VINE WATER STATUS AS A PARAMETER OF THE « TERROIR » EFFECT UNDER THE NON-IRRIGATED CONDITIONS OF THE VAUD VITICULTURAL AREA (SWITZERLAND)

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Abstract

Aims: The aim of the study was to assess whether, for vineyards in Vaud (Switzerland), vine water status might be a major natural factor in determining wine sensory characteristics, i.e., responsible for the so-called « terroir » effect.

Methods and Results: The impact of vine water status on fruit and wine characteristics was examined for 23 non-irrigated locations with different soil water holding capacities during three seasons (2007-2009). In 2009, a close relationship was observed between $\delta^{13}C$ and soil water holding capacity. Furthermore, the level of vine water status influenced both fruit and wine composition. Berry weight was strongly correlated to vine water status. The highest grape soluble solids content (SSC) at harvest was reached when water deficit was mild. Wine colour was related to vine water status: wine made from grapevines with low water status showed a significantly higher colour density. However, sensory analysis did not discriminate between wines from different water conditions.

Conclusion: In a dry year like 2009, vine water status was related to soil water holding capacity and determined grape and wine characteristics. However, no clear relationship was observed between wine sensory characteristics and vine water status.

Significance and impact of the study: This study confirms the importance of soil in determining grape and wine characteristics through its effect on vine water status.

Key words: vine water status, terroir, carbon isotope discrimination, wine colour, wine sensory analysis

Résumé

Objectif : L'objectif de cette étude est d'évaluer, pour le vignoble vaudois (Suisse), si le régime hydrique de la vigne est un facteur déterminant pour la qualité sensorielle des vins et si celui-ci est à la base de l'effet terroir.

Méthodes et résultats : Le régime hydrique de la vigne a été étudié sur 23 sites non-irrigués et possédant des réserves différentes en eau des sols. En 2009, le régime hydrique de la vigne mesuré par le $\delta^{13}C$ a été dépendant des réserves en eau des sols. Le régime hydrique a fortement influencé la taille des baies et l'accumulation de sucres. La couleur des vins a été plus prononcée sur les sites ayant subi une contrainte hydrique plus importante. Cependant, le régime hydrique n'a pas influencé les caractéristiques sensorielles des vins.

Conclusion : Lors d'un millésime sec comme 2009, l'alimentation hydrique de la vigne a été en relation avec les différentes réserves utiles en eau des sols. L'état hydrique de chaque site a influencé les caractéristiques des raisins et des vins.

Signification et impact de l'étude : Cette étude confirme l'importance du facteur sol en relation avec le régime hydrique de la vigne dans l'effet terroir.

Mots clés : régime hydrique, terroir, discrimination isotopique du carbone, couleur des vins, analyse sensorielle des vins

manuscript received 29th October 2010 - revised manuscript received 26th May 2011

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J. Int. Sci. Vigne Vin, 2011, **45**, n°3, 139-147

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INTRODUCTION

The influence of environmental factors on the composition and quality of wines is known in viticulture under the concept of terroir. Soil, as one of the major environmental factors and terroir parameters, clearly influences fruit and wine characteristics. It is possible that in some wine-producing regions, fruit and wine quality are primarily controlled by factors that regulate vine water status. For instance, the research by Seguin in the Bordeaux vineyard in the early 1970s underlined the fundamental role of soil in regulating the vine water supply and its impact on wine quality (Seguin, 1986). According to this author, plant physiology, fruit composition and wine quality can be related to soil water holding capacity (SWHC). More recently, several studies have highlighted the importance of SWHC as being part of the terroir effect (Bodin and Morlat, 2006; Zufferey and Murisier, 2007; Van Leeuwen *et al*., 2009). Furthermore, variation in yield and vine vigour is often associated with variation in SWHC (Cortell *et al*., 2005). It has been unanimously accepted that water supply to grapevines during the ripening process plays a key role in grape and wine quality (Ojeda *et al*., 2002; Tregoat *et al*., 2002; Van Leeuwen *et al*., 2009). It is generally acknowledged that regular, but moderate, water supply contributes positively to wine quality (Deloire *et al*., 2004).

Vine water uptake conditions can be monitored either by measuring variations in soil water content or by means of physiological indicators. The quantity of water in the soil can be directly monitored by means of a neutron moisture probe (Seguin, 1986) or by using tensiometers. Physiological indicators directly estimate vine water status. Those physiological indicators are numerous: pre-dawn leaf water potential or stem water potential (Choné *et al*., 2001), micromorphometry techniques (monitoring the trunk diameter micro-variations) (Ton and Kopyt, 2004), sap flow measurement (Fernandez *et al*., 2008), and carbon isotope discrimination measured on grape sugars (Gaudillère *et al*., 2002).

The first aim of the study was to evaluate the effect of different SWHCs on vine water status. Leaf water potential and carbon isotopic discrimination were the techniques chosen to assess vine water status. The second aim was to assess the influence of vine water status on vine physiology and fruit composition. Finally, the third aim was to elucidate whether the variation in wine attributes can be explained by differences in vine water status.

MATERIALS AND METHODS

1. Vineyard sites

The project was conducted over three seasons (2007-2009) on 23 non-irrigated locations distributed across the entire Vaud vineyard. An on-farm approach was adopted, *i.e*., each location (circa 200 m^2) was in the middle of a large commercial vineyard. Locations were planted with *Vitis vinifera* L. cv. Gamaret, a Swiss red variety developed by researchers from the Agroscope Changins-Wädenswil (ACW) in the 1970s from a cross between Gamay x Reichensteiner. Gamaret shows medium precocity and gives coloured wines with well-structured tannins. This cultivar has been well established in Switzerland over the last few years, with a planting area of 380 ha in 2009 - one reason for its success being its very good resistance to grey mould (*Botrytis cinerea*).

Most vines (in 21 locations out of 23) were grafted onto 3309C rootstock (*V. riparia* x *V. rupestris*). On a few locations, where the $CaCO_3$ content in soil was high, Fercal rootstock was used. The study sites were planted in 2003. Vines on all locations were trained in espalier (single Guyot with vertical shoot positioned foliage). The plantation density varied between locations and depended mainly on the mechanisation type of each wine farm. The average plantation had 7500 ± 1000 vines/ha.

Numerous studies have highlighted the importance of crop load in determining wine quality (Murisier and Zufferey, 1997). In order to standardize this factor, yield was limited by cluster thinning of pea-sized berries. The average yield was thus 10 t/ha. The leaf area/fruit weight ratio was set to be over 1 m^2/kg, allowing a good maturation.

The date of harvest was determined separately for each location based on the fruit chemical analyses. Generally, all locations were harvested within one week. In 2007 and 2009, the harvest took place during the first week of October (veraison around the second week of August) while in 2008, it took place during the second week of October (veraison around the third week of August).

2. Soil types and soil water holding capacity (SWHC)

Table 1 lists the locations with their soil types and SWHC. SWHC was assessed from soil profiles in layers of 10 cm thickness (decimetric reserves). The SWHC has been computed for each location taking into account the amount of stones, texture, root colonisation and rooting depth (Letessier and Fermond, 2004). The SWHC corresponds to the maximal amount of water in a soil that a plant can extract. The soils were divided into three classes according to their SWHC: low SWHC (< 100 mm) on 6 locations, medium SWHC (100 - 150 mm) on 4 locations and high SWHC (> 150 mm) on 13 locations.

The majority of soils in the study area (i.e., approximately 80 % of the surface area) were alpine

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moraines, a heterogeneous mixture of different size debris transported by the Rhone glacier. Moraines can be classified into three types (Letessier and Fermond, 2004): bottom moraines with few stones (< 30 % coarse elements), stony moraines (30-60 % coarse elements), and gravely moraines (> 60 % large elements). In some places, a relatively thin layer of moraine has been observed lying on top of marly sandstones or Jurassic sandy limestones. Some colluvial deposits found at the foot of slopes originate from progressive erosion of the dominating slopes.

3. Climatic characteristics

Figure 1 depicts the evolution of monthly rainfall and monthly mean temperature for 2007-2009 compared with average values (1961-1990). The year 2007 was characterized by abundant rainfall in the summer and a warm April. In 2008, climatic conditions were close to the average values, although temperature tended to be higher than the average. August 2009 was the warmest month of the 3-year study. In addition, 2009 was the driest year, well below the average.

4. Vine water status

Vine water status was assessed by the pressure chamber technique (Scholander *et al*., 1965) and by means of carbon isotope discrimination measured on grape sugar at harvest. Pre-dawn leaf water potential measurements were made in the early hours of the morning (between 0200 and 0600) in total darkness on eight mature leaves centrally placed in the foliage on ten locations in the La Côte region (Table 1, site n° 1, 2, 3, 10, 11, 13, 14, 15, 18 and 23). The mean values of eight leaves per location are used in the figures. The levels of water stress (low, mild, high) and the corresponding water potential critical values were used according to Carbonneau (1998). Stem water potential was measured three times on eight locations (Table 1, site n° 2, 3, 10, 11, 13, 14, 15 and 18) during August 2009. Eight leaves were wrapped in a plastic sheet covered with aluminium foil to stop transpiration for one to two hours before measurement. Stem water potential was measured at the hottest time of the day (from 1400 to 1500) on mature leaves. The mean values of eight leaves per location are used in the figures. The levels of water stress (low, mild) and the corresponding water potential critical values were used according to the results of Choné (2001).

There are two naturally occurring isotopes of carbon, ^{12}C and ^{13}C. Most of the atmospheric CO_2 is ^{12}C (98.9 %) with 1.1 % being ^{13}C. Plants incorporate ^{12}C more easily into their biomass during photosynthesis, which results in carbon isotope discrimination (Farquhar *et al*., 1982). After pressing the grapes, a sample (few millilitres) of juice was taken, autoclaved and then the dry extract was converted into CO_2 using pure oxygen. The $\delta^{13}C$ was determined by continuous flux mass spectrometry (Avice *et al*., 1996) on all 23 locations. Carbon isotopic composition was expressed as

$$\delta^{13}C = ((R_P - R_S)/R_S) \times 1000$$

where R_P is the $^{13}C/^{12}C$ ratio of the product to be analysed and R_S is the $^{13}C/^{12}C$ ratio of PDB (Pee Dee Belemnite) standard.

5. Vine physiology and fruit composition

The total leaf area (TLA) was determined on eight locations (Table 1, site n° 2, 3, 10, 11, 12, 13, 14 and 15) during the 2009 season. TLA was determined on 10 vines per location. The area of an individual leaf was computed as described by Carbonneau (1976). Vine vigour was estimated by taking 50 pruned branches at the penultimate position on the fruit branch from different vines on every location.

Fruit maturation was monitored on all locations every two weeks from veraison (onset of maturity) to harvest. Two hundred berries were harvested from each location, weighed fresh and manually pressed to extract the juice.

Table 1 – Experimental sites with their soil types and their soil water holding capacity (SWHC).

Site N°	Soil categories	SWHC (mm)
1	Gravelly moraines	75
2	Gravelly moraines	90
3	Gravelly moraines	90
4	Marly sandstones	200
5	Stony moraines	160
6	Marly sandstones	250
7	Bottom moraines	155
8	Marly sandstones	190
9	Bottom moraines	230
10	Gravelly moraines	80
11	Bottom moraines	240
12	Bottom moraines	160
13	Bottom moraines	260
14	Gravelly moraines	80
15	Stony moraines	290
16	Bottom moraines	100
17	Gravelly moraines	130
18	Gravelly moraines	140
19	Colluvia	240
20	Marly sandstones	180
21	Jurassic sandy stones	100
22	Jurassic sandy stones	95
23	Colluvia	245

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The analytical parameters were measured using the WineScan® at the oenological laboratory from ACW. The WineScan® is an instrument based on the Fourier transform infrared spectroscopy that allows the analysis of the major grape quality and wine component parameters (FOSS NIRSystems, USA). The fruit composition parameters included soluble solids content (° Brix), pH, titratable acidity (g/L) expressed as tartaric acid, tartaric acid (g/L), malic acid (g/L) and yeast assimilable nitrogen (YAN in g/L).

6. Wine composition

Microvinification was conducted identically for all lots by the same winemaker. For each location, 150 kg of grapes were manually harvested and used for wine making. The same fermenting yeast was added for all lots (F10, Laffort). Diammonium phosphate (300 mg/L) was added to each must to ensure complete fermentation. In order to achieve a similar wine alcohol content for sensory analysis, some lots were chaptalized to obtain the minimal sugar content of 22,7 °Brix. Chaptalization was used in the protocol so that conditions closest to practical use were simulated. Malolactic fermentation was performed for all wines. Before bottling, the free SO_2 content was adjusted to 37 mg/L.

Wine composition was assessed at bottling using infrared spectroscopy. The analysed parameters were the following: pH, dry extract (g/L), content of malic, lactic and tartaric acid (g/L), titratable acidity (g/L) expressed as tartaric acid, volatile acidity (g/L), glycerol content (g/L), ethanol content (%v/v), anthocyanin content (mg/L), colour intensity index and total polyphenol index. The wine colour density (absorbance units) is defined as the sum of absorbance measured at two wavelengths, 420 nm and 520 nm . The total polyphenol index is calculated based on wine absorbance at 280 nm (Ribéreau-Gayon *et al*., 1972). The anthocyanin content is evaluated using a decoloration step with sulphur dioxide and measuring the difference in wine absorbance at 520 nm (Ribéreau-Gayon and Stonestreet, 1965).

7. Sensory analysis

Sensory analysis of the experimental wines was conducted two months after bottling by a panel of 13 experienced tasters drawn from the ACW staff members (ages ranging between 24 and 62 years). The panel was trained in two 3-hour sessions to describe the aromas and the mouthfeel properties of wines. Reference standards were prepared to represent the descriptors and were used during training to « calibrate » the panel. During test sessions, wines were characterized by conventional profile (ISO 13299, 2003). They were evaluated in duplicate according to a completely randomized design (Williams Latin square). Each wine was descriptively assessed for its appearance, nose and palate. The panellists rated the intensities of 23 sensory attributes on computer using FIZZ software (Biosystèmes, Couternon, France). An overall appreciation note was also given. Wines were evaluated on an unstructured linescale from 0 (absence of the sensation) to 10 (very intense perception of the sensation). Wine scores were obtained by summing scores of all judges for the two replicates.

8. Data analysis

Location means were used and Duncan test was performed to assess significant differences using the XLSTAT Version 2007.5 (Addinsoft, Paris, France). The relationship between variables was analysed by Simple Linear Regression and Pearson's Coefficient of Determination (R^2). The significance of this coefficient is indicated with asterisks: $p<0.05$ (*), $p<0.01$ (**) or $p<0.001$ (***). Multivariate analyses, such as Principal Component Analysis (PCA), were carried out on the sensory data using the R software (R Development Core Team, Vienna, Austria). The objective of PCA is to sum up and simplify the data for visualization by reducing the dimensionality of the dataset (Jolliffe, 2002).

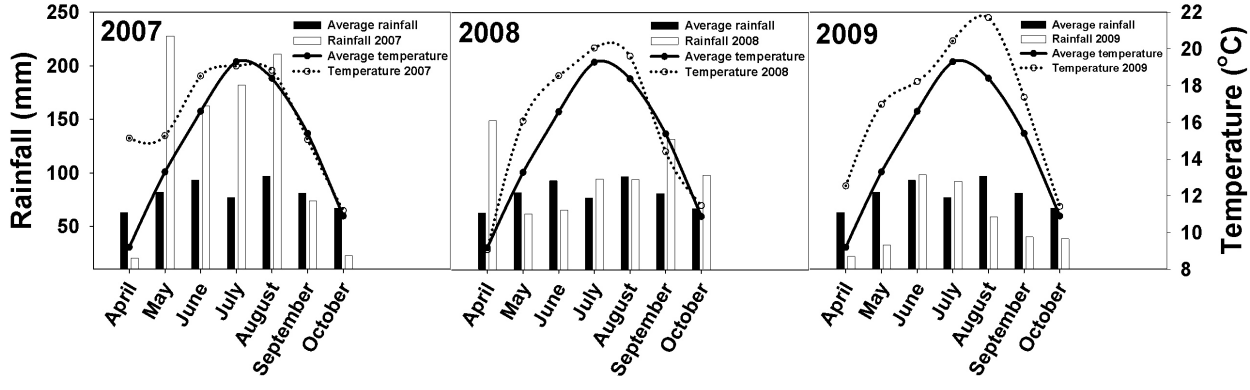


Figure 1 – Monthly rainfall and mean temperature for 2007 to 2009.
Data were collected from the Pully weather station. Average values (1961-1990) are depicted for comparison.

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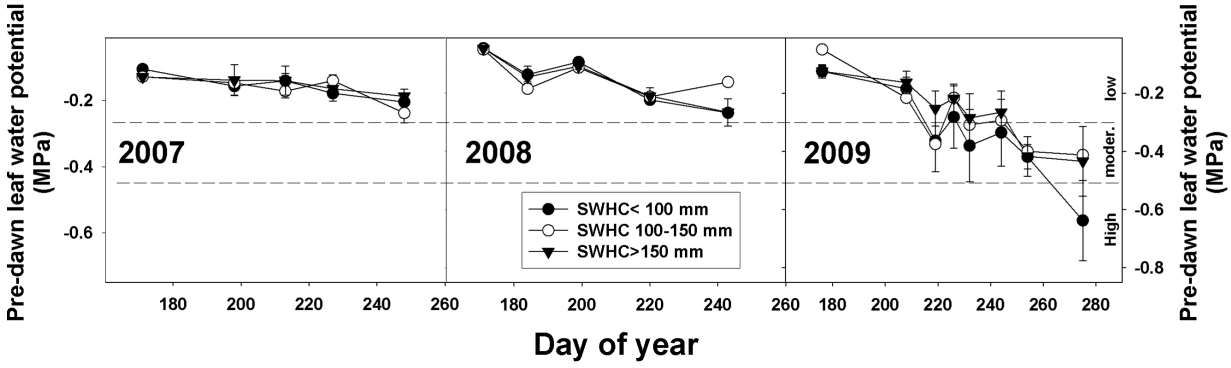


Figure 2 – Seasonal evolution of the pre-dawn leaf water potential as affected by the soil water holding capacity (SWHC).
Water stress levels according to Carbonneau (1998) are depicted on the right of the graph. Vertical bars: standard error.
Gamaret, La Côte region, 2007-2009. Low SWHC = 5n, medium SWHC = 1n and high SWHC = 4n.

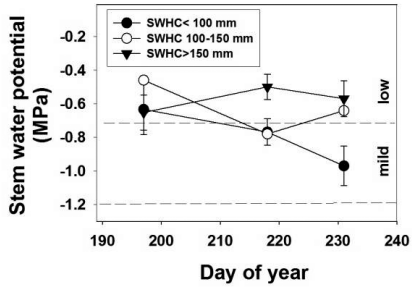


Figure 3 – Evolution of the stem water potential as affected by the soil water holding capacity (SWHC).
Water stress levels according to Choné (2001) are depicted on the right of the graph. Vertical bars: standard error. Gamaret, 2009.
Low SWHC = 4n, medium SWHC = 1n and high SWHC = 3n .

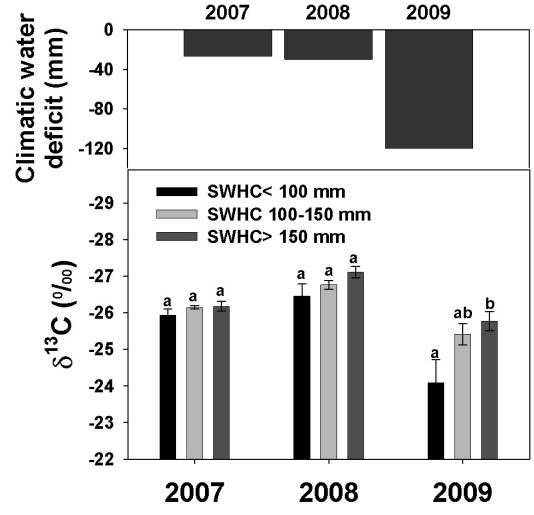


Figure 4 – Climatic water deficit (rainfall - PET) from the Pully weather station during the grape ripening phase (August to September).
Carbon isotopic composition in must sugars ($\delta^{13}C$) at harvest in the different SWHC classes. Means with the same letters are not significantly different at P<0.05. Gamaret, 2007-2009. Low SWHC = 6n, medium SWHC = 4n and high SWHC = 13n.

RESULTS

1. Grapevine water status

Results of the evolution of the pre-dawn leaf water potential are presented in Figure 2. Only in 2009 did vines on different SWHC show a differentiated water status although differences were not significant.

Stem water potential was measured on eight locations during the 2009 season (Figure 3). After veraison (day 220 of the year), values of stem water potential were significantly lower in locations with low SWHC as compared to those with high SWHC.

Figure 4 depicts the results for the carbon isotopic composition on grape sugars at harvest in the different SWHC classes in 2007-2009. Less negative values were observed during the dry 2009 vintage. During 2007 and 2008, there was no difference in $\delta^{13}C$ among the three classes of SWHC. On the other hand, in the dry 2009 vintage, $\delta^{13}C$ values were significantly lower (absolute value) on must sugars from sites with low SWHC and the highest values were found on high SWHC sites.

In 2009, seasonal average values of pre-dawn leaf and stem water potential were closely related to $\delta^{13}C$ (R^2=0.55*** for pre-dawn leaf water potential and R^2=0.85*** for stem water potential) (data not shown).

2. Fruit parameters at harvest

Vine water status had no influence on TLA and vine vigour (data not shown).

Only 2009 was dry enough to allow discrimination of fruit at harvest between the different SWHCs.

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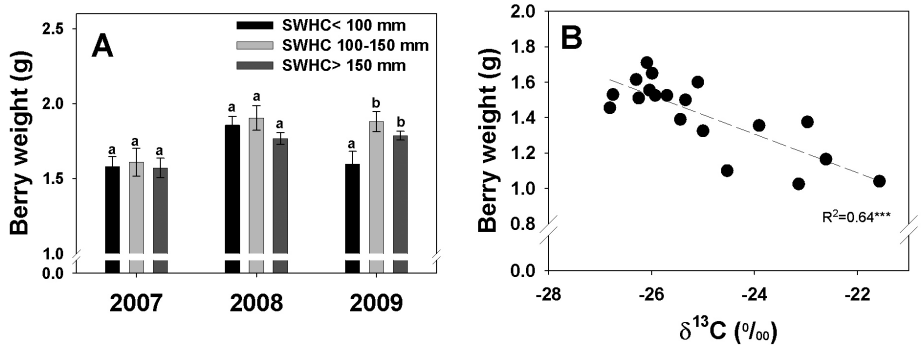


Figure 5 – A) Berry weight at harvest for the three vintages (2007 to 2009) in relation to soil water holding capacity (SWHC). B) Relation between carbon isotopic composition ($\delta^{13}C$) and berry weight. Gamaret, 2009.

Means with the same letters are not significantly different at P<0.05. Low SWHC = 6n, medium SWHC = 4n and high SWHC = 13n.

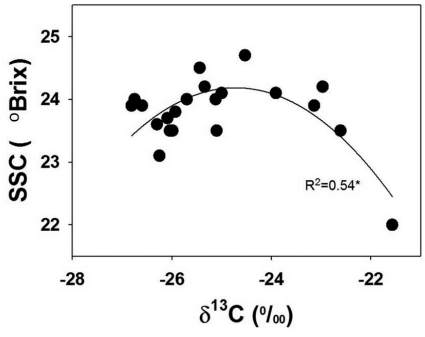


Figure 6 – Relation between soluble solids content in berries and the carbon isotopic composition of sugars at harvest. Gamaret, 2009.

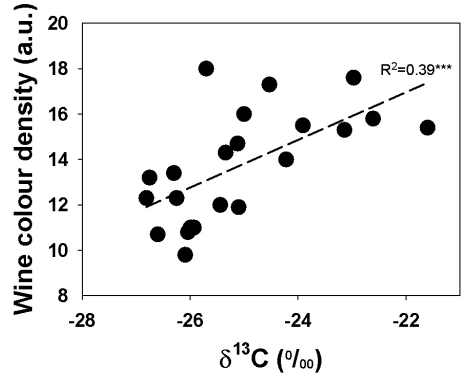


Figure 7 – Relation between $\delta^{13}C$ and wine colour density. Gamaret, 2009.

Therefore, the analysis of the effect of vine water status on fruit composition was considered only for the 2009 season. Berry weight was the only fruit parameter correlated to vine water status (Figure 5). Berry weight was reduced by as much as 30 % under conditions of water stress. Average berry weight was significantly different between SWHC classes . The relationship between grape SSC at harvest and the vine water regime ($\delta^{13}C$) was best described by a quadratic function (Figure 6). For other fruit parameters (pH, titratable acidity, tartaric and malic acid, and YAN), no significant correlation with $\delta^{13}C$ was observed (data not shown).

3. Wine characteristics

As for fruit composition, only 2009 values are discussed here, since for 2007-2008 vine water status had no influence on wine characteristics. The only analytical value that was correlated to vine water status was the wine colour density (Figure 7). None of the wine sensory attributes was found to be significantly correlated with the $\delta^{13}C$ (Figure 8). However, the data presented in Figure 8 show that drier conditions in the vineyard tended to be associated with positive wine aroma descriptors (spicy and fruity).

DISCUSSION

1. Vine water status

Carbon isotopic composition ($\delta^{13}C$) in grape sugars at harvest was closely correlated to plant water relations during ripening as assessed by water potential measurements. The results complete and confirm observations made by several authors on different varieties and in different pedoclimatic conditions (Gaudillère *et al.*, 2002; Tregoat *et al.*, 2002; De Souza *et al.*, 2005; Van Leeuwen *et al.*, 2009). $\delta^{13}C$ is an appropriate tool for the assessment of plant water status, as previously discussed by Condon *et al.* (2004). In the conditions of this study, vine water status was dependent on vintage. Only in 2009 did the $\delta^{13}C$ discriminates significantly between vineyards from different SWHC classes. Zufferey and Murisier (2007) have shown the important role of SWHC for Chasselas water status in Vaud vineyards.

This study also showed that $\delta^{13}C$ from berry sugars at harvest can be a valuable tool in terroir studies for the evaluation of vine water status between locations. Its advantage lies in the fact that it does not require any field measurements and can be measured directly on must

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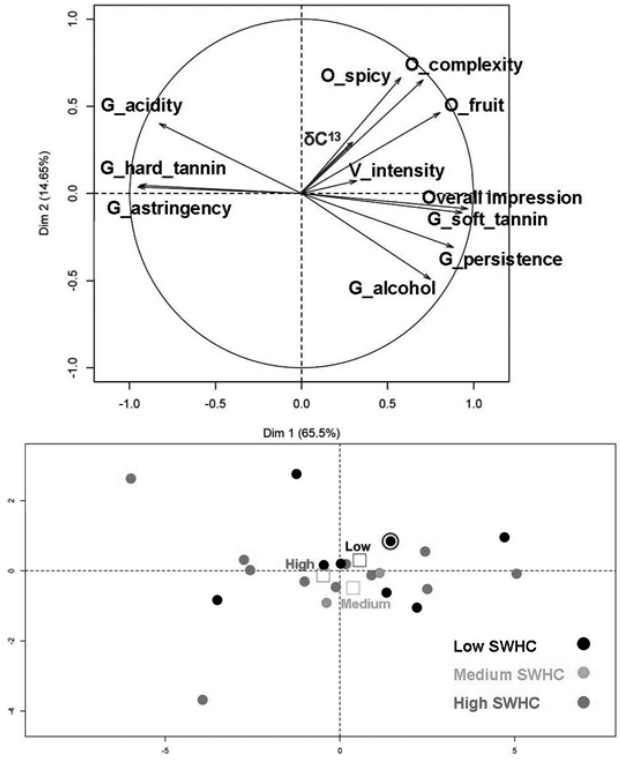


Figure 8 – PCA representation of the main sensory variables and the position of wine produced from different locations.

Sensory variables: V_ = visual, O_ = olfactory, G_ = gustatory. $\delta^{13}C$ was added to the analysis as illustrative variable. None of the sensory variable was correlated to $\delta^{13}C$. Gamaret, 2009. The blue circle indicates the location where the most severe water deficit was registered ($\delta^{13}C$ = -21.5‰). Squares represent barycentre of each SWHC.

samples. Thus, a large number of sites can be sampled at low cost in order to assess vine water uptake conditions between veraison (onset of maturity) and harvest. This is not the case with water potential measurements, which is a more time consuming and labour intensive approach.

2. Fruit parameters

It is known that water status affects the physiological behaviour of vines. Several studies have shown that changes in vine water status have an effect on grape composition by influencing yield, vegetative growth, canopy microclimate and fruit metabolism (Tregoat *et al*., 2002; Shackel, 2007; Intrigliolo and Castel, 2008). In the present case, vines were subjected to different water regimes as a result of the variation in soil water holding capacity. Berry weight was found to be influenced by the level of water deficit. Corroborating studies under non-irrigated conditions showed the role of water stress on berry size (Tregoat *et al*., 2002; Medrano *et al*., 2003; Koundouras *et al*., 2006). These effects were confirmed in irrigation trials by Ojeda *et al*. (2002), Salon *et al*. (2005) and Chaves *et al*. (2010).

The water status of grapevines affected the SSC in berries. Water restriction has been reported to have both negative and positive effects on the accumulation of soluble solids in berries. A positive effect could be due to its impact on carbon partitioning within the plant. Under mild water stress, fruits become the major sink for photosynthates (Lebon *et al*., 2006) especially in the absence of vegetative growth. Furthermore, water restriction reduces berry size and hence, by concentration, increases the SSC. On the other hand, the negative effects of a water restriction are mainly explained by a severe reduction in photosynthesis. Under low to moderate water deficits, stomata closure is among the first processes occurring in leaves, resulting in a reduced carbon assimilation (Chaves *et al*., 2003). During moderate water deficit, the positive effects of water deficits outweigh the negative ones. When $\delta^{13}C$ values were under -24‰, SSC increased proportionally with increasing water stress. Conversely, when water stress became excessive, SSC decreased as a consequence of reduced photosynthesis and transport of assimilates. The location where vines were exposed to the most severe water restriction ($\delta^{13}C$= -21.5‰) showed drought symptoms such as defoliation. As a result, this location produced grapes with the lowest SSC. Tregoat *et al*. (2002) and Van Leeuwen *et al*. (2009) reported that the highest grape SSC at harvest was reached when water deficit was mild.

3. Wine chemical and sensory parameters

Water deficit had beneficial effects on the Gamaret wine colour. The improved colour of red wines may be the result of higher anthocyanin biosynthesis in the berry as a consequence of water deficit (Esteban *et al*., 2001; Castellarin *et al*., 2007; Koundouras *et al*., 2009). Numerous studies have reported the positive effect of water restriction on wine colour (Roby *et al*., 2004; Salon *et al*., 2005; Koundouras *et al*., 2006; Chalmers *et al*., 2010). Although the trend existed, the impact of vine water status on wine colour was not detected during sensory evaluation. This is probably due to the generally high level of coloration of Gamaret wines, which may explain the difficulty for panellists in evaluating the different levels of colour intensity.

In contrast to Koundouras *et al*. (2006), no clear relation between water deficit and wine sensory attributes was observed. None of the wine sensory attributes were significantly correlated with vine water status ($\delta^{13}C$). However, wines made from vines with low water status seemed to show a higher score for the « spicy » attribute. Although not significant, it was rather the olfactory attributes (aroma) of wines that were found to be positively influenced by low water status. Matthews *et al*. (1990)

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and Hakimi-Rezaei and Reynolds (2010) have also reported the positive effect of low vine water status on wine aroma. No relationship was observed between the overall wine quality and vine water status.

Although the location with the most severe water stress gave grapes with low SSC, the wine produced from this location was still well noted during sensory analysis. Therefore, the potential of red grapes can still be excellent in spite of a severe water deficit slightly restricting the amount of sugars in the must. This is probably due to the fact that the quality of red wine depends more on its level of phenolic compounds than on sugar levels in grapes at maturity (Matthews *et al*., 1990).

CONCLUSION

Most studies dealing with vine water status and wine production are irrigation trials. On the contrary, this study was conducted under field conditions with non-irrigated farming methods. Variations in vine water supply imposed by the soil and its impact on grape and wine quality were investigated. This work clearly showed the link between soil water holding capacity and vine water status on a dry year. It is often argued that, unlike most plant crops, grapevines are usually grown best under sub-optimal water conditions in order to get high fruit quality for wine making. According to these findings, vine water status influenced berry size and wine colour during the dry 2009 vintage. However, no relation was observed between vine water status and the sensory characteristics of wines. Under the conditions in Vaud, although the ability of soil to modulate vine water status was shown to affect berry size, it was not of primary importance in determining the sensory quality of wines. Consequently, in the Vaud region with generally sufficient rainfall during the growing season, soil water holding capacity and vine water status would appear not to be the major environmental factors (terroir) responsible for the differences in wine sensory characteristics.

Acknowledgments: The authors would especially like to acknowledge L. Germanier for winemaking. Warmest thanks also go to K. Pythoud for helping in the collection of vine physiological data. Jill Béchet is also acknowledged for her assistance with the English translation.

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