WATER STATUS MODELLING: IMPACT OF LOCAL RAINFALL VARIABILITY IN BURGUNDY (FRANCE)

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Abstract
Water status is a key factor in vine development and berry ripening. Water status is strongly affected by environmental parameters such as soil and climate. Whereas at local scale the soil variability is frequently accounted for, little scientific reports are available concerning the impact of local rainfall variability on grapevine water status. In order to accurately register the space and time variations of rainfall at local scale, a dense rain-gauges network has been installed in Burgundy. It is composed of 45 rain-gauges over a 28 km² area. Rainfall data collected by each rain-gauge in 2014 and 2015 was used as input variables in the grapevine water balance model proposed by Lebon *et al* (2003). All other climate variables, vineyard and soil parameters were kept strictly identical for each simulation in order to capture the consequences of the sole spatial variability of rainfall on vineyard water status.
As rainfall dynamics impact on the vineyard depends on the soil water content, water balance was modeled considering successively soils with low (50 mm) and medium (150 mm) soil water holding capacities, representative of the soils of the area. The daily fraction of transpirable soil water, averaged on the grape ripening period, was used as an output variable to assess the potential consequences of soil water status on grape characteristics.
During the 2014 (2015) vintage, the mean FTSW from veraison to harvest varied from 0.22 to 0.41 (0.09 to 0.25) for soils with low water capacity with an average difference of 0.04 (0.03). Ranges of 0.31 to 0.76 (0.09 to 0.16) with average differences of 0.09 (0.02) were observed for soils with higher water capacity in 2014 (2015).
Therefore, it seems that the spatial variability of rainfall at local scale could significantly affect the vineyard water balance, depending on the vintage and the soil water capacity.
The contribution of local rainfall variability to vineyard water balance in comparison to other factors also impacting the vineyard water status is discussed.

Keywords: Water status, Model, Rainfall, High Resolution, Burgundy.

1 INTRODUCTION

Grapevine requires limited input of water, and when grown on terroirs providing moderated water deficit during the fruit development, it usually produces grape with high enological potential (Seguin. 1983, Coipel et al. 2006, van Leeuwen et al. 2009). Terroir studies often consider the consequences of soil, topography, climate and plant material on grapevine water status (Vaudour et al. 2015). At local scale, soil water status variability is addressed mainly through soil, terrain (via GIS) or plant based studies (André et al. 2012, Bellvert et al. 2014, Bonfante et al. 2015, Brillante et al. 2016). The role of climate variation at fine scale has recently been considered through terrain impact on both radiative balance (and therefore vineyard evapotranspiration) and rainfall runoff (Hofmann et al. 2014). While rainfall is known to be highly variable in space, especially during summer when storms might induce considerable variations in water input on very short distances (e. g. rainfall events reported in Berne et al. 2004), rainfall local variability impacts on grapevine water status have little been taken in consideration so far.
The current paper reports a first attempt to fill this gap. Using the Lebon et al. (2003) water balance model, it compares the potential changes in grapevine water status induced by local rainfall variability captured by a 45 rain gauges network installed in Côte de Beaune wine growing area (Burgundy, France).
In order to follow accurately the water balance of vine, winegrowers in Burgundy need precise rainfall data. To complete this goal, a high density rain gauges networks called Hydravitis was implemented in 2012 in the Côte de Beaune region in Burgundy (Pauthier et al. 2014). With a 1.61 rain gauges/km² density, this network enables following the spatial variability of rainfall over the area. With such high-resolution data the question at the basis of this study was: what is the part of rainfall variability in the output of water status models?

To answer to this question we used the Lebon et al. (2003) model with Hydravitis network measurements as input rainfall data to simulate Fraction of Transpirable Soil Water (FTSW, Pellegrino et al. 2004). To assess the response of the model between medium and low water capacity soils, two runs were performed, using successively a 150 mm and a 50 mm total transpirable soil water (TTSW).

2 MATERIALS AND METHODS

The study was conducted over a 28 km² area located in the North of the Côte de Beaune wine growing region (figure 1). Climate is oceanic with continental and Mediterranean influences (Chabin et al. 1984). These influences are represented by moderately cold winter and warm summers, with about 760 mm of precipitation (Dijon data, http://www.meteofrance.com/climat/france/dijon/21473001/normales). Precipitations are evenly distributed along the year (from 43 to 86 mm each month) but during the fruit development period (July to September) most of the rainfall occurs as thunderstorms which limit soil water supply because of their high intensity and the runoff they induce. The terrain of the study area is hilly, due to erosion of a southeast exposed hillside facing a large Plain (Soane Plain) during the Quaternary period. The elevation ranges from 200 m to 450 m (Saone Plain).
In order to capture space and time variability of rainfall, a very dense rain gauges network composed of 45 Rainnew 111 (Rainwise® inc) tipping-bucket rain gauges has been installed and completed from 2012 to 2014. These rain gauges are linked to a Hobo Pendant UA-002-64 event-temperature logger (Onset® corp.) that records the time of occurrence of bucket tips. The implementation of the gauge network followed the WMO recommendations (WMO, 2008)), at a maximum angle of 30° between the top of the gauge to the top of the highest nearest obstacle. In order to assess measurement uncertainty, a pair of two gauges have been installed within a distance of three meters between each gauge. The resolution (0.258 mm/tip) and the average measurement error (ranging from 0.6 to 4.2 %) of the rain gauges have been tested during a preliminary study. Network implementation and control are detailed in Pauthier et al. (2014).

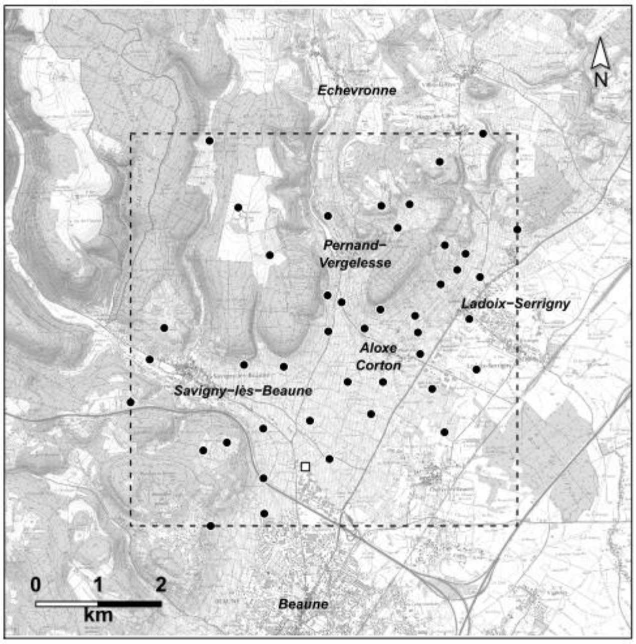

Figure 1: The Hydravitis network. Black dots indicate the location of the rain gauges providing the data used in this study (note that only 43 rain gauges are shown, as two additional rain gauges are located less than 10 m from another one to check the measurement error). The white square indicates the location of Beaune weather station.

During the 2014 and 2015 vegetative period of the vine, rain gauges were controlled every week in order to limit the potential clogging of the rain gauges.
Despite this very frequent maintenance, clogging, battery or malfunctioning problems appeared on a few rain gauges. Erroneous or missing data was replaced by spatial interpolation using ordinary kriging, a common tool for rainfall interpolation (Azimi-Zonooz et al. 1989, Dirks et al. 1998. Nalder and Wein, 1998; Bois 2007; Bargaoui and Chebbi 2009).
Hydravitis rainfall data from 2014 and 2015 was used as input of the Lebon et al. (2003) water balance model.

Water balance modelling
The Lebon model is based on a geometrical canopy model from Riou et al (1989) coupled to a soil water balance routine accounting separately for grapevine transpiration and bare soil evaporation. This water balance model requires as input: reference evapotranspiration (ET_0) and rainfall as water inputs, daily solar radiation for solar radiation interception modeling and daily air temperature for degree days canopy development modeling. The canopy expands from budburst to 10 days after flowering (estimated to be the date at which the canopy growth is limited due to trimming). The vineyard geometry was set for North to South aligned rows (vertical-shoot-position training), with an inter-row distance of 1 m, a maximum canopy height (width) of 0.7 m (0.35 m) and a minimum porosity (proportion of gaps though the canopy) of 0.25. These parameters were set to match usual canopy geometry met in the study area.
Temperature and relative humidity data was collected from a weather station located at Beaune (white square on figure 1). Solar radiation and wind speed data was taken from a weather station located at Volnay (7.5 km south-eastwards of the study area, as theses variables were not recorded at Beaune station). ET_0 was calculated using the Penman-Monteith FAO-56 model (Allen et al. 1998).

For 2014 and 2015 vintages, 45 runs of Lebon model were performed, with the same parameters and input climate variables except rainfall. For each run, rainfall data collected from a different rain gauge was used. These 45 runs were performed twice: once for a soil with a Total Transpirable Soil Water (TTSW) set to 50 mm and one with a TTSW set to 150 mm.
For each run, the average Fraction of Transpirable Soil Water (FTSW) was averaged for the veraison-to-harvest period (dates retrieved from local consultant weekly bulletin).

Note that Lebon et al. (2003) model has been developed for flat terrain. Although an adaptation to slope condition has been proposed recently by Hofmann et al (2014), Lebon model was preferred because this study is limited to evaluate the sensitivity of vineyard water balance to the sole local rainfall space and time variability only, for two contrasted soil water capacity

3 RESULTS AND DISCUSSION

The veraison-harvest rainfall amounts presented in figure 2 show that during this period some significant spatial variability in the rainfall accumulation can occur in Burgundy. In 2014 rainfall ranged from 18.8 mm to 34.3 mm and from 50.8 mm to 71.7 mm in 2015. In 2014 the wettest areas were located on the north-western parts of the study zone, were a thunderstorm (on September 9th) brought 15 mm of rainfall. In 2015, the highest amount of rainfall was recorded on the west of the study area. In both summers, the eastern part of the network, located in a broad plain downhill (*Saone Plain*) collected less rainfall. A possible "shelter effect" from the relief westward (as already described by Chabin, 2004), might explain this local rainfall distribution. Yet, the hypothesis of a recurrent spatial structure of rainfall needs to be further investigated within a long term analysis of rainfall pattern at this scale.

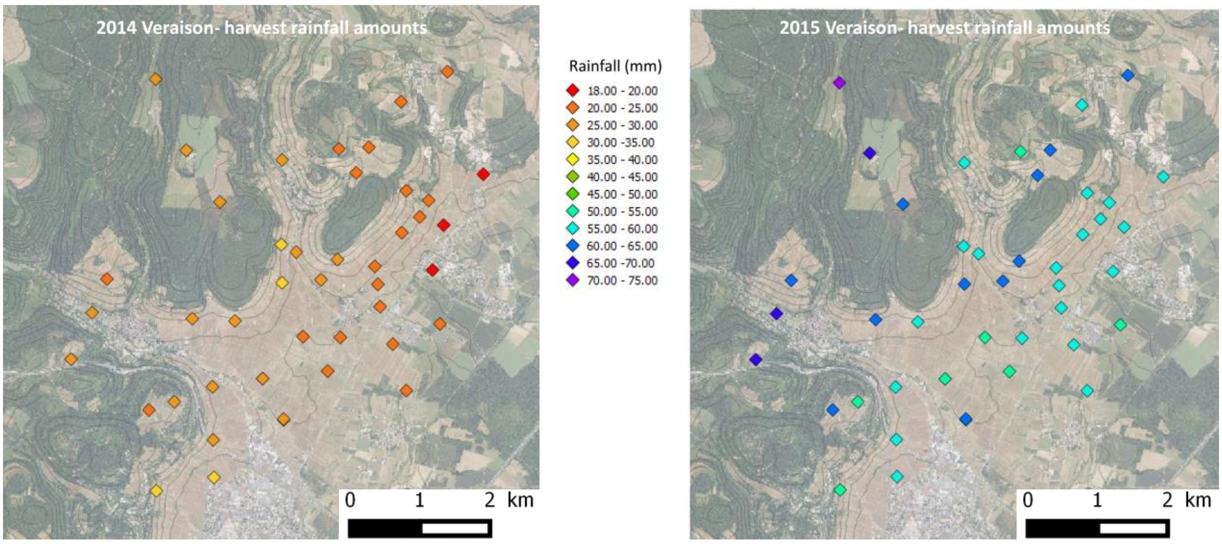

Figure 2: Rainfall cumulated during the veraison-to-harvest period in 2014 (left) and 2015 (right).

The impact of this spatial variability of rainfall on the vine water status is assessed through FTSW averaged from veraison to harvest for soils with medium water capacity (TTSW=150 mm, figure 3 bottom) and low water capacity (TTSW=50 mm, figure 3 top). For soils with a medium TTSW, 2014 highest FTSW values are located on the northern parts with values ranging between 0.53 and 0.79 and the lowest values (about 0.35 to 0.50) are located in the central parts of the study area (figure 3, bottom-left). The north-eastern part of the area exhibits high FTSW values, whereas low rainfall amounts were collected from veraison to harvest: in this zone, soil was fed though with about 30 mm of rainfall during strong thunderstorm taking place just before veraison (on August 9th). In 2015, grapevine soil available water was lower than during 2014 figure 3, right. The spatial distribution of veraison-to-harvest FTSW is similar to cumulated rainfall pattern during the same period. The highest FTSW values are located on the western part (0.11 to 0.16) of the study area and the lowest on the eastern part (0.08 to 0.11).

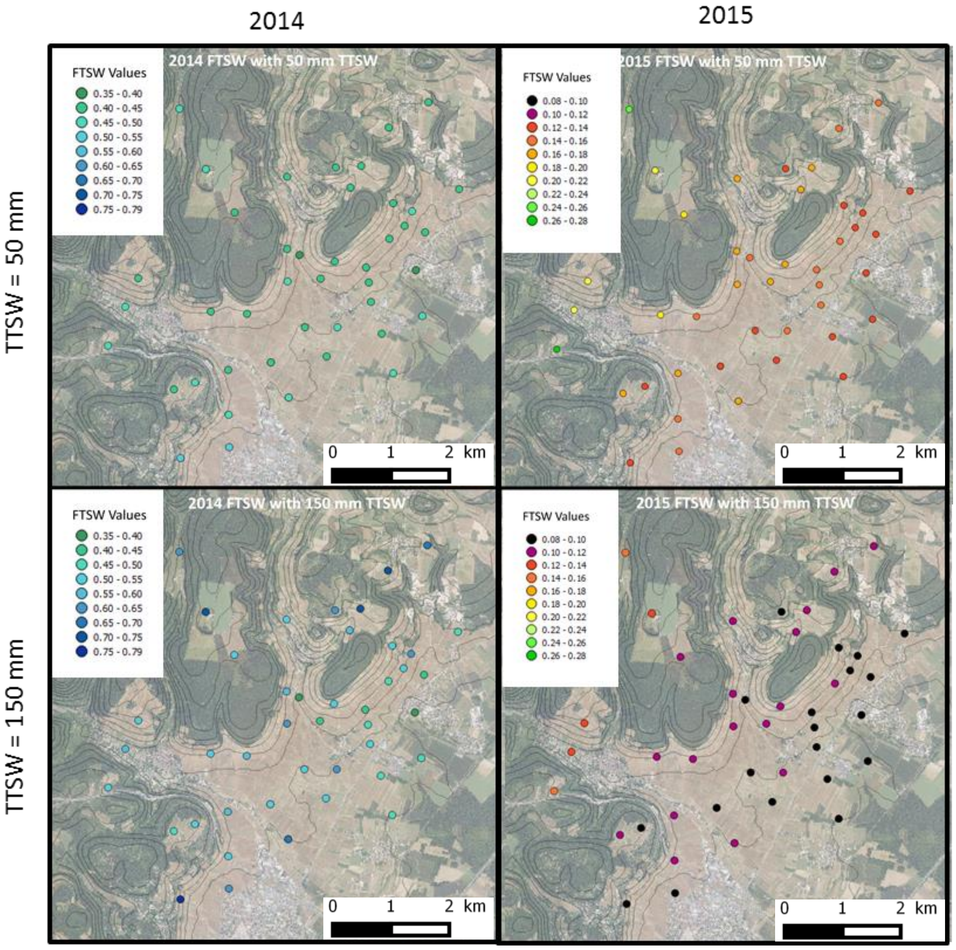

Figure 3: Fraction of Transpirable Soil Water (FTSW) during the veraison-to-harvest period in 2014 (left) and 2015 (right) for a soil with a 50 mm Total Transpirable Soil Water (TTSW, top) and a 150 mm TTSW (bottom).

2015 veraison-to-harvest FTSW spatial patterns considering a low TTSW (50 mm) follow the same structure as for medium TTSW simulations, with values ranging from 0.12 to 0.27 (figure 3, right). Despite a lower soil water capacity, veraison–to-harvest FTSW was higher for 50 mm TTSW soils than for 150 mm TTSW soils (figure 4). Soils with soils with low water capacity have a quicker reload with the same rainfall amount than for soils with medium water capacity. For example a rainfall of 25 mm will represent 50% of a 50 mm TTSW whereas it will represent 16.6% of a 150 mm TTSW. During 2015, a substantial heatwave occurring early July, following a rather dry spring, resulted in low FTSW in Burgundy. Rainfall accumulations after this heatwave were quite low and do not allow to catch up the water deficit in medium TTSW soils. In contrast, rainfall in July 2014 was high and filled most of the soil water capacity before veraison. Veraison-to-harvest FTSW was mostly modified by rainfall spatial variations during this period. For 2014 vintage, FTSW spatial structure and range differ according to the soil water capacity. Low TTSW soil simulations resulted in smaller spatial variability (from 0.38 to 0.52) than for medium TTSW soils (from 0.35 to 0.79, figure 4).

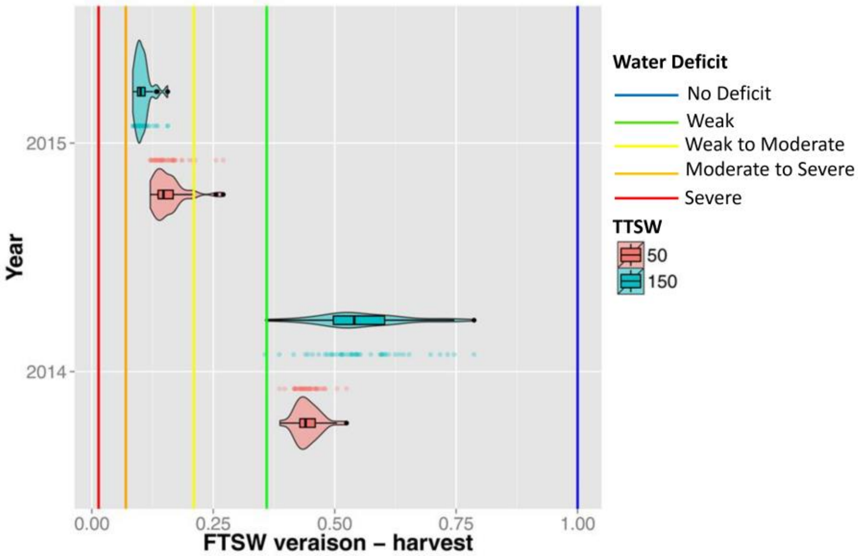

Figure 4: A) Fraction of Transpirable Soil Water (FTSW) during veraison-harvest period for 50 mm TTSW (red) and 150 mm FTSW (blue). Water deficit classes were those derived from van Leeuwen et al (2009) predawn leaf water potential classes (transformed in FTSW using the exponential equation given by Lebon et al, 2003).

In 2014, all simulations resulted in a "No deficit" class as proposed by by van Leeuwen et al (2009 ; figure 4). The water deficit classes were estimated from van Leeuwen et al. (2009) predawn leaf water potential classes, transformed into FTSW values using the exponential relationship proposed by Lebon et al. between predawn leaf water potential and FTSW from measurements performed on two experimental plots in Alsace. In 2015, for low TTSW, the deficit is classified as "weak" with values between 0.2 and 0.3 to "moderate to weak" with values between 0.12 to 0.2. For medium water capacity soils, the deficit is classified as "moderate to weak" with centered values around 0.10. This classification exhibits moderate change in grapevine water status due to local rainfall variability in our experiments. However, the FTSW variations are strong (i.e. vintage 2014, TTSW 150 mm) and one could expect dramatic change in plant water status due to local rainfall variability.

4 CONCLUSION

Water availability is an important issue for viticulture either for adapting training systems and plant material to soil/climate/topography or for irrigation scheduling and crop cover management. When using water balance models, accurate input data must be used to perform a relevant simulation. At local scale, rainfall, a critical input variable of water balance models, is often monitored using a limited number of rain gauges. Because of the costs related to weather stations (purchasing, maintenance and data transmission), commercial vineyards tend to limit the number of rainfall monitoring devices in space. In this study, we show that local variations of rainfall might induce considerable changes in available soil water for grapevine, despite moderate variation in relief. Burgundy rainfall is highly variable in time (between and within each year). During 2014, precipitation patterns induced stronger variations in soil water status than soil water capacity would (at least for the two TTSW compared here). Depending on the soil water capacity, local rainfall spatio-temporal variations have fluctuating consequences on FTSW, which can produce counter-intuitive results (higher veraison-to-harvest FTSW for soils with a low TTSW compared to soils with a medium FTSW).

While these results quantify potential contribution of local rainfall to vineyard water status variations at local scale levels, it does not address the contribution of terrain induced changes in runoff and vineyard evapotranspiration that considerably affect vineyard water balance. Such approach will be developed in further study.

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