A GENERIC METHOD TO ANALYZE VINE WATER DEFICIT CONTINUOUSLY

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Abstract

In the context of global warming, water scarcity is becoming an increasing issue worldwide. However, the reference method to characterize vine water deficit is based on water potential measurement, which is a destructive and discontinuous method. The current climatic context emphasizes the need for more precise and more continuous vineyard water use measurements in order to optimize irrigation and vine water deficit monitoring. Our work proposes a quantitative method to characterize vine water deficit variations in a continuous fashion. Combining sap flow and climatic raw data, the framework uses expert knowledge and mathematical modeling to characterize dry soil crop coefficient (~~K_{cb}~~Kc_B) and automatically compute a daily water deficit index K_s. As a case study we used an experimental design set in French vineyards where contrasted vine water deficit profiles were obtained by using differential irrigation treatments. We analyzed Tr/ET_{ref} ratio variations to identify the timing and value of maximal ~~K_{cb}~~Kc_B. After that preliminary step, we computed and aggregated K_s profiles for each treatment and compared irrigation effects on K_s profiles. Because sap flow and climatic sensors are installed outdoor, determination of maximal ~~K_{cb}~~Kc_B value is particularly sensitive to environmental variations. As such, we studied the effect of measurement uncertainties on ~~K_{cb}~~Kc_B computation and K_s profile by imposing variations in the timing and value of ~~K_{cb}~~Kc_B. Implications and perspectives to improve irrigation practices are discussed.

Keywords: sap flow, Ks, water use, irrigation, dry soil crop coefficient.

1 INTRODUCTION

Various authors have reported the effect of vine water use on fruit maturation (Deluc et al, 2009) or yield. Vineyard performances (quality and quantity) are therefore directly dependent upon irrigation strategies. Typically, irrigation scheduling relies on an estimate for vine maximal transpiration (T_m) under any given climate. T_m can be calculated from reference evapotranspiration (ET_{ref}) and the basal crop coefficient (~~K_{cb}~~Kc_B = T_{max}/ET_{ref}) as in Allen et al. (2009). To estimate when irrigation needs to be applied, the computation of a stress coefficient is necessary ($K_s = T/T_m$, i.e. the ratio between actual and maximum crop transpiration). Using sap flow sensors it is possible to compute daily K_s throughout the season and authors have shown the relationship existing between K_s and other vine water use measurements (Ferreira et al, 2012; Poblete-Echevarria et al, 2013). However, the sap flow approach requires a good characterization of ~~K_{cb}~~Kc_B and various authors have reported results regarding the value of ~~K_{cb}~~Kc_B at different periods of the season (Picon-Toro et al, 2012). This work aims at improving our interpretation of transpiration profiles and K_s variations obtained using sap flow sensors. It presents a method to characterize continuously vine water deficit variations. The method was implemented in vineyards subjected to contrasted water regimes for evaluation and we tested its sensitivity to ~~K_{cb}~~Kc_B variations.

2 MATERIALS AND METHODS

Site location: A same experimental design was set up in 3 sites across the Languedoc Roussillon (southern of France). Sites were distant from each other (Maximal distance between sites was 200 km).

Climatic data: Hourly meteorological data on wind speed, air temperature, relative humidity, global radiation and precipitations were extracted from local meteorological stations for each site. Hourly vapor pressure deficit (VPD) and reference evaporative demand (ET_{ref}) were calculated according to the method described in FAO-56 (Allen et al., 2009).

Phenological data: The main phenological phases (budbreak, bloom, nouaison, veraison) were estimated visually in each experimental plot when 50% of the plants reached the stage.

Vine water status: *Leaf water potential at predawn:* measurements were conducted weekly to biweekly from the end of June to harvest date with a pressure chamber (PMS 600, PMS instruments Company, Corvallis, OR, USA) between 3.00 am and 5.00 am. *Sap flow:* the energy balance method was used to measure sap flow with

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Megjegyzés [bch1]: Nouaison ou set ?

Sap IP system (Dynamax, Houston, TX, USA). In each selected row, 2 vines were equipped with one sensor each. Each sensor measured vine sap flow rate every 15 minutes. The 2 selected vines were within 25 meters of each other within the same row. Sap flow rates measured on each vine were averaged on an hourly basis within each row. Various expert methods were applied to filter out nighttime, weak and erroneous signals. Sap flow measurements were scaled at the plant level according to plant leaf area estimates corresponding to each sensor. The daily sap flow assumed to measure daily vine transpiration was computed by adding all hourly sap flow rates measured during the day.

Plant material and vineyard layout:

Table 1: vineyard layout

Site	LB	PR	StG
Varietal	Cabernet Sauvignon	Merlot	Merlot
Rootstock	n/a	SO4	110R
Trellis and pruning system	2 wires VSP, spur	2 wires VSP, spur	1 wire VSP, spur
Spacing (m)	2.5 x 1	2.5 x 1	2.5 x 1

Megjegyzés [b2]: Plusieurs irrigations pour PR et StG, fichier texte joint, je mets le total dans la case

Treatment design: The irrigation treatment consisted of two modalities, replicated twice. In the non-irrigated subplots, vines only received natural precipitations during the growing season while in the irrigated subplots; vines received regular extra-amounts of water through a dripper line (1 to 2 drippers per plant).

Table 2 : water applied in irrigation treatment

Site	LB	PR	StG
Irrigated amount (mm)	8	62	72
Number of irrigations	1	12	5

Megjegyzés [b3]: Plusieurs irrigations pour PR et StG, fichier texte joint, je mets le total dans la case

Ks Computation: Ks is the ratio between actual and maximum crop transpiration, defined as:

$$Ks(t)=T(t)/T_{max}(t) \quad (1)$$

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Ks represents the level of daily vine water use by reference to its maximal level. *Ks*=1 reflects a situation when maximal level of vine water use is fully satisfied. When *Ks*<1, daily vine water use is limited. *T* is the daily measured transpiration from sap flow and T_{max} is daily maximal vine transpiration obtained under dry soil condition when soil moisture is non-limiting, defined as in Allen et al. (2009).

$$T_{max}(t)=Kc_B(t)\, ET_{ref}(t) \quad (2)$$

ET_{ref} is the reference evapotranspiration and Kc_B a coefficient linearly related to the leaf area index (LAI) or to the fraction of ground coverage (Picón-Toro et al., 2012). $Kc_B(t)$ profile is divided into two main growth stages as reported by Allen et al (2009) as presented in figure 1.

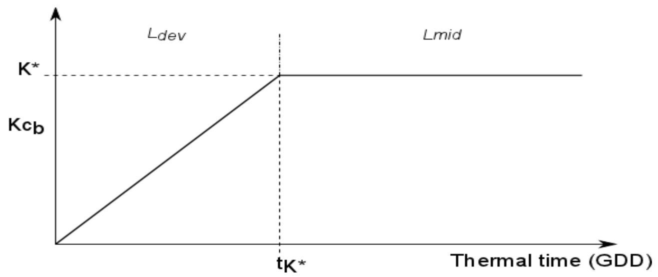

Figure 1: Theoretical curve of Kc_B variations during the season

To determine $Kc_B(t)$, two hypotheses on the curve shape are assumed:

$$Kc_B(t)=f(t) \text{ for } t<t_K* \quad (3)$$

where $f(t)$ is assumed to be linear in t, and t_K* is the breakpoint for which Kc_B reaches the plateau K^*. The key point is to set t_K*, or K^*. The analysis of curve shape, associated with rules based on phenology, meteorology and predawn leaf water potential described in Thebault et al. (2013) leads to the proposal of a small finite set of t_K* candidates. The final choice is left to the stakeholder who is best aware of management practices or uncontrolled events that could interfere with vine growth (irrigation, leaf removal, trellis system…) and therefore with Kc_B curve.

The sensibility analysis was carried out using the R software, described in R Development Core Team (2009).

3 RESULTS AND DISCUSSION

Transpiration profile analysis

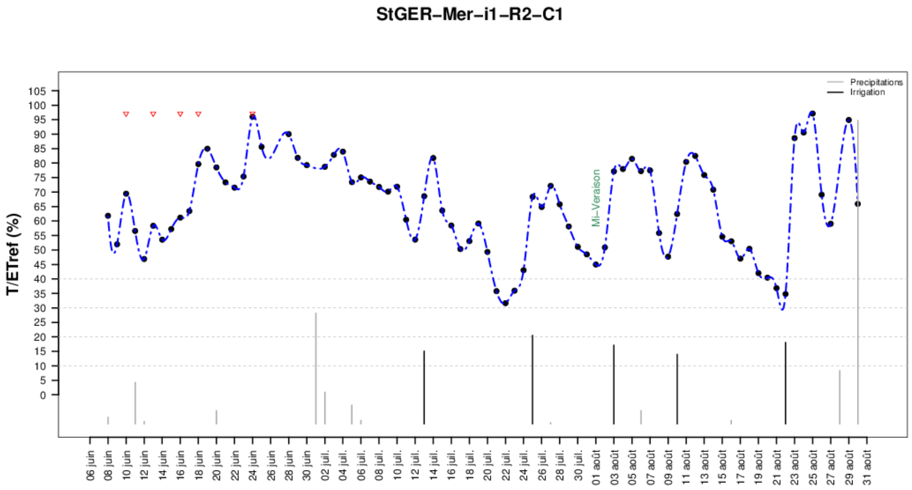

Figure 2: variations of T~~r~~/ET_{ref} ratio in StG site (irrigated) -tK* is reached on June 24

A function was attached to each T~~r~~/ET_{ref} profiles and was used to extrapolate transpiration ratio value when data was missing between 2 dates. Each profile was analyzed individually. Results for K* value and tK* for each replicate are reported in Table 3. Value and date for K* are used to simulate ~~K_{cb}~~Kc_B seasonal variations with thermal time according to equation (3). Using ~~K_{cb}~~Kc_B profile variations, we computed daily Ks according to equation (1). K_s profiles were analyzed for each replicate. We reported the seasonal K_s profile attached to the same replicate of the StG site (irrigated) in Figure 3. We observe that after each water input Ks increases.

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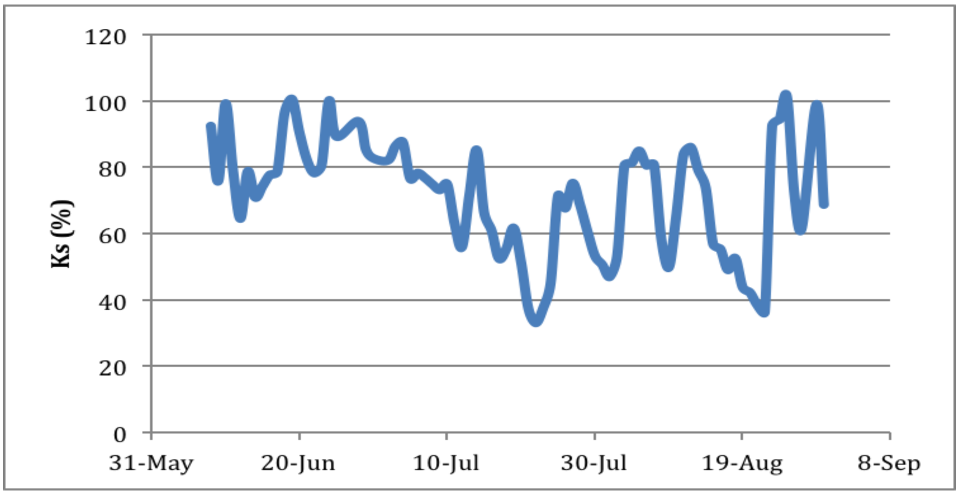

Figure 3: Ks profile for StG Me site (irrigated treatment)

Table 3 : K* and tK* for each replicate

Varietal	site	treatment	K* (%)	tK*	tK* - (°C.d)
CS	LBCS	i0r1c1	24.2	30-Jun	634
CS	LBCS	i0r1c2	23.0	15-Jun	428
CS	LBCS	i0r2c1	24.8	15-Jun	428
CS	LBCS	i0r2c2	27.3	6-Jul	699
CS	LBCS	i1r1c1	40.7	6-Jul	699
CS	LBCS	i1r2c1	39.3	20-Jun	488
CS	LBCS	i1r2c2	26.1	18-Jun	463
ME	PR ME	i0r1c1	27.7	20-Jun	478
ME	PR ME	i0r2c1	20.8	15-Jun	423
ME	PR ME	i0r2c2	14.4	14-Jun	414
ME	PR ME	i1r1c1	20.2	14-Jun	414
ME	PR ME	i1r1c2	42.0	14-Jun	414
ME	PR ME	i1r2c2	21.3	15-Jun	424
ME	StGME	i0-C-r1c1	53.7	8-Jun	413
ME	StGME	i0-C-r1c2	44.1	24-Jun	592
ME	StGME	i0-C-r2c1	44.1	24-Jun	592
ME	StGME	i0-C-r2c2	71.4	24-Jun	592
ME	StGME	i0-r1c1	80.5	24-Jun	592
ME	StGME	i0-r2-c1	41.4	July 3rd	716
ME	StGME	i1r1c2	86.3	21-Jun	550
ME	StGME	I1r2 c1	96.0	24-Jun	592

Irrigation effect on Ks profile

For each treatment an average daily K_s was computed. Area under each average K_s profile was computed to analyze irrigation effect over different periods. Results are displayed in table 4.

Table 4: Irrigation effect on aggregated K_s value

Treatment	LB-CS-i0	LB-CS-i1	PR-ME-i0	PR-ME-i1	StGER-ME-i0	StGER-ME-i1
Set-Harvest	856	905	571	667	465	802
Set-Veraison	545	567	390	352	352	485
Veraison-Harvest	290	317	237	282	99	301

Irrigation effect

In site LB, only one irrigation was applied on August 16th (ie. after veraison). Consequently differences are minimal between the 2 sites before veraison. The rain event (August 28-30) further minimizes difference between treatments. In LB water deficit is moderate even in the non-irrigated site.

In site PR, 5 small irrigations (5 mm on average per application) were applied before veraison. However, no differences are seen between the 2 treatments. The non-irrigated treatment is even experiencing less water deficit before veraison than the irrigated treatment, probably as a consequence of vineyard spatial variability. This suggests that irrigation pre-veraison had no effect at the PR sites because plant was not experiencing any water deficit at the time irrigation was applied. Treatment difference appears only over the period veraison-harvest

suggesting that a moderate level of water deficit was reached only at the end of the season in the non-irrigated treatment (aggregated Ks = 237 vs 282 in the non-irrigated and irrigated treatment respectively, Table 4).
In site StG, water deficit is observed preveraison in the non-irrigated treatment. Irrigation effect is seen before veraison since the first irrigation was applied on July 13th (before veraison). The difference between treatments is further enhanced post-veraison, as water becomes more limiting in the non-irrigated treatment. Despites different responses to irrigation across all sites, aggregated Ks is higher under irrigated treatment over the period set-harvest and veraison- harvest. Field results show that the aggregated Ks method is useful to discriminate and quantify irrigation effect (timing and volume) on vine water status variations in contrasted situations.

Because uncertainties over K* and tK* directly impact K_s, we tested model sensitivity when K* varies within a 20% range or when tK* varied within a 20 days window. Effects of K* and tK* variations on aggregated Ks value in each replicate are reported in figure 4 and 5.

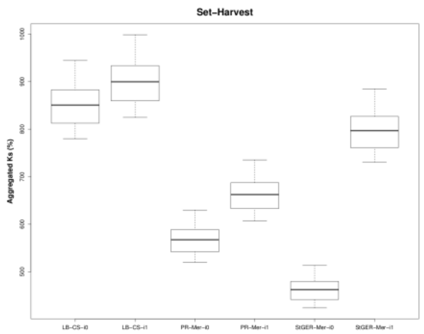

Figure 4 : effect of 20% variations on K* value - Aggregated Ks profile (Set- Harvest)

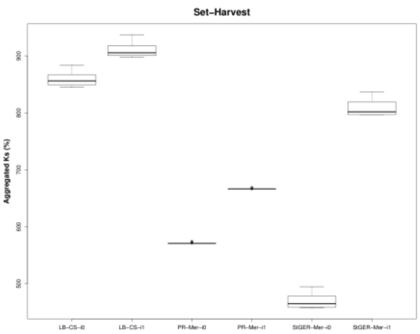

Figure 5: effect of +/- 10 days variations on tK* value - Aggregated Ks profile (Set- Harvest)

Box plots were obtained from a randomized selection of 50 average K_s profiles for each treatment. Figure 4 shows the effect of +/- 10% variations imposed on K* on the distribution of aggregated Ks profiles. Figure 5 shows the effect of +/- 10 days variations on tK* on the distribution of aggregated Ks profiles. The sensitivity analysis confirms that irrigation effects remains detected by the Ks method even if we account for uncertainty on K* determination. Irrigated sites always show higher aggregated Ks over the period Set-Harvest.

4 CONCLUSIONS

K* and tK* values obtained in the field are comparable to values reported in the literature with similar vine spacing (Ferreira et al, 2012, Poblete-Echeverria et al, 2013; Picon toro et al, 2012). The method can be applied to compare vine water use profiles obtained under contrasted environmental conditions or practices. The analysis shows that the model is sensitive to uncertainties in K*. However since K* is related to canopy size and spacing density (Picon toro et al, 2012), uncertainties on K* are limited to a small range of variations. Furthermore, the range of variations due to uncertainty over K* can be reduced using other methods. Combining K* determination with aerial imagery, for instance, can improve our ability at characterizing Leaf Area Index or ground cover fraction which are related to canopy size and spacing (Johnson et al, 2005). The method can be generic and useful to discriminate irrigation effect across different treatments. As such, the method opens new perspectives to optimize irrigation as a function of vineyard water use. Last, because K_s profiles can be aggregated to characterize different vine water regimes, the method is promising to improve our understanding of the relationships between vine water deficit and fruit maturation.

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