Intra-block variations of vine water status in time and space

Variations intra-parcellaires temporelles et spatiales du régime hydrique de la vigne

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Abstract: Vine water status was measured on 96 plots of three vines inside a vineyard block of 0.28 ha during three years: 2003, 2004 and 2005. Three physiological indicators were implemented: stem water potential, carbon isotope discrimination measured on grape sugars at ripeness ($\delta^{13}C$) and canopy temperature measured by high resolution remote sensing. For stem water potential, measurements were taken on every single vine of each plot. The objectives of this study were to assess (i) the spatial distribution of vine water status inside a vineyard block, (ii) the temporal stability of this distribution from one date to another in the same year and (iii) the temporal stability of this distribution from one year to another.

The three physiological indicators provided accurate data of vine water status, as was shown by high correlation coefficients between stem water potential values and canopy temperature, as well as between stem water potential and $\delta^{13}C$. Vine water status maps obtained with either stem water potential data or $\delta^{13}C$ data showed similar patterns of spots that were more or less affected by water deficit stress, in relation to local soil water holding capacity.

Stem water potential was measured in September 2004 on two days in a row, one cloudy day and the next day with higher temperatures and clear conditions. Stem water potential values were highly correlated between these two days, which confirms the fact that stem water potential is mainly influenced by soil water status. However, stem water potential values were in average 0.08 MPa higher on the cloudy day, which shows a measurable but limited influence of evaporative demand on absolute stem water potential values. Both stem water potential values and $\delta^{13}C$ data were well correlated from one year to another, which shows a stability of spatial distribution of vine water status inside the block. This can be explained by the fact that soil water holding capacity is invariable from one year to another.

Surprisingly, stem water potential values measured at the same time between vine 1, vine 2 and vine 3 of each plot were not very well correlated, although the soil can be considered homogeneous inside a plot (3 m^2). This observation shows high variability in vine to vine water status, in relation to individual vine rooting depth and canopy size. Consequently, replicates on several adjacent vines have to be averaged out to obtain accurate vine water status data for each plot.

Key words: Vine water status, precision viticulture, carbon isotope discrimination, stem water potential

Introduction

Vine development and grape ripening are highly related to vine water status (van Leeuwen et Seguin, 1994). Vine water status depends on soil water holding capacity, evaporative demand and canopy architecture. It is considered as one of the main parameters of terroir (van Leeuwen *et al.*, 2004). Vine water uptake can be assessed either by measuring variations in soil water content, by establishing water balance models or by implementing physiological indicators. Over the last years, a series of physiological indicators of vine water status have been developed: carbon isotope discrimination measured on grape sugars (Gaudillère *et al.*, 2002), stem water potential (Choné *et al.*, 2001) and the difference between air and canopy temperature (Riou et Lebon, 2000). Vine water status is likely to show intra-block variability, depending on variations in soil water holding capacity and canopy size. Soil water holding capacity is related to vine rooting depth and soil texture. Canopy size varies with vine vigour. Vigorous vines do have high leaf area and, consequently, do have high transpiration rates. Few data is published about intra-block variability in vine water status. Vine water status also varies in time, during the season and from year to year. Day to day variations in vine water status may be related to day to day variations in evaporative demand, as a result of changes in solar radiation, temperature, wind speed and Vapour Pressure Deficit (VPD), or rainfall. Year to year variations in vine water status are great and they depend on water balance (Rainfall – Reference Crop Evapo Transpiration;

van Leeuwen *et al.*, 2004). The objectives of this research were to assess the accuracy of three physiological indicators (carbon isotope discrimination, stem water potential and the difference between air and canopy temperature) to show intra-block variations in vine water status and the stability in time of this spatial distribution, from day to day and from year to year. The advantages and drawbacks of each of these physiological indicators are discussed.

Materials and methods

Location, vine material and climatic conditions of the vintages

This study was carried out in a vineyard block of 0.28 ha located in Villenave d'Ornon (Bordeaux region, France) during the vintages 2003, 2004 and 2005. 2003 was a very warm and rather dry vintage, 2004 was rather dry with temperatures close to average values and 2005 warm and very dry (table 1).

Table 1 - Climatic conditions of the 2003, 2004 and 2005 vintage in Villenave d'Ornon

	2003	2004	2005
Average temperature April-September (°C)	19.9	18.2	18.9
Rainfall April-September (mm)	385	387	234

The soil of the block showed great variation in texture, ranging from gravel to heavy clay. Cultivar was *Vitis vinifera* L. cv Merlot grafted on Fercal rootstock, planted in 1991. Vine density was 6 250 vines/ha (1.6 m interrow spacing; 1 m inter vine spacing). Vines were vertical shoot positioned and hedged at 1.5 m. The block was dry farmed. Measurements were carried out on 96 plots of three vines each, regularly distributed over the block.

Physiological indicators implemented to assess vine water status

Carbon isotope discrimination ($\delta^{13}C$) was measured on grape sugar at ripeness according to Gaudillère *et al.* (2002). One sample was taken on each plot of three vines. Stem water potential was measured on one or two days during each year (Choné *et al.*, 2001). Six pressure chambers were previously calibrated and used simultaneously to take the measurements on each individual vine of the 96 plots (288 measurements) in less than 2 hours, between 12 et 14 hour solar time. Canopy temperature was measured on the same days as the stem water potential at 12 hour solar time with a thermal infrared camera (THERMACAM PM595, Flir systems Inc., Wilsonville, Oregon, USA) located in a helicopter on a stationary flight. Altitude (approximately 150 m) was calculated in order to obtain a pixel size of approximately 10 cm. Pixels located on the centre of the row of each plot were extracted from the images and averaged to obtain canopy temperature.

Geostatistics

Spatial distribution on the 96 plots was analysed by means of geostatistical analysis. Mapping was carried out by the ordinary-point kriging technique.

Results and discussion

Validation of the three physiological indicators to assess spatial distribution of vine water status

Vine water status was highly variable inside the block. On 7 September 2004, stem water potential ranged from –0.4 MPa (no water deficit stress) to –1.4 MPa (severe water deficit stress) and $\delta^{13}C$ from –24 to –26.5. Stem water potential was well correlated to $\delta^{13}C$ (Figure 1). The results were more ambiguous for the difference between canopy temperature and air temperature. As a result of the very small pixel size, that was needed to extract pixels with only canopy from the images, and the specification of the camera used, three images were necessary to cover the block. Poor results were obtained when the difference of canopy and air temperature extracted from the three images were correlated to either stem water potential or $\delta^{13}C$ (data not shown). However, fairly good correlations could be established between the canopy and air temperature extracted from plots located on one image of a part of the block and stem water potential on the same plots (figure 2). Vine water status maps were established from the results of $\delta^{13}C$ (figure 3) and stem water potential (figure 4) obtained on the 96 plots in 2004 and 2005. $\delta^{13}C$ and stem water potential maps show similar spatial distribution of vine water status. Surprisingly, high water deficit stress occurs on the part of the block were the soil is clayey and low water deficit stress there where the soil contains a high amount of gravel.

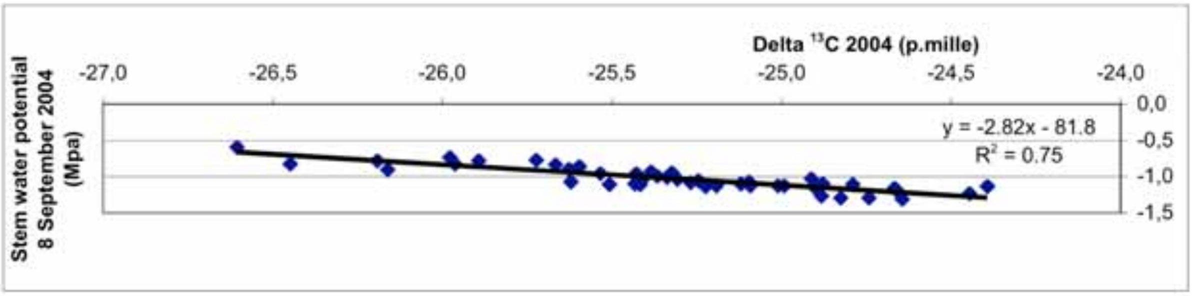


Figure 1 - Correlation between stem water potential and δ^{13}C on 8 September 2004 (data from 48 plots).

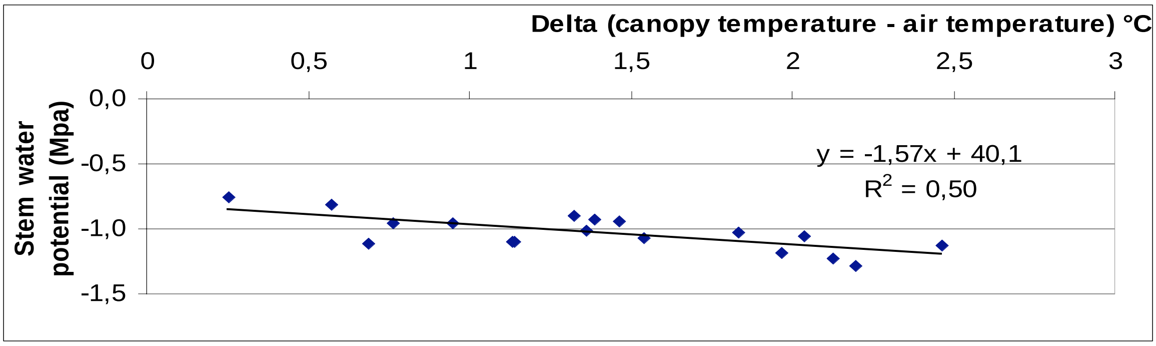
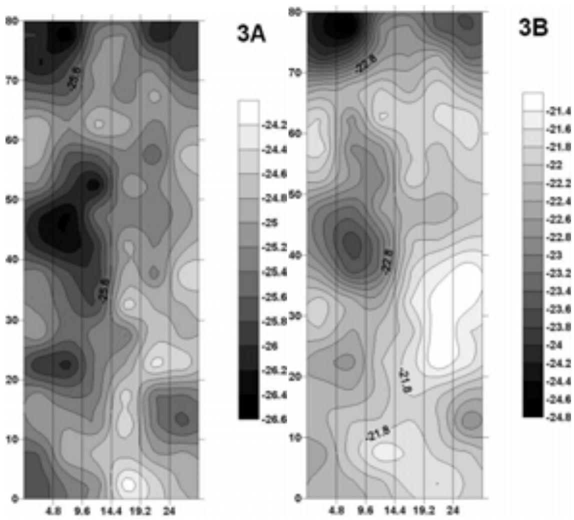


Figure 2 - Correlation between stem water potential and the difference between canopy temperature and air temperature measured by means of remote sensing on 8 September 2004 (data from 17 plots).



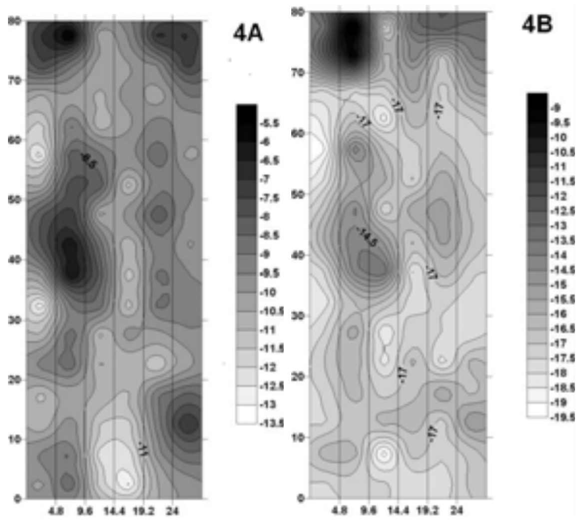


Figure 3 - Spatial distribution of vine water status in a vineyard block, assessed with δ^{13}C measured on grape sugars (3A: 2004; 3B: 2005).
Figure 4 - Spatial distribution of vine water status in a vineyard block, assessed with stem water potential (4A: 7 September 2004; 4B: 7 September 2005).

The effect of soil and climate on stem water potential

Three applications of the pressure chamber technique are widely used: daily leaf water potential, pre-dawn leaf water potential and stem water potential. Daily leaf water potential reflects the water potential of one individual leaf. It is highly dependant on the microclimatic environment of this single leaf. Consequently, daily leaf water potential is highly variable from one leaf to another on the same vine which makes it difficult to relate daily leaf water potential to physiological parameters like leaf transpiration (Choné *et al.*, 2001). Pre-dawn leaf water potential reflects whole vine water status at the end of the night, when this potential is in equilibrium with the wettest soil layer explored by the root system. Although pre-dawn leaf water potential is highly dependant on soil water availability, it is not always easily related to physiological parameters like transpiration or photosynthesis, because it is measured at a moment that the vine is not physiologically active in the absence of light. Stem water potential is easily related to physiological parameters like transpiration, because it reflects whole vine water status during the day, when the vine is physiologically active (Choné *et al.*, 2000). Stem water potential is a result of soil water availability, climatic parameters like evaporative demand and canopy architecture. In order to assess the relative impact of soil and climate on stem water potential values, measurements were carried out two days in a row with highly changing climatic conditions: 7 September 2004, which was a rather cool and cloudy day and 8 September 2004, which was a warm and sunny day (Table 2). Variability in stem water potential on the block during the same day can be attributed to variations in soil water availability, in relation to soil texture and rooting depth. Variations in stem water potential on each plot between the two days can be attributed to climatic parameters, because soil water availability and canopy architecture of each plot are not likely to vary from one day to another.

Table 2 - Climatic conditions on 7 and 8 September 2004 in Villenave d'Ornon (France)

	T-minimum (°C)	T-maximum (°C)	T-average (°C)	Insolation (mega Joule/m^2)
7 September 2004	16.7	27.2	22.0	11.52
8 September 2004	17.3	31.0	24.2	19.36

Stem water potential values obtained on 7 and 8 September 2004 were highly correlated (Figure 5). They showed a great intra-block variability, ranging from –0.4 MPa to –1.4 MPa on 7 September, as a result of variations in soil water availability among the plots. Average stem water potential values were 0.08 MPa lower on the 8 September 2004 (-1.02 Mpa) compared to 7 September 2004 (-0.94Mpa), showing a significant but limited effect of climatic parameters on stem water potential. These results show that although stem water potential values are not completely independent of climatic conditions, they do reflect mostly soil water availability.

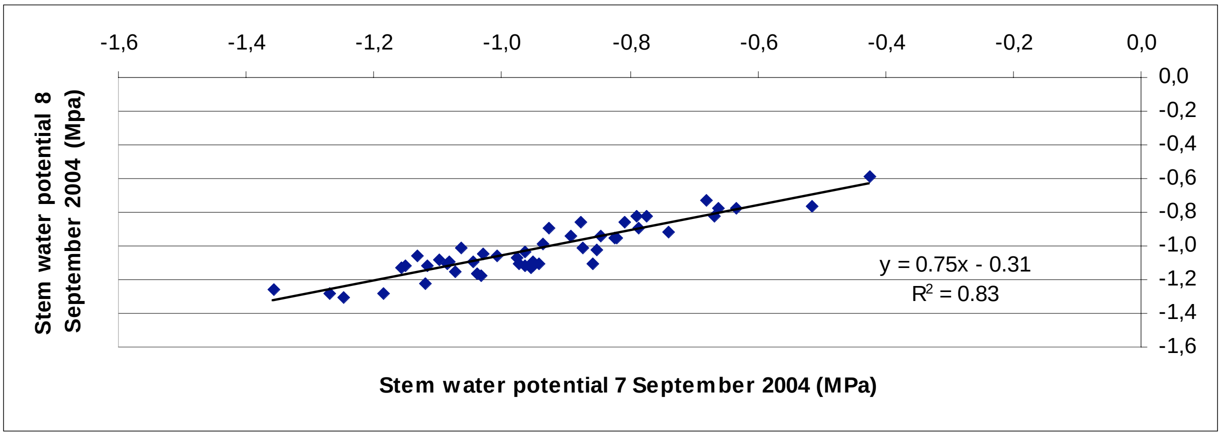


Figure 5 - Correlations between midday stem water potential values on 7 and 8 September 2004 (48 plots).

Stability of spatial distribution of vine water status from one year to another

$\delta^{13}C$ values (figure 6) and stem water potential values (figure 7) were well correlated from one year to another. This observation shows a good stability of the spatial distribution of vine water status over the years, although the intensity of the water stress can vary to a considerable extent depending on the climatic conditions of the vintage (rainfall and evaporative demand). On the studied block, vines planted on the zone with a gravely soil were every year less subjected to water deficits than vines planted on the zone with the clayey soil (figures 3 and 4).

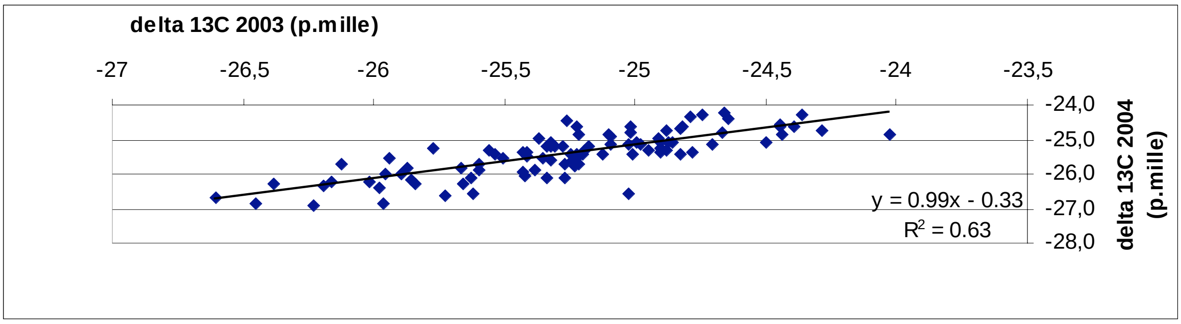


Figure 6 - Correlations between $\delta^{13}C$ values obtained in 2003 and 2004 (96 plots).

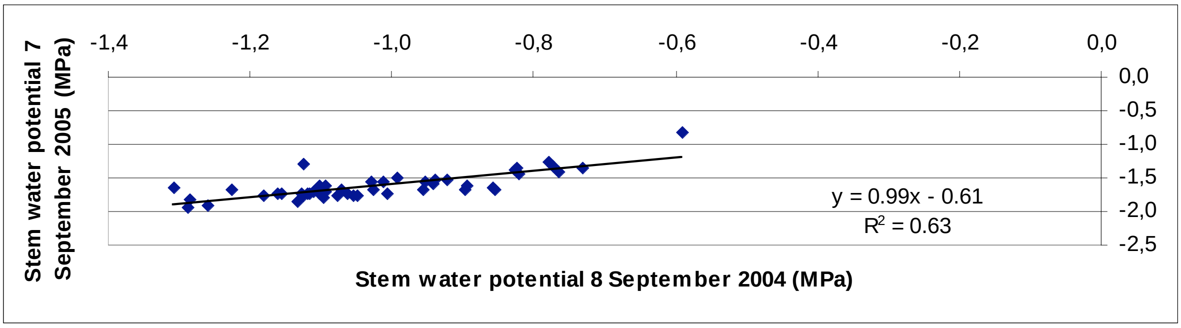


Figure 7 - Correlations between midday stem water potential values obtained on 8 September 2004 and 7 September 2005 (48 plots).

4) Vine to vine variations in water status

Stem water potential values obtained on vine 1 of every plot correlated poorly to stem water potential values obtained at the same time on vine 2 of every plot. Stem water potential values correlated also poorly between vine 2 and vine 3, as well as between vine 1 and vine 3 (table 3). This shows high vine to vine variability in stem water potential, although the soil could generally be considered homogeneous in the 5 m^2 explored by three adjacent vines. Similar results are reported by Choné *et al.* (2001). Vine to vine variability of stem water potential could be explained by variations in individual vine rooting depth, leaf area, hydraulic conductivity or the presence of wood diseases. Variations in rooting depth provoke variations in soil water holding capacity for each vine. Vine to vine variations in leaf area generate variations in transpiration rate and, consequently, variations in soil water depletion kinetics. Generally, physiological indicators of vine water status are implemented to assess availability of soil water for the vines. As a consequence of vine to vine variability in vine water status, plot values should always represent the average of measurements taken on several vines.

Table 3 - Correlations between stem water potential values obtained on vine 1, 2 and 3 of each plot.

Date	R^2 vine 1 - vine 2	R^2 vine 1 - vine 3	R^2 vine 2 - vine 3
7 September 2004 (n = 95)	0.36	0.26	0.44
8 September 2004 (n = 46)	0.35	0.26	0.38
7 September 2005 (n = 96)	0.40	0.31	0.29

Conclusion

Monitoring of spatialized vine water status by means of physiological indicators inside a vineyard block showed great variability, in relation with variations in soil texture. Stem water potential, $\delta^{13}C$ measured on grape sugars at ripeness and differences between canopy and air temperature measured by means of remote sensing allowed to map this variability. Stem water potential is the most precise indicator of vine water status. It can be used to monitor changes in vine water status over the season. The principal drawback of this technique is that its implementation is very time consuming. Six pressure chamber, operated by 12 persons were necessary to collect stem water potential values on 288 vines in less than two hours. $\delta^{13}C$ measured on grape sugars at ripeness is much easier to implement, but only one value is obtained per year on each plot, indication average vine water status from véraison through ripeness. Measuring differences between canopy and air temperature by means of remote sensing is a promising technique for the mapping of vine water status inside a vineyard block. Data is immediately available in spatialized form. However, this technique is not yet completely validated in vines. Image processing techniques have to be improved to extract the data exclusively from the canopy and to exclude pixels containing information from the soil. The assessment of stem water potential on two following days with contrasting climatic conditions showed that stem water potential values are mainly determined by soil water availability, although they are not completely independent on climatic conditions. Average vine water status of a block varies considerably from year to year depending on climatic parameters (rainfall, evaporative demand). However, relative intra-block distribution of vine water status showed a good stability over the years.

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