization trials, no significant differences in the incidences of berry shrivel were observed in relation to the soil fertilization. Major differences were found in the wine qualities of the different wines. Wines produced from healthy berries were always rated as the best wines, whereas wines produced from shrivelled berries were always rated as the lowest quality. The low quality parameters found in the must did not improve in the wine making process. Wines produced from berries affected by bunch stem necrosis were rated better than berry-shrivel-wines, however, rated less than the wine produced from healthy berries. The determinations of macronutrients' level in the berries showed significant differences regarding the concentration of Ca. In the variety 'Zweigelt' in 2009, an average of 36 mg·L^{-1} of Ca were found in healthy berries and 107 mg·L^{-1} in berries affected by berry shrivel. In 'Pinot Blanc' in 2010, the average of Ca in healthy berries was 46 mg·L^{-1} and 70 mg·L^{-1} in berries affected by berry shrivel. No significant differences were found for K and Mg in the berries.

K e y w o r d s : berry shrivel, "Traubenwelke", potassium, magnesium, soil fertilization, wine quality.

Introduction

Incidences of berry shrivel (BS) were first described in Austria in 1997 (Reisenzein and Berger 1997), however, since 2005, this disease has also been reported in Southern Germany. It is likely that BS has already existed in Germany for a number of years, since the visible symptoms of BS are similar to those identified with bunch stem necrosis (BSN). Berries affected by BS lose their turgescence during the onset of ripening. These berries show a reduced sugar accumulation, low pH, reduced content of anthocyanins as well as an increase of tannins in the skin (Krasnow *et al.* 2009). The must weight remains low at around 10 °Brix, therefore affected berries cannot be used for wine-making and must be removed before harvest. Since the rachis remains green and often indicates no form of outer damage when affected by BS, the detection of affected grapes is time-consuming as it is essential to examine each individual grape carefully in order to identify affected berries.

Possible causes of BS have been suggested and discussed in numerous publications (Stücklin 2007, Bondada and Keller 2007, Schumacher *et al.* 2007, Redl 2005, Keller 2008, Pardatscher 2004, Reisenzein and Berger 2001, Griesser *et al.* 2012, Hall *et al.* 2011, Kührer and Gabler 2011, Kührer 2010). Research was conducted to understand and determine the causes and effects of BS. To date, no single factor has been identified as the main cause of the disease. Furthermore, there is a likely genetic predetermination, as some varieties, rootstocks or clones were considered more susceptible than others (Schumacher *et al.* 2007, Stücklin 2007). Varieties where BS was observed more often are 'Zweigelt', 'Pinot Noir', 'Pinot Gris' and 'Pinot Blanc' or 'Chasselas'. Investigations in Switzerland showed that the rootstocks 5C and SO4 are more susceptible, whereas 5BB, 125AA or 3309 are less susceptible. Comparing the clones of 'Pinot Noir', the clones Mariafeld, 2/45 or 10/5 seem to be more affected by BS (Schumacher *et al.* 2007). In South Tyrol BS was identified in conjunction with extreme weather conditions, such as wet and cold conditions after full bloom and hot and dry weather towards 14.8 °Brix (Raifer and Roschatt 2001). In the USA research associated with BS tended to focus more on the physiological parameters such as phloem/xylem sap flow (Bondada and Keller 2012, Keller 2008) and

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compositional changes (Krasnow *et al.* 2009) in affected berries compared to healthy berries. Research conducted in Austria focused on investigating the disproportion of K and Mg in the soil as well as high temperatures as possible causes for the BS disorder (Redl 2005).

A well-balanced ratio between K, Mg and Ca is important for the growth of healthy plants and good quality wines. These cations can act as direct competitors during uptake by the roots. If one of these ions is available within the soil in excess, the roots will then essentially take up a greater proportion of this ion and can limit the uptake of the other essential ions, even if they are sufficiently present in the soil. Physiological disorders such as BS or BSN are supposed to be associated with an unbalanced proportion of these cations in the plant.

The objectives of the present study were to find possible effects of the fertilization of K and Mg on the incidence of BS and thereby affordable ways to decrease the risk of the occurrence of BS. The consequences of the disorder BS should be easier understood by the investigation of the shift of K, Mg and Ca into affected berries and the resulting wine quality.

Material and Methods

Site description: The 'Zweigelt' vineyard was located in the South of Germany, in Weinstadt-Endersbach (48°49'05.54'' N, 9°22'18.54'' E, 246 m a.s.l.), and consisted of an area of 1438 m². The average annual temperature in 2009 was 9.9 °C and the average annual amount of precipitation was 905 mm, in 2010 the average annual temperature was 8.9 °C and the annual amount of precipitation was 772 mm. The soil type was classified as endostagnic Regosol (calcaric).

The vines were all St 9 clones on 5BB rootstocks, planted in 2002 and trained to one cane with 10-11 buds. The distance between vines within the rows was 1.2 m and between rows 2 m. Three treatments were distributed in a randomized block design consisting of 12 plots in 4 rows. Each treatment was present in one of the rows. One plot contained 24 vines in an area of 57.6 m².

The 'Pinot Blanc' site was located in the South of Germany, in Ehrenkirchen (47° 55' 33.22'' N, 7°44'59.92''E, 297 m a.s.l.), and consisted of an area of 2070 m².

The average annual values for temperature and the amount of precipitation in 2009 were 11.7 °C and 984 mm, respectively. In 2010, the average annual temperature was 10.31 °C and the annual amount of precipitation was 888 mm. The soil type was classified as haplic Regosol (calcaric, siltic).

The vines were 0212 clones on 5BB rootstocks, planted in 2000 and trained to one cane with 9-12 buds. The spacing of each vine was 2.4 m² and between rows 2 m. The trial design was a completely randomized 5x5 latin square. The 25 plots consisted of five different treatments in five replicates. One plot contained 20 vines in an area of 48 m².

Weather data were collected by the Landwirtschaftliches Technologiezentrum (LTZ) Augustenberg, Germany, at meteorological stations near the experimental sites and provided by the program Vitimeteo (State Institute of Viticulture and Enology, Freiburg, Germany and the Agroscope Changins-Wädenswil, Switzerland).

Fertilization: In the block design at the "Zweigelt" site, three fertilizing treatments were used: (1) no fertilization of K and Mg, (2) fertilization of K (41 kg/ha K) and Mg (16 kg·ha^{-1} Mg) as recommended, (3) 300 % of the recommended amount of K and Mg as recommended. At the 'Pinot Blanc' site, five fertilizing treatments were selected. As the trial site was suitable, two more treatments were implemented in order to examine a wider range of fertilization levels. (1) no fertilization of K and Mg, (2) recommended amount of K (28 kg·ha^{-1} K) and Mg (24 kg·ha^{-1} Mg), (3) 300 % of the recommended amount of each K and Mg, (4) no K and 300 % of the recommended amount of Mg, (5) no Mg and 300 % of the recommended amount of K. In order to generate an unbalanced ratio of K and Mg in the soil in a short time, the amounts were tripled in the varieties (3), (4) and (5).

On both sites fertilization was applied by hand in 2009 and 2010 at approximately 60 days prior to anthesis, using ESTA® Kieserit (K+S Kali GmbH, Kassel, Germany) and Kaliumsulfat (K+S Kali GmbH, Kassel, Germany).

During the trial, vineyard management regarding plant protection, defoliation, tipping or soil cultivation remained the same for all treatments at each site according to commercial practices in southern Germany.

Leaf samples: In 2009 and 2010, 60 leaves were sampled for each treatment throughout each season. Twenty leaves were collected on three separate occasions: 1) at full bloom, 2) at veraison and 3) at the ripening stage of the berries of 14.8 °Brix. Leaves were collected at mid-shoot position, opposite the first or second cluster. Contaminations (e.g. fertilizer or fungicide) were removed with a soft brush and deionized water. Subsequently, samples were dried to constant weight in a drying oven at 45 °C, and then placed in plastic bags and sent to the LTZ Augustenberg, Germany, for analysis of K, Ca and Mg. The ratio of K and Mg was calculated by K/Mg and the cation ratio was calculated by K/(Mg+Ca).

Soil samples: For each treatment, a mixed sample across all plots was taken. Per plot, two samples were randomly collected within the rows. Soil samples were collected in January 2009 prior to the first fertilization in order to determine the supply status of K, Mg, humus and pH. Samples were collected with a Pürckhauer auger at two depths ranging from 0-30 cm and 30-60 cm. Analysis of the nutritional status of the soil was conducted at the LTZ Augustenberg, Germany. Due to the results received in the analysis, a recommendation of the amounts of fertilizers was calculated according to the "Düngung von Ertragsreben" (Ministerium für Ernährung und Ländlichen Raum Baden-Württemberg, 2006). This recommendation was taken as a basis for the calculation of the different treatments. In order to monitor the nutritional status in each of the different treatments, soil samples were taken in the same way after harvest in 2009 and 2010.

Berry samples: Berry samples consisting of 100 berries each were collected at BS symptom onset.

One sample of healthy berries and berries affected by BS was collected in each treatment. At the 'Pinot Blanc' site in 2010, one sample of berries affected by BS was collected over all the treatments as not enough affected berries could be sampled for each treatment. All berries were pressed, stabilized with 0.2 ml of a 5 % SO_2 solution and concentrations of Ca, Mg and K were analysed with atomic absorption spectroscopy (AAS).

Wine Production: At the “Zweigelt” site in 2010, healthy grapes of the control treatment with the recommended amount of fertilizers were harvested. Berries affected by BS and BSN were detected and harvested separately. In all treatments, all grapes were mashed after harvest, fermented on the skins and the following additives applied: 20 g/l of Siha 8 yeast (E. Begerow GmbH & Co., Langenlonsheim, Germany), 22.7-37.9 $g \cdot L^{-1}$ saccharose (depending on the treatment) to adjust the amount of alcohol and 50 $g \cdot hL^{-1}$ Vitamon Combi (Erbslöh, Geisenheim, Germany) as yeast nutrition. After one week, the mash was pressed and 6 days later, 1 $g \cdot hL^{-1}$ of sK 2 (Erbslöh, Geisenheim, Germany) was added for biological deacidification. This was stopped after 5 ½ weeks, using 50 $mg \cdot L^{-1}$ SO_2 and another 30-50 $mg \cdot L^{-1}$ SO_2 6 weeks later. Before filling, 15-20 $mg \cdot L^{-1}$ SO_2 was added.

Musts and wines were analysed with GrapeScan™ (FOSS NIRSystems, Inc., Laurel, USA) for the contents of glucose, fructose, total acidity, tartaric acid, malic acid, volatile acid, alcohol, glycerine, gluconic acid, NOPA, ammonium and must weight. The concentrations of Ca, Mg and K were analysed with AAS.

Consumer preference analysis: Three “Zweigelt” wines were evaluated in a sensory seminar with 137 participants. One was made from healthy grapes, one from berries affected by BS and one from berries affected by BSN. Each participant tested the three wines blindly without knowing which one was which. After tasting, the wines were evaluated with rank number 1 for the best and 3 for the worst wine. These results were statistically analysed with Friedman rank sum test at $\alpha = 0.05$.

Scoring: For each treatment, each grape of 20 vines was rated which added up to about 300 grapes per treatment. The grapes were examined by hand and the amount of shrivelled berries was estimated.

Statistical analysis: Scores and samples were statistically analysed by ANOVA with proc mixed statements (SAS ® Institute INC, USA) at $\alpha = 0.05$.

Results

Incidence of BS: In 2009, the 'Zweigelt' site showed BS symptoms at an average of 22.3 % compared with the 'Pinot Blanc' site at 5.1 %. (Fig. 1A). In 2010, BS was present at both sites and incidences similar to 2009. BS was at 29.3 % at the 'Zweigelt' site and 5.9 % at the 'Pinot Blanc' site (Fig. 1B). There were no significant differences between each of the treatments at either of the sites.

Nutritional status in the leaves: The ratio of K/Mg and concentrations of K and Mg in the leaves were higher at the 'Pinot Blanc' site compared to the 'Zweigelt' site throughout the whole seasons of 2009 (Fig. 2A) and 2010 (Fig. 2B). At each site, the ratios of the different fertilization treatments did not show significant differences. At the 'Pinot Blanc' site in 2009, the treatment with 300 % of the recommended amount of K and Mg showed the highest ratio at 14.8 °Brix, whereas all the other treatments did not differ much. At the 'Zweigelt' site, ratios of all treatments lay in the same range between 2 and 4.

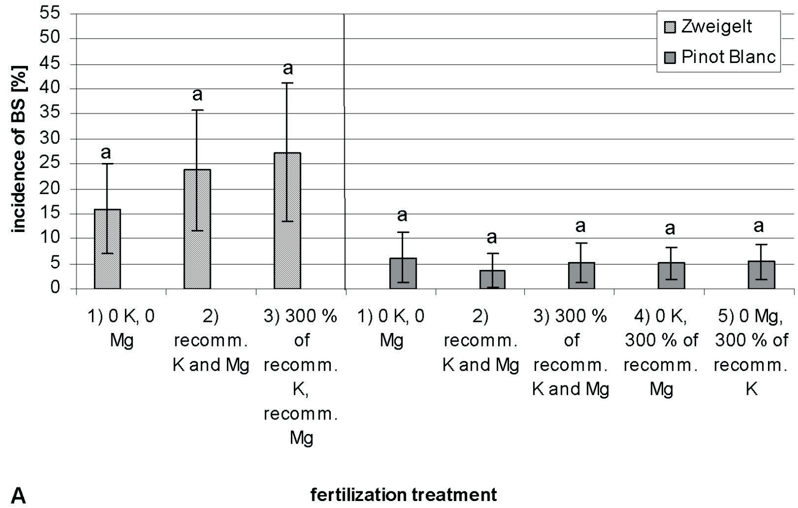
A regression of the cation ratio and the logarithmic transformed incidences of BS showed a linear relationship in 2010 with $y = 4.53 - 5.12x$, $R^2 = 0.75$.

Nutritional status in the berries: The amounts of nutrients in the berries and significant differences are shown in Tab. 1. Significant differences were found for concentrations of Ca. Comparing the results within the treatments at the 'Zweigelt' site, the amounts of Ca in berries affected by BS were significantly higher for all the treatments in 2009: 223 % in treatment 1, 261 % in treatment 2 and 129 % in treatment 3. In 2010, only the affected berries of treatment 1 showed significantly higher Ca levels with 104 % more Ca than healthy berries. At the 'Pinot Blanc' site in 2010, the amount of Ca in affected berries was significantly higher in all treatments with 56 % respectively.

Nutritional status in the soil: It was not possible to change the ratio of K and Mg in the soil in the different treatments considerably. At the 'Zweigelt' site prior to trial initiation, the amount of K in 0-30 cm depth was 24 mg/100 g and Mg was at 22 mg/100 g. In 30-60 cm K was at 14 mg/100 g and Mg at 22 mg/100 g. These levels are considered as sufficiently supplied. After harvest in 2010, in treatment 1 with no fertilization of K and Mg, 26 mg/100 g K were analysed in 0-30 cm and 18 mg/100 g in 30-60 cm. Mg was at 22 mg/100 g in 0-30 cm and 21 mg/100 g in 30-60 cm. In treatment 3 with 300 % of the recommended amount of K and Mg as recommended, 30 mg/100 g K and 23 mg/100g Mg were observed in 0-30 cm and 22 mg/100 g of both K and Mg in 30-60 cm. The level of Mg supply remains in the range that should be pursued. The level of K rises in treatment 3 and is considered as more than sufficient.

At the 'Pinot Blanc' site, the amount of K was at 26 mg/100 g and Mg at 14 mg/100 g in 0-30 cm prior to trial initiation. In 30-60 cm, K was at 24 mg/100 g and Mg at 16 mg/100 g. These levels are considered as sufficiently supplied. After 2 years, the control plots without fertilization of K and Mg showed 31 mg/100 g of K and 15 mg/100 g of Mg in 0-30 cm and 24 mg/100 g K and 15 mg/100 g Mg in 30-60 cm. Amounts of K in the upper soil varied only from 26 mg/100 g in treatment 3 to 32 mg/100 g in treatment 5.

In the subsoil, highest amounts of K were found in treatment 2 with 28 mg/100 g and lowest amounts in treatment 1 and 5 with 24 mg/100 g. Mg varied from 13 mg/100 g in treatment 5 to 16 mg/100 g in treatment 3 in the upper soil. In the subsoil, the same amount of Mg (15 mg/100 g) was found in all treatments except for treatment 5 with 14 mg/100 g. The level of Mg supply remains in the range that should be pursued. Regarding the level



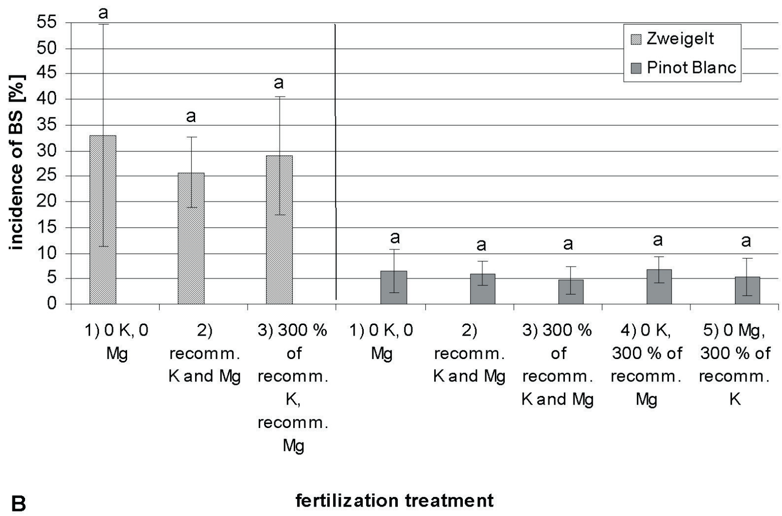


Fig. 1: Incidences of BS at both sites in 2009 (**A**) and 2010 (**B**) in the different fertilization treatments. aMeans with the same letter do not differ significantly at $p < 0.05$ within each site. Error bars indicate standard deviation.

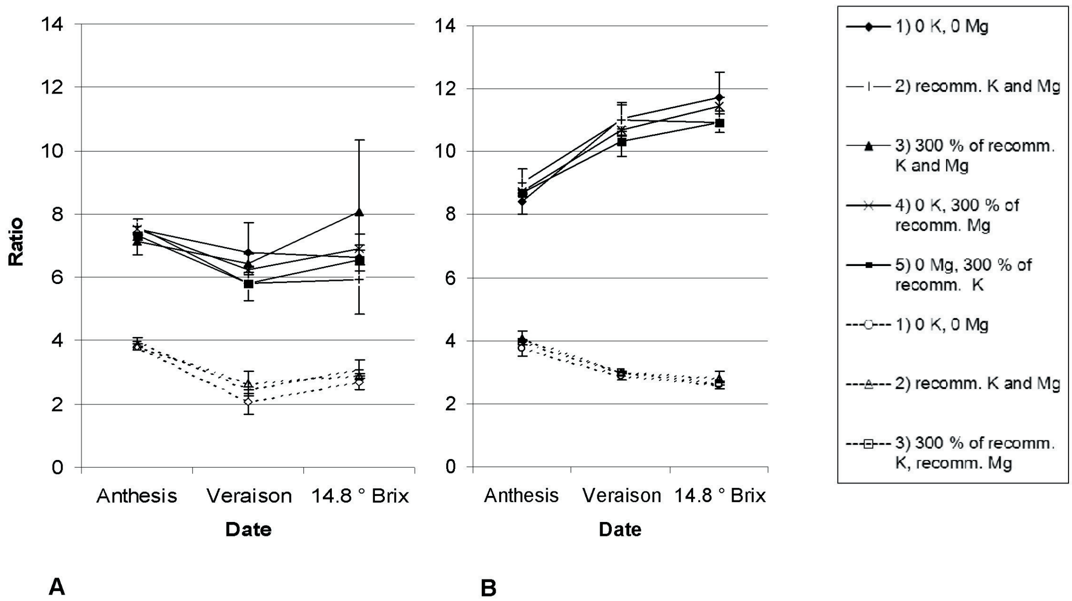


Fig. 2: Ratio of amounts of K and Mg in leaves of treatments 1-5 at the "Pinot Blanc" site (—) and treatments 1-3 at the "Zweigelt" site (---) in 2009 (**A**) and 2010 (**B**). Error bars indicate standard deviation.

Table 1

K, Mg and Ca in healthy berries and berries affected by BS in the different treatments at both trial sites in 2009 and 2010. [ab]Means followed by the same letter in each column do not differ significantly at $p < 0.05$

Zweigelt 2009		Means		
fertilization	berries	K [mg·L^{-1}]	Mg [mg·L^{-1}]	Ca [mg·L^{-1}]
1	healthy	1253 a	38 a	33 a
	BS	1183 a	34 b	107 b
2	healthy	1336 a	37 a	30 a
	BS	1386 a	36 a	107 b
3	healthy	1288 a	41 b	46 a
	BS	1244 a	39 b	106 b
Zweigelt 2010		**Means**		
fertilization	berries	K [mg·L^{-1}]	Mg [mg·L^{-1}]	Ca [mg·L^{-1}]
1	healthy	1086 a	58 a	41 a
	BS	833 a	65 a	84 b
2	healthy	1087 a	66 a	48 a
	BS	898 a	59 a	69 a
3	healthy	1072 a	59 a	46 a
	BS	841 a	62 a	72 a
Pinot Blanc 2009		**Means**		
fertilization	berries	K [mg·L^{-1}]	Mg [mg·L^{-1}]	Ca [mg·L^{-1}]
1	healthy	1302 a	71 a	56 a
	BS	1243 a	65 a	62 a
2	healthy	1384 a	66 a	56 a
	BS	1254 a	69 a	60 a
3	healthy	1365 a	69 a	55 a
	BS	1241 a	69 a	61 a
4	healthy	1191 a	85 a	55 a
	BS	1287 a	76 a	62 a
5	healthy	1372 a	72 a	64 a
	BS	1315 a	68 a	57 a
Pinot Blanc 2010		**Means**		
fertilization	berries	K [mg·L^{-1}]	Mg [mg·L^{-1}]	Ca [mg·L^{-1}]
1	healthy	1636 a	66 a	45 a
	BS	1335 a	70 a	70 b
2	healthy	1652 a	66 a	45 a
	BS	1335 a	70 a	70 b
3	healthy	1652 a	68 a	45 a
	BS	1335 a	70 a	70 b
4	healthy	1552 a	67 a	45 a
	BS	1335 a	70 a	70 b
5	healthy	1749 a	70 a	46 a
	BS	1335 a	70 a	70 b

of K supply, treatment 4 with 30 mg/100 g in 0-30 cm and treatment 5 with 32 mg/100 g show a supply that is higher than the optimal level.

Ratios of K and Mg in the soil are shown in Fig. 3. After harvest in 2010, all treatments at the 'Zweigelt' site lie under the optimal range of 2:1 and all treatments at the 'Pinot Blanc' site (except for treatment 3) lie above this ratio.

M u s t s a n d w i n e s : The results of the analysis of the musts showed differences in all parameters analysed. In the musts, mustweight, NOPA, pH and K showed the highest values in the control and the lowest in the must of berries affected by BS, whereas acidity and Ca had the highest values in these musts. Furthermore, as expected, in the control wines highest alcohol levels and pH and lowest acidity and concentrations of fermentable sugar were observed (Tab. 2).

The results of the consumer preference analysis indicated significant differences between the wines. Out of 137 tasters, 135 tasters rated the control wine as the best wine, 114 rated the wine made from berries affected by BSN as the second best wine and 115 rated the wine made from berries affected by BS as the worst wine on rank no. 3. Statistical analysis showed rank number 1.0 for the control wine, 2.2 for wines made of berries affected by BSN and 2.8 for wines made of shrivelled berries.

Discussion

The amount of affected berries at the 'Zweigelt' site was higher each year the experiment was conducted compared to the amount of affected berries at the 'Pinot Blanc' site. This might be due to the fact that the variety 'Zweigelt' is more susceptible to BS than the variety 'Pinot Blanc'. The rootstock (5BB) was the same at both sites and is considered to be less susceptible for BS than others. Only in 2008, prior to this trial, the occurrence of BS at the 'Pinot Blanc' site was approximately 40 % - which shows the variation of this disease in a period of one year and indicates that weather conditions are one of the main other factors causing BS, besides the nutritional status in the soil. Cool and wet conditions during blooming and ripening are likely causes for both BSN and BS (SIEGFRIED 2010, pers. comm.). In 2010, such conditions could be found. At the 'Zweigelt' site, 16.7 % of the yearly amount of precipitation were recorded from veraison until harvest. At the 'Pinot Blanc' site it was even 22.5 % of the yearly amount of precipitation in 2010. In 2009, in this period only 3.6 % of the yearly amount of precipitation were recorded at the 'Zweigelt' site and 5.5 % at the 'Pinot Blanc' site. This might explain the higher rates of incidence of BS in 2010.

Comparing the results of the leaf and soil analysis at both field sites, at the 'Pinot Blanc' site, the ratio of K·Mg^{-1} was within the range considered to be optimal. However, at the 'Zweigelt' site, a very narrow ratio was determined, due to an overfertilization of Mg in the years prior to the trial. For soil, a ratio of K:Mg at 2:1 is considered optimal. Within a two year trial period, it was not possible to alter the proportion of K:Mg in the soil effectively. Former studies have proven that there is little effect on the uptake of K when K fertilizers are applied in excess (MORRIS *et al.* 1980). In tomato plants, the same can be applied to Mg (BRYSON and BARKER 2002). However, 2010 a slight increase of K can be observed at both trial sites in the treatments given 300 % of the recommended amount of K, which might possibly be enlarged by continuing the trials.

The quantity of K and Mg that reached the leaves did not increase in either of the treatments that were given three times the amount of fertilizer considered optimal.

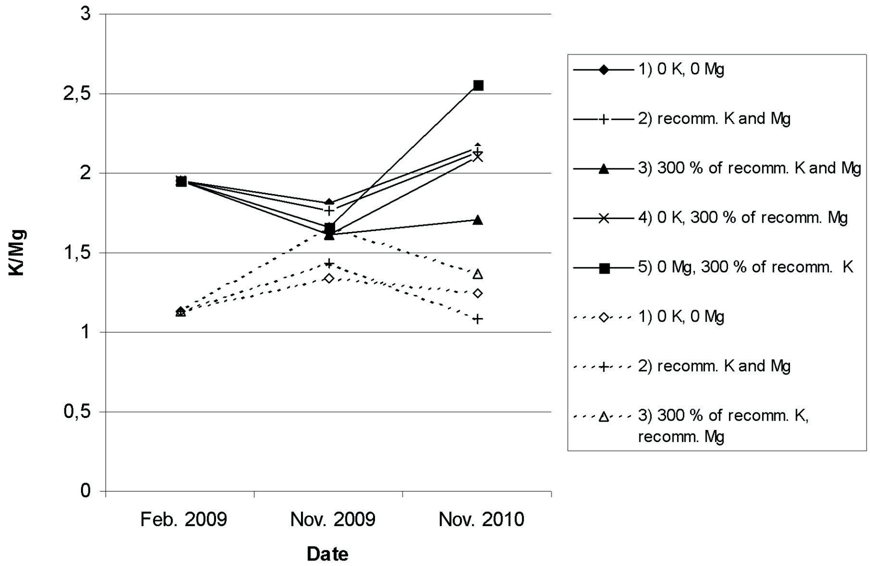


Fig. 3: Ratio of amounts of K and Mg in the soil of treatments 1-5 at the "Pinot Blanc" site (—) and treatments 1-3 at the "Zweigelt" site (---).

Table 2

Analysis of control (healthy), BS and BSN musts and wines harvested in 2010

must	must weight (°Brix)	total acidity ($g \cdot L^{-1}$)	Tartaric acid ($g \cdot L^{-1}$)	pH	NOPA ($mg \cdot L^{-1}$)	K ($g \cdot L^{-1}$)	Ca ($mg \cdot L^{-1}$)
BSN	17.7	12.5	7.7	3.0	134	1.00	63
control	20.5	8.5	6.0	3.1	197	1.28	37
BS	14.5	14.3	8.7	2.8	81	0.90	79
wine	alcohol ($g \cdot L^{-1}$)	total acidity ($g \cdot L^{-1}$)	pH	fermentable sugar ($g \cdot L^{-1}$)	sugarfree extract ($g \cdot L^{-1}$)	volatile acid ($g \cdot L^{-1}$)	free SO_2 ($mg \cdot L^{-1}$)
BSN	90.7	7.2	3.1	2.3	24.1	0.47	32
control	101.2	5.3	3.4	1.8	22.2	0.51	20
BS	77.2	8.7	3.0	2.7	23.6	0.39	15

This can be explained with the already sufficient supply of K and Mg in the soil, which can be seen in the treatment without any fertilization. The concentrations of K and Mg in the leaves remained within the normal range even after the second year. Only the ratio of $K \cdot Mg^{-1}$, which is considered optimal at 3.5.-7.0 (VANEK 1978), does not lie in this range but shows no correlation to the incidences of BS. However, the pathway of nutrients from the roots to the leaves is influenced by a large number of parameters (SCHACHTSCHABEL *et al.* 1984, MARSCHNER 1986, RICHTER 1998a, GISI *et al.* 1990). When the absolute amount of nutrients in the soil can be increased after fertilization for a certain time the uptake can be disturbed by fixation in the soil, pH-value or drought. Nutrients in the shoots and in the trunk were not analysed and therefore storage could be possible.

The ratio of all cations in the leaves showed a significant correlation with the incidence of BS in 2010. The range of all cations in the leaves is considered optimal between 0.30-0.40 (COGA 2009). Almost all of the samples analysed were under or above this range. A ratio higher than 0.4 means that the amount of K rises, which is the case at the 'Pinot Blanc' site. This is also reflected in the $K \cdot Mg^{-1}$ ratio in the leaves and in the soil. At the 'Zweigelt' site, the ratio is smaller as more Mg is present. Since the petioles were not used for analysis, the amount of nutrients taken up and stored might have been even higher, as the petioles may be seen as a storage for nutrients that can be moved to the blades when needed (GERENDAS 2011, pers. comm.).

The higher amounts of K and Mg given by fertilization were not reflected in the berries. The most obvious and most constant effect is the higher concentration of Ca in berries affected by BS, which was already found in the rachis of affected grapes (KRASNOW *et al.* 2009). Although not significantly, the concentration of K in berries affected by BS is often lower than in healthy berries, which was already found in prior studies (KRASNOW *et al.* 2009, KELLER 2008, MEHOFER and REGNER 2010). As K is mainly transported via the phloem, a cessation of the phloem flow might contribute to the development of BS. Grapes, where the pedicels were girdled and the phloem destructed, showed similar symptoms to grapes with BS (ERHARDT 2010). In contrast to K, Ca is a xylem mobile element. It reaches its maximum quantity within the berries early compared to other nutrients, at approximately 30 (POSSNER and KLIEWER

1985) - 60 DAA (Rogiers *et al*. 2006a). If a cessation of xylem and/or phloem flow should occur during ripening when shrivelling becomes apparent, most of the Ca^{2+}-ions are already accumulated within the berries. An increase of oxalic acid which is observed in healthy berries was not identified in shrivelled berries (Keller and Bondada 2007). This acid can bind Ca^{2+}-ions and therefore reduce the quantity of free ions. The differences found in the berries were also reflected in the musts. The control contains more sugar, less acid, more K and less Ca. The wines were not cleared or corrected artificially, as the purpose was to show the poor quality wine from affected grapes. The lack of K is reflected in the high acidity, as it is normally involved in controlling the pH in the grape juice (Boulton 1980).

Factors causing BS still remain unclear. The variation of K and Mg fertilizers did not increase or decrease the incidences of BS. Yet, trials must be continued in order to observe long-time effects. The evaluation of the resulting wine quality illustrates the importance of drawing winegrowers' attention to this disorder and its detection before harvest.

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