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USEFULNESS AND LIMITS OF THE CROP WATER STRESS INDEX OBTAINED FROM LEAF TEMPERATURE FOR VINE WATER STATUS MONITORING

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Abstract

Aims: This work aimed i) to calibrate the accuracy of estimating vineyard water status by crop water stress index (CWSI) compared to stem water potential; ii) to determine the time interval during the day that best correlates to stem water potential and iii) to understand the its usefulness.

Methods and Results: Four levels of irrigation were set up in 2017 on a Cabernet-Sauvignon vineyard grafted to 110R in *Morata de Tajuña* (Madrid, Spain). The experimental design was a completely randomized four-block design. During two seasons, 2018 and 2019, stem water potential (SWP) and leaf temperature were measured at three time points during the day (8:00; 12.00 and 16:00 solar time) in five dates during 2018 and three dates in 2019. CWSI was calculated based on leaf temperature as the ratio $(Ttreat - Twet)/(Tdry - Twet)$. Leaf temperature ($Ttreat\ leaf$) was measured with an infrared camera model FLIR-E60; Four shaded leaves per treatment were sampled at each time of measurement, for a total of 16 leaves per measurement interval. ANOVA for CWSI and stem water potential was also performed to compare the sensitivity of each parameter to vine water status. All statistical analyses were performed with the Statistix10 package.
Results showed that stem water potential was slightly more sensitive than CWSI to estimate vine water status. Different relationships were found during the season between CWSI and SWP. The determination coefficient was higher at midseason than at the beginning or late in the growing season. The highest R^2 were found at noon and during the evening, being no-significant in the morning.

Conclusions: Crop Water Stress Index obtained from leaf temperature could be used to estimate plant water status although assuming that it is less sensitive than Stem Water Potential. The index was more accurate in describing the plant water status in midseason than either early or late in the season and better at midday and evening than in the morning.

Significance and Impact of the Study: The study confirms the use of CWSI as a tool to determine vineyard water status and its limitations. Limitations include its effectiveness being confined to midseason and measurements are recommended to be collected from noon onwards. We propose to keep CWSI lower than 0.6 from budbreak until bloom and to move within 0.6 to 0.8 during maturation to ensure SWP is over -1.0MPa (-10 bar) and within -1.0 and -1.2 MPa during ripening.

Keywords: Crop water stress index, stem water potential, thermal images

Introduction

The application of irrigation in vineyards is a worldwide practice, but water is increasingly a scarce and limiting resource. For that reason, in countries with a warm climate and low annual rainfall, Regulated Deficit Irrigation (RDI) strategies are being validated to reduce the use of water in certain periods without the production or quality being compromised. For this reason, it is necessary to monitor the crop status. Stem water potential (SWP) is the usual method for monitoring water status, by using a pressure chamber (Améglio *et al.,* 1999). Although the values extracted from these measures are a faithful reflection of the reality of water plant status, the methodology followed to perform these measurements in field is tedious. Measuring SWP implies that the sample size that can be obtained is small, it is a destructive technique and it is necessary to employ specialized staff for the measurement. Another added problem appears is the subjectivity of the measure since it depends on the visual sensitivity of each person.

Alternatively, to SWP for determination of water potential in vineyards, thermal images can be used for this purpose. The use of thermal information for detecting plant water status became popular with the use of thermal infrared sensors in the 1960 (Tanner, 1963). Later, Idso *et al.* (1981) developed the index called the crop water stress index (CWSI) based on canopy temperature. From these images, the surface distribution of the leaves and canopy temperature can be obtained. In water stress situations, the crop transpiration is reduced due to partial stomata closure which results in a reduction of its cooling capacity, and in an increase in temperature (Gallardo *et al.,* 2006), also for that reason Wang and Gartung (2010) concluded that a representative canopy temperature (Tc) could be used as a good indicator of water stressed plants.

The core of this work is the analysis of thermal images for the precise determination of canopy temperatures and estimators that allow the determination of the vineyard water status.

Material and Methods

Four irrigation levels were set up in 2017 on a drip-irrigated, Cabernet-Sauvignon/110R vineyard located in Morata de Tajuña (Madrid, Spain). Emitters dose was 1.3L/hour, 2.0L/hour, 3.0L/hour and 3.75L/hour for treatments one to four respectively. There was one emitter per plant. The training system was a Vertical Shoot Position (VSP). Vines were two-bud, spur pruned along a unilateral cordon with 11-12 shoots per meter of raw. The experimental design was a randomized complete four-block design with three rows per single plot, one central-control row, and two adjacent ones acting as buffers. Weather data was collected from a weather station at the same vineyard site. The farm treatment was Treatment two which was the reference used to decide when to start irrigation and to establish the deficit irrigation level. Treatment two was irrigated 40% of ETo. Irrigation started when midday SWP from budbreak to full bloom was lower than -0.8MPa. During ripening, the aim for treatment two was to keep SWP at around -1.2MPa. SWP was measured weekly the same day as the irrigation events.

During the seasons 2018 and 2019, stem water potential (SWP) and leaf temperature were measured at three times during the day (8:00; 12.00 and 16:00 solar time) in five dates during 2018 and three dates during 2019. Each measuring interval has a duration of 30 minutes. CWSI was calculated based on leaf temperature as the ratio $(Ttreatment - Twet)/(Tdry - Twet)$. Leaf temperature ($Ttreatment\ leaf$) was measured with an infrared camera model FLIR-E60; $Tdry$ reference was established as ambient temperature + 5ºC (Jones, 1999), $Twet$ reference was measured with a thermocouple placed on the downside of a continuously wetted cloth placed in the shade. Four shaded leaves per treatment were sampled at each time interval, for a total of 16 leaves per measurement interval. At the same time, another similar 16 leaves were sample to measured SWP. Protocol to measure SWP followed Scholander *et al.* (1966) taking into account the Turner (1988) considerations to avoid errors. Leaves tagged for SWP were different to those used for the temperature control.

ANOVA for CWSI and SWP was performed to compare the sensitivity of each parameter to vine water status. Relationships between CWSI and SWP were performed for i) each day and time interval (n=16) ii) for the same time interval – average of each treatment - during the season (n=20 in 2018 and n=12 in 2019) iii) All data pooled together, with the average per treatment and time interval with all 2018 and 2019 data. All statistical analyses were performed with the Statistix10 package.

Results and Discussion

Sensitivity to Water Deficit Status by CWSI and SWP
Season 2018 was slightly warmer than 2019. In 2018 differences between irrigation treatments arose both for CWSI and SWP (Table 1). In 2019, SWP always resulted significant while CWSI only 66% of measurements resulted significant (Table 1). We can conclude that both parameters are good indicators of water status but SWP is slightly a better indicator. It is interesting to know if there is a relationship among both parameters as SWP has some limitations to be measured in a commercial vineyard as the time consuming and small sample size to extend this result to a wide area. Thus, next step is to know if we can use CWSI to infer the SWP.

Relationship between CWSI and SWP
What time of the day is the best to calculate CWSI? We have found significant relationships between CWSI and SWP. When the relationships were obtained for each interval time (Table 2), the determination coefficient increased along the day and along to mid-season. As season progressed, leaves aged, variability increased and the relationships in September decreased. At early morning (9 am) regression resulted weakly significant in 2018 (R^2 ranging from no-significant to 0.67) and no significant at all in 2019 (Table 2). When all data collected at 9 am were pooled together (average per treatment and date), we obtained no-significance in both seasons. Some authors also reported a weak relationship when water deficit is mild (Pagay and Kidman, 2019; Bellvert *et al.,* 2015) what in our circumstances appear early in the season (data not shown) and in the morning. Thus early morning would not be a right time to measure leaf temperature to calculate CWSI. Belfiore *et al.* (2019) obtained a better estimation of water status around midday.

At midday and in the evening, the relationships use to be significant (Table 2). Both time intervals seemed to be right to calculate CWSI. Just by looking at the determination coefficient (Table 2) we cannot conclude which is the interval time at which the relationship is more accurate. When we go deeper into the data, and analyse if those relations are /are not different we found that in both 2018 and 2019 they are not statistically different. Thus, *we can measure leaf temperature to calculate CWSI either at midday or at evening as they do not differ.*
Next step is to know if this significant relationship we obtained for each season could be valid along years for the same vineyard or on the contrary if this relationship is different each year. As relationships for morning and evening are not different, we pooled midday and evening data together for both years and analysed if relations for 2018 and 2019 were different. Results indicated no differences between 2018 and 2019 regression lines (Figure 1). *This result confirms that this relationship is consistent along seasons, for the same vineyard, although it is highly recommended to support this conclusion with some more seasons of study.* Other studies do not address on this regard but when they calculate the regression lines, they pool all seasons together assuming vineyard characteristics (water regime, canopy development, etc.) remain the same in time (Santesteban *et al.,* 2016).

We can conclude that there is a significant relationship between CSWI and SWP and the best time to measure is during the evening (15:00 solar time).

One aspect to take into account is that although the relationship is highly significant the determination coefficient is rather low. We can make up the lower determination coefficient with many measurements in the vineyard as data collecting is quite fast.

Recommended values of CWSI
The final goal of using CWSI is to obtain a value out of leaf temperature data and to determine the vineyard water status. We did not differentiate a different relationship for different stages as Bellvert *et al.* (2015) and Matese *et al.* (2018) suggest but we propose different CWSI optimal ranges for different seasonal time as goals are different. According to Figure 1, we propose to keep CWSI lower than 0.6 from budbreak until bloom and to move within 0.6 to 0.8 during maturation to ensure SWP is over -1.0MPa (-10 bar) and within -1.0 and -1.2 MPa during maturation.

Conclusions

CWSI is an available parameter to measure vineyard water status during midseason, when canopy is full developed. In the evening (15 solar time) is when results are more consistent along the season and between seasons. We recommend to keep CWSI above 0.6 from budbreak to bloom and between 0.6 to 0.8 during maturation.

Appendix

Table 1: Significance of the ANOVA for the Crop Water Stress Index and Stem Water Potential in 2018 and 2019.

Year	Day of the year	Morning		Midday		Evening	
		CWSI	SWP	CWSI	SWP	CWSI	SWP
2018	170	ns	***	*	ns	ns	***
	205	*	***	*	***	***	**
	219	*	***	***	***	**	**
	247	-		ns	*	ns	*
	268	**	***	ns	***		
2019	190	ns	**	ns	***	*	**
	211	**	**	*	***	***	**
	253	ns	*	*	**	**	**

Table 2: Relationship between Crop Water Stress Index and Stem Water Potential (-bar) for different time intervals and dates in 2018 and 2019 (SWP = a + b·CWSI).

Year	Day of the year	Morning				Midday				Evening			
		a	b	R^2	Sig	a	b	R^2	Sig	a	b	R^2	Sig
2018	170	ns				1.50	9.98	0.68	***	ns			
	205	0.85	13.41	0.36	*	2.73	10.49	0.61	***	2.26	14.59	0.73	***
	219	3.49	16.72	0.67	***	3.62	10.24	0.63	***	1.38	13.09	0.69	***
	247	-				4.70	12.37	0.69	***	1.03	17.63	0.4	***
	268	2.35	10.51	0.37	*	ns				-			
	Global 2018	ns				-2.23	21.09	0.64	***	1.25	14.35	0.51	***
2019	190	ns				3.02	7.78	0.26	*	4.57	9.52	0.6	***
	211	-4.21	20.73	0.67	***	1.83	12.99	0.51	***	3.22	12.09	0.4	***
	253	ns				ns				ns			
	Global 2019	ns				0.57	12.48	0.32	*	3.32	10.48	0.39	*
Global 2018 and 2019						a= 1.70 b=13.12 R^2=0.45***							

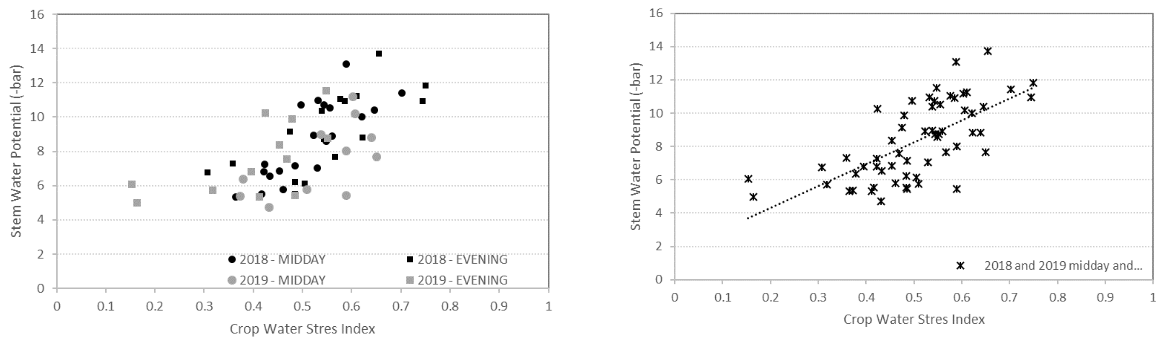

Figure 1: Relationship between CWSI and SWP in 2018 and 2019 at midday and evening (left) and all data pooled together (right).

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