THE ROLE OF SOIL WATER HOLDING CAPACITY AND PLANT WATER RELATIONS IN ZONE/TERROIR EXPRESSION

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Summary

The spatial variability in soil type and depth and water holding capacity is very high in many viticultural regions of the world. Differences in rooting depths and water extraction profiles and their seasonal dynamics add additional variability and it is extremely difficult to deduct direct causal relationships between these factors and fruit composition even within small units of climatic zones, and much less so over larger climatic trans-sects. The influence of water status on grape composition has been studied intensively for many years, yet indirect effects caused by changes in plant water status have been largely neglected. For example, vineyard sites with limited water supply will be more prone to early leaf drop causing substantial changes in the light environment of the fruit, which in itself will change fruit temperature. Additionally, there is almost certainly a different link between plant water status and fruit and wine composition for red and white cultivars and within each respective group between varieties of different geographic origin. Another unresolved problem is the coupling of soil to plant water status. Many plant water status indicators such as stem, or midday or pre-dawn (Ψ_{PD}) leaf water potential are difficult to link to quantitative soil water data. We have recently started to use the concept of total transpirable soil water (TTSW) and the fraction thereof (FTSW), originally proposed for herbaceous plants, to evaluate the coupling between soil water availability and plant water status measurements for contrasting vineyard sites. Even for soil water holding capacities over the root profiles between 380 and 100 L/m^2, and a TTSW varying from 50 to 175 L/m^2, respectively, we found a single common relationship between Ψ_{PD} and FTSW for all vineyards, irrespective of water extraction profiles and canopy systems (Gruber and Schultz 2004 in press). This relationship has also been proven stable across different wine regions in Europe. This system may provide a platform to better link quality parameters to plant and soil water status. Some recent results also suggest that indirect effects of changes in water supply may be more important than previously thought for fruit composition. These effects seem not restricted to changes in canopy microclimate or co-limiting factors such as nitrogen, but seem to extend to substances influencing micronutrient metabolism of yeasts, which may alter aromatic expression. It is clear and has been proven many times that water relations are important in quality formation and in the expression of terroir characters, yet it is still difficult to provide conclusive linkages between all the involved parameters.

Water and “terroir” expression, a question of red and white

In areas where viticulture is mostly irrigation-dependent, regulation of grapevine water relations is considered an important tool in quality management (among others, Hardie and Considine 1976, Bravdo et al. 1985, Matthews and Anderson 1988, Matthews et al. 1990, Esteban et al. 2001, Kennedy et al. 2002). There is a significant body of literature dealing with the effects of water relations on the composition of red grapes (i.e., all previously cited and many more), especially on phenolic compounds; yet information of the effects of plant water status on the composition of white varieties is scarce (van Zyl 1984, McCarthy and Coombe 1985).

Contrary to red varieties, where some degree of deficit is termed beneficial in regulating the ratio between vegetative and reproductive growth (Matthews et al. 1987) and as a consequence favouring the formation of phenols including colour components (Hardie and Martin 1989, Dry et al. 2001, van Leeuwen et al. 2003), white varieties in general seem more sensitive to stress periods and can show negative compositional changes (Christoph et al. 1998). These may be related among other possibilities to reduced nitrogen availability as a co-factor in developing water deficits.

Nitrogen is a difficult parameter in this context, since on the one side it is necessary for growth and the amino acid fraction is needed by the yeast to accomplish fermentation. On the other side there is a negative correlation between amino acid concentration and the formation of the higher alcohol 2-phenyl ethanol and it's ester, usually associated with fruity characteristics in white wines ((Maigre et al. 1995, Goldspink und Frayne 1995). Additionally, due to maceration times and fermentation on the skins, nitrogen is almost completely extracted from the berry skins in red grape processing which is not the case for white grapes. Thus, for white grapes, nitrogen and water status may be equally important for "terroir" characteristics, although it is extremely difficult to define an optimum here (Peyrot des Gachons et al 2000, Choné 2001).

Grapevine water status, stability or variability?

Aside of Mediterranean-type, low summer rainfall climates with a more or less continuous decline in water availability over most of the growing season, temporary water deficits are also commonly occurring in temperate, summer rainfall regions, specifically on vineyard sites with shallow soils and low water holding capacity (Füri and Kozma 1977, Beran 1986, Lebon 1993, Giorgessi et al. 1998, Morlat et al. 1992, van Leeuwen and Seguin 1994). As compared to an irrigated vineyard situation in moderate or even hot climates, the natural cycles of stress and relieve can be much more pronounced albeit completely unpredictable in frequency, duration and severity in these areas and are naturally part of the 'terroir' and the year to year variation in wine quality. As compared to most standard irrigation practices where soil moisture is replenished at very moderate soil water potentials (somewhere between 0.05 and 0.2 MPa, McCarthy 1995, Grant 2000), vines in these situations suffer substantial water deficits almost every year. Figure 1 shows a compilation of data on the plant water status of three varieties from different climatic regions and vineyards differing in water holding capacity within a given region. There are three examples added from irrigated vines for each of the varieties. It is clear that irrigation stabilises the plant water status (expressed as pre-dawn water potential) at a level rarely found naturally over the growing season in these areas. Of all the data shown, at least the data from the Loire valley in France and the Rheingau in Germany can be considered coming from very cool climate regions (Fig. 1). Additionally, vintages such as 1999 and 2002 the source for the Rheingau data were not considered to be particularly dry. Figure 1 also shows, that the differences in water status between vineyards within each of the regions is larger than the differences in general water status between different climate zones. It is also clear, that variability in water status during a particular season increases from warm to summer rainfall climates which adds another complication to the causal chain from soil water holding capacity to wine quality, respectively "terroir" expression.

Many plant water status indicators such as stem, or midday or pre-dawn (Ψ_{PD}) leaf water potential are difficult to link to quantitative soil water data. We have recently started to use the concept of total transpirable soil water (TTSW) and the fraction thereof (FTSW) to evaluate the coupling between soil water availability and plant water status measurements for contrasting vineyard sites. Even for the two sites shown in Figure 1 (right panel, deep loess and shallow soil), where soil water holding capacities over the root profiles range from 380 to 100 L/m^2, and TTSW varies from 175 to 50 L/m^2, respectively, we found a single common relationship between Ψ_{PD} and FTSW for all vineyards, irrespective of water extraction profiles and canopy systems. This relationship has also been proven to be stable for different vineyards across Europe (Gruber and Schultz 2004 in press). Thus, provided that some quantitative data on the relation between Ψ_{PD} and grape composition exist, we may be able to improve our evaluation of the role of water holding capacity and wine quality in the future using this system.

Secondary effects of changes in plant water status

One much underrated factor in the evaluation of grapevine water relations and grape composition are the secondary effects of differences in fruit zone micro-climate due to differences in growth and/or timing of leaf senescence, particularly in the fruiting zone. For instance, in most studies water stress provoked decreases in acidity and increases in juice pH probably caused by an increased rate of malate respiration (Matthews and Anderson 1988, Ginestar et al. 1998). These variations can also be found between vineyards of the same region differing in water status (Lebon 1993, van Leeuwen and Seguin 1994) and as a consequence differing in leaf area development and the amount of leaf drop during stress (Lebon 1993, Winkel and Rambal 1993). Thus, whether observed compositional changes are due to water deficit *per se* or are a secondary effect of changes in fruit zone microclimate is unclear, since both effects are coupled. They are, however, certainly important in the expression of "terroir".

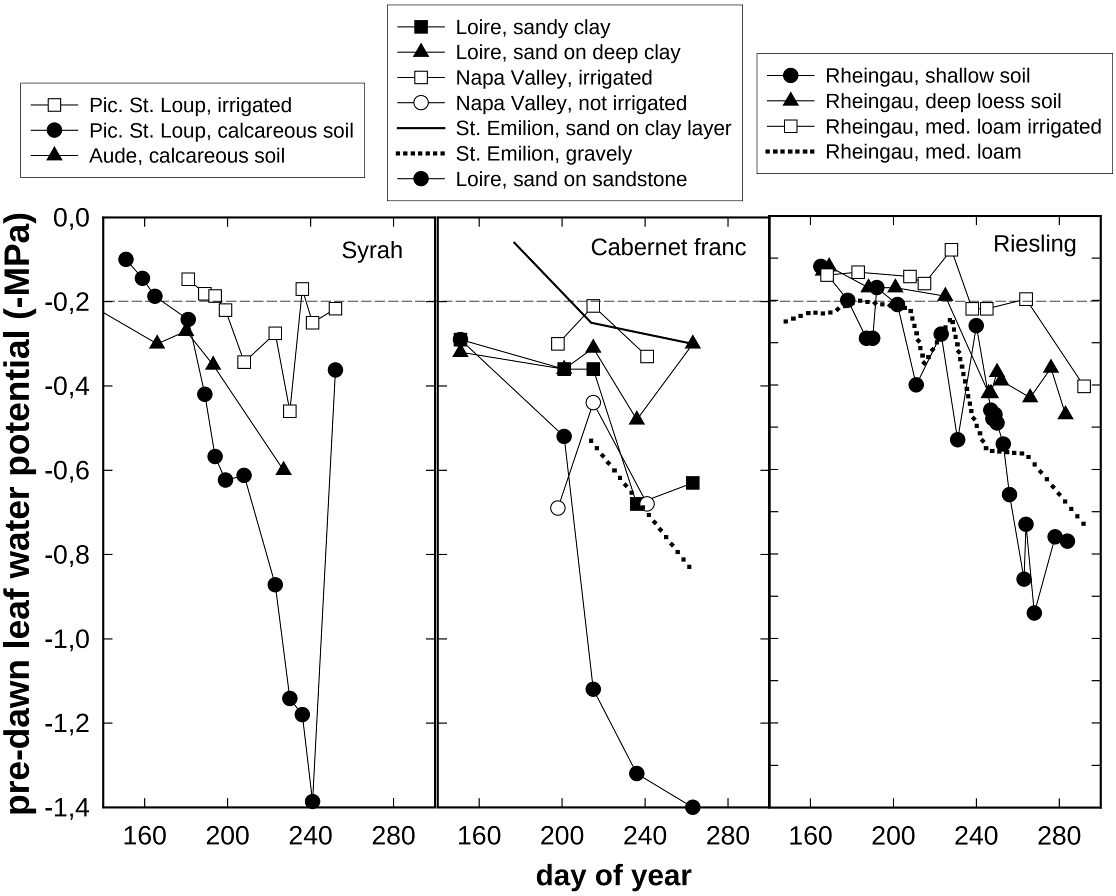

Figure 1: Seasonal courses of pre-dawn water potential from different vineyard sites in different growing regions and climates. Left panel data are for the variety Syrah from the Pic St. Loup area north of Montpellier (adapted from Schultz 2003) and the Aude region (adapted from Winkel and Rambal 1993), both in southern France. Central panel data are for the variety Cabernet franc from different vineyard sites in the Loire Valley (adapted from Morlat et al. 1992) and St. Emilion (adapted from van Leeuwen and Seguin 1994), France. Additional data are added from a trial in Napa Valley, California for an irrigated treatment and a water deficit treatment after veraison (Schultz and Matthews unpublished). Right panel data are for the variety White Riesling from the Rheingau region in Germany collected over two years (open symbol and dotted line 1999, closed symbols 2002).

Recent experiments with the grape variety Riesling have demonstrated, that these secondary effects are important for the formation of pigments (also in white grapes), glyco-conjugates and certain phenolic compounds (Castellarin et al. unpublished, Piccoli et al. unpublished) and that they can persist even after grape processing and fermentation. An increase in glyco-conjugates may reflect increases in monoterpene content and some secondary alcohols such as 2-phenyl ethanol, which have been demonstrated to respond to changes in microclimate in this variety (Zoecklein et al. 1998), but excessive fruit exposure can also cause undesirable aromas, such as increases in TDN (1,16-trimethyl-1,2-dihydronaphtalene), the kerosene-like character of Riesling (Marais et al. 1992). In fact, recent results from an irrigation trial showed that a balanced water status can improve the ageing capacity of white wines, even in the short term (months) and can slow down the formation of negative aroma characters (table 1). In this trial, bottled experimental wines from a steep slope vineyard were artificially aged (3 months at 32 °C) and compared to the "non-aged" control, both for an irrigated treatment and the control receiving only natural precipitation. In all wines ageing reduced positive aroma attributes and increased the negative ones, but more so for the wines not receiving supplemental water.

For red varieties, the story may be entirely different. Sensory panels have rated wine produced from sun-exposed clusters higher than those produced from shaded fruit and the response in grape coloration is usually judged positive (Morrison and Noble 1990).

Table 1: Sensory evaluation of experimental wines from previously irrigated White Riesling vines and those only receiving natural precipitation from the 2003 vintage with and without artificial ageing. Wines were rated on a scale from 0-5 by 115 judges on September 7, 2004.

attribute	irrigated		non irrigated	
	not aged	artificially aged	not aged	artificially aged
positive aroma attributes	3.45	2.37	2.85	1.93
negative aroma attributes	2.1	2.61	2.43	3.79
acidity	2.35	2.95	2.43	2.95
Bitterness	2.4	2.63	2.7	2.87

The yeast as a mediator of plant water relations and "terroir" expression?

The expression of quality of a particular site cannot be judged without considering the reaction of yeast to the juice matrix. One factor obviously influencing yeast viability and fermentation velocity is nitrogen. This can be supplemented before fermentation but it is not clear if differences in the form of nitrogen supplied matter with respect to the formation of secondary compounds in the wine. Water holding capacity and soil type certainly play a role in the nutritional status of the grapes at maturity but this may not be limited to nitrogen alone. For example Werwitzke (2003) found, that certain yeast strains did not metabolize some micro nutrients during fermentation of juice from water stressed vines, but were capable of doing so when fermenting juice from the irrigated treatments. This example just shows the complexity of the interactions involved in the expression of a certain wine characteristic attributed to a certain "terroir".

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