SPATIO-TEMPORAL ANALYSIS OF GRAPEVINE WATER BEHAVIOUR IN HILLSLOPE VINEYARDS. THE EXAMPLE OF CORTON HILL, BURGUNDY.

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Abstract

Hillslope vineyards show various and complex water dynamics between soil and plants, and in order to gain further insight into this phenomenon, 8 grapevine plots were monitored during three vintages, from 2010 to 2013, on Corton Hill, Burgundy, France. Plots were distributed along a topolithosequence from 330 to 270 meters asl. Grapevine water status was monitored weekly by surveying water potential, and, at the end of the season, using $\delta^{13}C$ analysis of grape juice. Soil profile of each plot was described and analysed (soil texture, gravel content, organic carbon, total nitrogen, pH, CEC). Soil volumetric humidity was measured weekly, using TDR probes. A pedotransfer function was developed to transform 2-dimensions Electrical Resistivity Imaging (ERI) into soil volume wetness and therefore to spatialise and observe variation in the Fraction of Transpirable Soil Water (FTSW). During the three years of monitoring, grapevines experienced great variation in water status, which ranged from low to considerable water deficit (as expressed by pre-dawn leaf water potential and $\delta^{13}C$ analysis of grape juice). With ERI imaging, it was possible to observe differences in water absorption pattern by roots, in different soils, and at different depth. In addition, significant differences were observed in grapevine water status in relation to variations in the physical characteristics of the terroir along the hillslope (i.e. the geo-pedological context, the elevation etc.). Grapevine water behaviour and plant-soil water relationships on the hillslope of Corton Hill have been extensively characterised in this study by ultimate technologies, allowing to present this terroir as a very interesting example for future generalisation and modelling of the hillslope vineyard water dynamics.

Keywords: Grapevine water stress, Electrical Resistivity Imaging, leaf water potentials, plant-soil water relations, FTSW, topographic effect, pedotransfer function.

INTRODUCTION

Water relationship between plant and soil is a key component of grape growing "terroir". That is because water dynamics in the continuum plant-soil-atmosphere influence the quantity and quality of fruits and consequently of wine (Van Leeuwen *et al.*, 2009). In Burgundy the exact role of this component and the grapevine soil-water relationships have been poorly investigated. It is not simple to describe the water characteristics of soil and to specify its effect on plants, especially over time. A practical solution to this problem, that could be adopted by both researchers and producers, is to measure electrical resistivity. This approach offers the possibility to make measurements rapidly on large surfaces and/or to easily reach soil depth of difficult access. These characteristics make the soil electrical resistivity a useful ancillary variable to spatialise other data such as soil volume wetness and soil water availability. The possibility to correlate soil volume wetness with electrical resistivity measurements has been shown by studies performed in the last ten years (Michot *et al.*, 2003, Srayeddin and Doussan 2008, Calamita *et al.*, 2012). Agricultural applications are still scarce but this method is very promising. Electrical resistivity surveys had already been used in grapevine research (Goulet and Barbeau, 2006, Courjault-Radé P. *et al*., 2010, André *et al.*, 2012) and are also proposed to grape growers by some companies. In this study we used a pedotransfer function we developed (see Brillante et al. 2014), to rely electrical resistivity to the soil volume wetness (SVW), to the available soil water (ASW) and to the fraction of transpirable soil water (FTSW). These models were developed using data collected over two years (2012-2013), in eight plots located on different soils on the hillslope of Corton Hill. An example of application is given in this proceeding where the models were applied to asses both in space and in time the variations of SVW, ASW and FTSW in two soils where grapevine experienced a significant difference water stress during the 2012 season.

MATERIALS AND METHODS

Simplified geology and pedology: Experimental vineyard (fig.1) is located on the south-exposed slope of Corton Hill, AOC Corton-Charlemagne, Burgundy, France. Corton Hill is located on the edge of the 'plateau Bourguignon' which corresponds to a stacking of sedimentary deposits dating from the Jurassic period. The base (250 m asl.) is formed by a compact and pure limestone dating from the Bathonian, locally named

“Comblanchien” with a thickness between 55 m and 70 m. Above, another limestone deposit is observed, dating from the Callovian with a thickness of approx. 15-25 m and locally named ‘Dalle nacrée’. Finally, up to the top of the hill (370m), a marl-limestone series dating from the Oxfordian is encountered. On this substratum soils are a mosaic of calcosol, calcisol and rendzines.

Monitoring scheme: It is composed of eight plots, hereafter named A, B, C, D, E, F, G, H (fig.1). Each of them is located at a different elevation along the slope, on different geological formations from the marl-limestone series (plots A, B, C, D, E) to the ‘Dalle nacrée’ (plots F, G, H). Plots (7 x 7 m square) contain 49 grapevines (*Vitis vinifera* L., cv. Chardonnay), grafted on SO4 rootstock. Grapevines have an age of 30-40 years.

Soil Analysis: Before the beginning of the monitoring a pit was dug in each of the study plots to allow the description of the soil profile, roots enumeration and soil sampling. Sixty-four soil samples were analyzed for the determination of texture, organic carbon, gravel amount, total nitrogen, calcium carbonate, pH and Cation Exchange Capacity.

Soil moisture measurements: Every plot is equipped with 3 access tubes for TRIME-TDR measurement of volumetric water content (SVW) (probe IPH/T3, IMKO, GmbH, Germany).

On each plot a row of 24 electrodes were planted at a distance of 0.75 m at the soil surface, for 2-dimensions electrical resistivity tomography (ERT) measurements (Multi-channel resistivitimeter Syscal Junior, Iris Instruments, France). Soil moisture and ERT measurements were performed on a weekly basis, from the beginning of July to the end of September. ERT and SVW data were collected each 10 cm along the soil profile. A preliminary calibration of the TDR for SVW estimate was performed using gravimetric method as a standard for SVW measurement. The universal calibration obtained by Topp et al. (1980) was found suitable for these soils ($SVWC_G = 1.06*SVW_{TDR}$, $0.05>p>0.01$, $R^2=0.53$, 18 degree of freedom, all soils together). ASW and the FTSW were computed as described in Pellegrino et al. (2006), but for each measurement depth rather than for the whole soil:

$$\mathrm{ASW}_{d,i} = \mathrm{SVW}_{d,i} - \mathrm{SVW}_{min,i} \quad (1)$$

$$\mathrm{TTSW}_{i} = \mathrm{SVW}_{fc,i} - \mathrm{SVW}_{min,i} \quad (2)$$

$$\mathrm{FTSW}_{i,d} = \frac{\mathrm{ASW}_{d,i}}{\mathrm{TTSW}_{i}} \quad (3)$$

where TTSW is the Total Transpirable Soil Water, *d* is the day of measurement; *i* represent the average depth of the 10 cm soil layer where soil water measurements were performed; *min* indicates the minimum value collected during the whole 2012-2013 measurement period, and *fc* indicates the day for which the soil is at field capacity.

Grapevine physiology measurements: Water status of grapevines was monitored weekly by means of leaf water potential (predawn and midday stem). The sample was composed of twelve leaves collected by simple random sampling (one leaf per plant).

RESULTS AND DISCUSSION

Substantial variability of soil texture was observed between the experimental plots, encompassing six textural classes, according to the USDA classification (fig. 1). Loam was the most common, followed by clay, while the sand textural class was rarely found in any layer of the eight sampling sites. Large differences were also found in the amount of gravels (which ranged from 1 to 70%), in the soil volume wetness (SVW) as measured by TDR (which ranged from 10 to 31% in volume) and in the electrical resistivity (ER) values (which ranged from 12 to 108 Ω·m). SVW was compared to ERI values in each cell of the resistivity grid and then every 0.1 m. The relationship between electrical resistivity and soil water depends on soil characteristics.

We used Multivariate Adaptive Regression Spline (MARS, Friedman 1991) approach to develop a pedotransfer function, published in Brillante et al. (2014) and to which the reader wanting more information should refer. This model predicts the SVW by ER and several soil properties (clay, silt, gravels, organic carbon) with an RMSE of 2%vol./vol. (figure 2). ASW and FTSW could not be estimated with satisfactory accuracy using SVW precited with this model, because of modelling error propagation. Therefore two other models were fitted to predict those variables, using a *random forest* algorithm for a regression approach that combines decision trees obtained by bootstrap procedures (see Breiman, 2001 for a detailed description of the method).

While SVW was compared directly to electrical resistivity values, the models for ASW and FTSW were obtained by relying those variables to analogue ones computed on electrical resistivity values as follow:

$$\mathrm{AERV}_{d,i} = \mathrm{ER}_{d,i} - \mathrm{ER}_{min,i} \quad (4)$$

$$\mathrm{FAERV} = \frac{\mathrm{AERV}_{d,i}}{\mathrm{AERV}_{max,i}} \quad (5)$$

where AERV is the acronym for Available Electrical Resistivity Variation and FAERV is for the Fraction of the Available Electrical Resistivity Variation, $\mathrm{ER}_{d,i}$ is the average of electrical resistivity values collected at each

10 cm wide cell grids at depth i, during day d and , $ER_{min,i}$ is the minimum recorded value of the electrical resistivity during the experiment..

Figure 3 shows the results of the random forest approach in modelling the ASW and the FTSW by respectively AERV and FAERV and several selected soil properties: gravels, clay, silt, and organic carbon. The predictive performances of the models were considered satisfactory enough for FTSW and ASW spatialisation using 2 dimension ER..

To apply those models we selected two plots, plots B and C, between the eight in our dataset. These plots were located within the same vineyard, and vines of the two plots were also in the same rows, but at 40 m of distance, along the slope. Plot B is located at a higher elevation than plot C. Both soils are calcaric-cambisoils on marls and their texture are similar. However, the amount of gravel differs: soil gravel content at plot C is always lower than 20% vol., with a median at approximately10% vol.. At plot B, it is always higher than 20% vol. with a median at approximately 28% vol.

In the 2012 vintage the climate was wet at the beginning of the season with about 100 mm of monthly rainfall for month from April to July, 58 mm in August and only 9 mm in September until the harvest. From veraison to harvest summer was dry for Burgundy with only 30-40 mm of rain, therefore grapevines experienced a moderate to strong water stress, as expressed by midday stem leaf water potentials (figure 5). The leaf water potentials reached their minimum at the end of the season, and were significantly different between the two plots.

Figure 6 shows the spatial distribution of the fraction of transpirable soil water at three dates: bunch closure, veraison and harvest. In general, the FTSW decreased during the season, and showed the lowest values in both soils at the end of the vintage. However spatial differences exist between blocs, and plot B showed greater variations than the plot C in all soil profile This was evident when looking at the layer between 0.8 m and 1 m that showed large variations in plot B and only slight in plot C. Further, at a depth higher than 1 m the FTSW in plot C was always near to zero because the SVW varied here only slightly probably because of a little absorption by roots was enough to void the reservoir. It seems that when soil is wet exploration by roots is reduced. This hypothesis is supported by the root profile in figure 4. Also lateral variations were present in the FTSW that were related to the position of grapevine along the ERI transect.

When the soil was generally wet the exploration by roots was reduced, indeed in plot B the FTSW showed greater variations than the plot C in all the soil profile.

CONCLUSIONS:

We developed three pedotransfer models to assess the soil volume wetness in soil and its availability to grapevines by electrical resistivity, in field conditions. These models were applied to monitor soil transpirable water dynamics for two vineyard plots that were near in space but that exhibited large differences stem leaf water potential. ER 2-dimension monitoring revealed great differences in the FTSW spatio-temporal patterns between those 2 plots, suggesting diverse root system development/functioning. The application of electrical resistivity to the study of the water relations of plant and soils is promising but further work is necessary to better understand the possibilities of investigation given by the application of those models.

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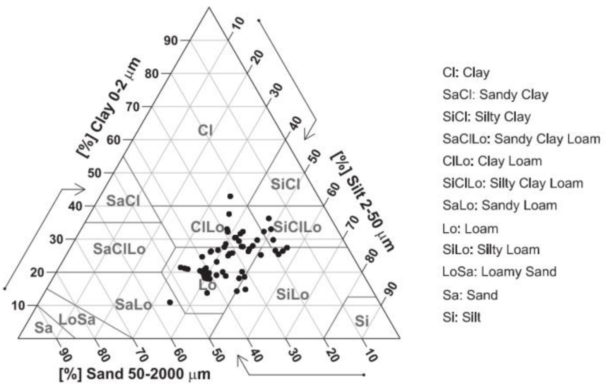

Figure 1: Soil texture across the 8 sampling locations. The USDA texture triangle is used.

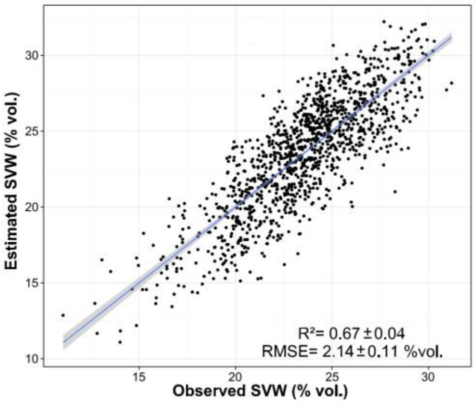

Figure 2: Predicted and observed data for the MARS model used to predict the SVW. Data are on a straight line with intercept zero and slope one.

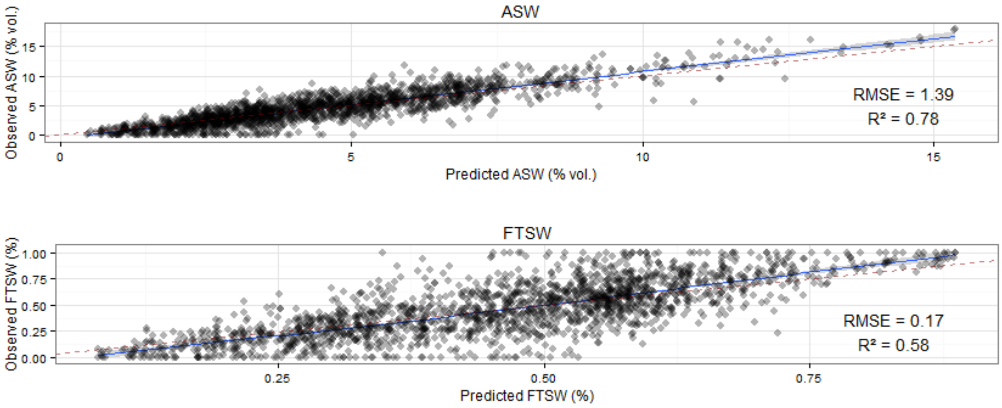

Figure 3: Predicted and observed data for the random forest approach used for predicting the ASW and the FTSW.

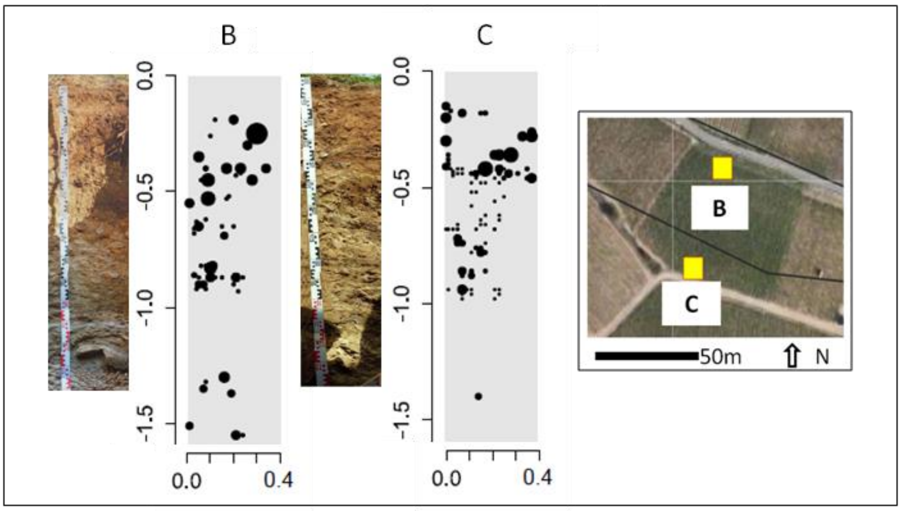

Figure 4: Plot B and C relative location, soil profile and roots distribution.

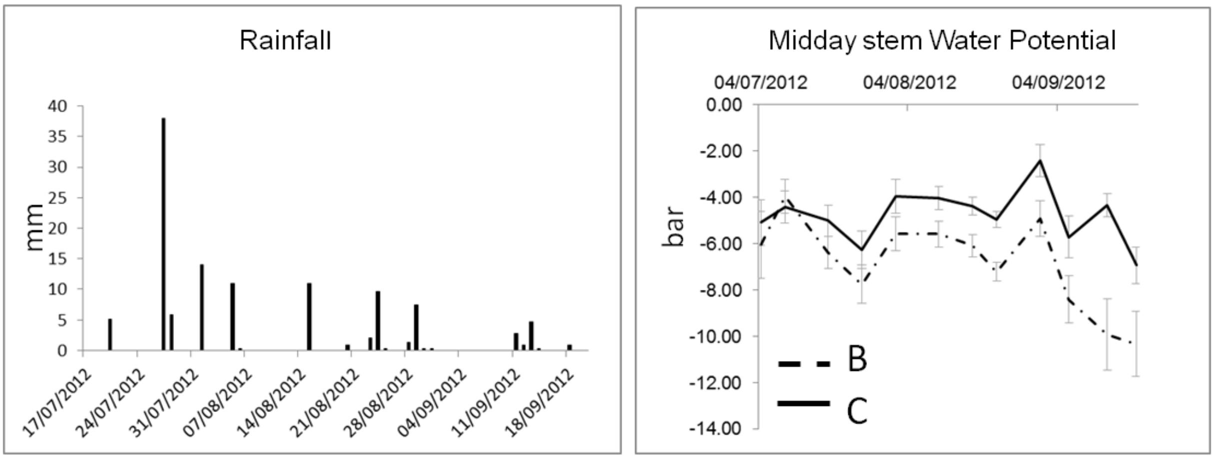

Figure 5 Rainfall during the 2012 vintage and midday stem leaf water potentials for plot B and C.

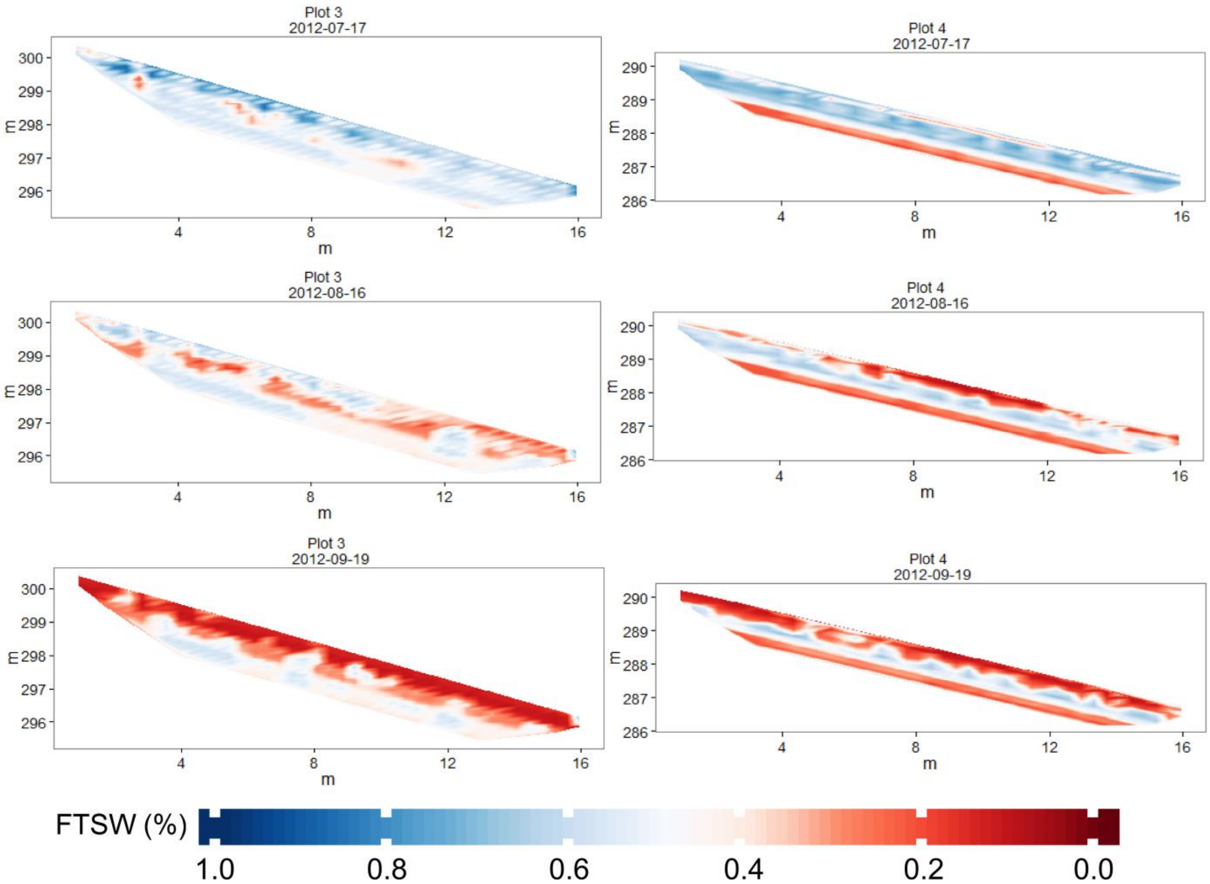

Figure 6: Variation of the FTSW in plot B and C during the 2012 vintage. Plot B is on the left, plot C is on the right. From top to bottom: bunch closure, veraison, maturity. Depth of the images is different in soil B and C, in B maximum depth of investigation is 1.5 m, while in plot C is equal to 1.3 m (the difference in depth is caused by the difference in soil properties availability for the application of the models).