

# THE USE OF WATER POTENTIALS IN IRRIGATION MANAGEMENT OF TABLE GRAPE GROWN UNDER SEMIARID CLIMATE IN TUNISIA

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## Abstract

**Aim :** To evaluate the usability of various plant water potentials in table grape irrigation management under a semiarid climate.

**Methods and results:** Two water regimes were set up. The « control » water regime was the one usually used in the vineyard. The « 50 % Irrigation » water regime delivered only half the quantity of water to the vines. Predawn leaf ( $\psi L_{PD}$ ), predawn stem ( $\psi S_{PD}$ ), midday leaf ( $\psi L_M$ ), and midday stem ( $\psi S_M$ ) water potentials were measured during the growing season. The results show that the four water potentials can accurately measure the vine water status in table grape vineyard at a daily and seasonal time scale. But,  $\psi L_M$  appeared to be the most reliable indicator to differentiate between the two water regimes with a frequency of 73 %. The « 50 % Irrigation » water regime induced in the 'Italia' cultivar an anisohydric behavior and a decrease of 29.4 % in vine vigor and 11.5 % in berry weight. Under the Tunisian climate, 'Italia' cultivar may exhibit night time transpiration that decreases  $\psi L_{PD}$  by 19.5 %.

**Conclusion :** Preliminary minimum  $\psi L_M$  threshold to produce high quality table grape would be -0.8 and -1.1 MPa for pre- and post-veraison, respectively.

**Significance and impact of the study:** The pressure chamber is an effective device for irrigation management in commercial table grape vineyards under semiarid conditions.

**Key words:** water potential, table grape, semiarid, anisohydric, night time transpiration

## Résumé

**Objectif :** Évaluer la performance de différents potentiels hydriques de la vigne dans la gestion de l'irrigation d'un vignoble de table conduit sous climat semi-aride.

**Méthodes et résultats:** Deux régimes hydriques ont été mis en place. Le premier, dénommé « control », est celui utilisé habituellement dans le vignoble. Le second, dénommé « 50 % Irrigation », apporte à la vigne la moitié de la quantité d'eau du premier. Le potentiel foliaire de base ( $\psi L_{PD}$ ), le potentiel tige de base ( $\psi S_{PD}$ ), le potentiel foliaire à midi ( $\psi L_M$ ) et le potentiel tige à midi ( $\psi S_M$ ) ont été mesurés durant une saison. Les résultats montrent que ces quatre potentiels décrivent convenablement le statut hydrique de la vigne à l'échelle de la journée et du cycle végétatif. Cependant,  $\psi L_M$  semble être l'indice le plus fiable, capable de différencier entre les deux régimes hydriques avec une fréquence de 73 %. Le stress induit par le régime hydrique « 50 % Irrigation » s'est traduit chez la vigne de variété « Italia » par un comportement de type anisohydrique ainsi que par une baisse de 29.4 % de la vigueur et de 11.5 % du poids moyen de la baie. Sous le climat tunisien, cette variété est capable de transpiration nocturne qui peut baisser son  $\psi L_{PD}$  de 19.5 %.

**Conclusion :** Il a été possible d'établir des seuils préliminaires de  $\psi L_M$  pour une production d'un raisin de table de qualité : -0.8 MPa avant véraison et -1.1 MPa après véraison.

**Signification et impact de l'étude :** La technique de la chambre à pression s'avère être efficace pour la gestion de l'irrigation d'un vignoble de table sous climat semi-aride.

**Mots clés :** potentiel hydrique, raisin de table, semi aride, anisohydrique, transpiration nocturne

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## INTRODUCTION

Irrigation is necessary for table grape production under semiarid climates, where water is often the major limiting resource. For that reason, good water management is essential to achieve high water-use efficiency. Therefore, viticulturists need high performance tools for irrigation management to reach both good yields and high quality grapes.

Many methods are now available for that purpose, ranging from basic approaches that use climatic data to compute crop evapotranspiration (Allen *et al.*, 1998) to sophisticated “physiological tools” that use, for example, linear displacement transducers (Cifre *et al.*, 2005). One method in particular, the pressure chamber technique (Scholander *et al.*, 1965), has been widely used in vineyard irrigation management. There is abundant literature about the use of pressure chamber in wine grape production (Van Zyl, 1987; Choné *et al.*, 2000; Ojeda *et al.*, 2002; Williams and Araujo, 2002), but its use in table grape production is less documented (El-Ansary *et al.*, 2005; Du *et al.*, 2008).

Irrigation management strategies in wine and table grape production are very different. For the former, the frequency and amount of water supply are generally low, leading to a moderate water stress for the vine, which is known to be a key factor to obtain high quality wines (Van Leeuwen *et al.*, 2009). In contrast, water stress in table grape production (especially early in the growing season) can lower grape quality by reducing berry weight (Ojeda *et al.*, 2001). To avoid this, the quantities of water applied to table grape production in semiarid regions are substantial. They exceed 350 mm/year in southern Italy (Colapietra, 2004) and even 560 mm/year in Australia (Coombe and Dry, 2005).

With the pressure chamber technique, several parameters can be measured and used as water stress indicators: predawn leaf water potential, midday leaf water potential and midday stem water potential. The use of each indicator to assess grapevine water constraint is reported in the work of Myburgh (2011). Predawn leaf water potential and stem water potential appear to be the most reliable indicators.

The first objective of this study is to evaluate the efficiency of the pressure chamber technique in managing irrigation of table grape production under Tunisian semiarid conditions. The second objective is to determine which of the water potentials mentioned above is best to detect differences in grapevine water status under two water regimes. Since there is increasing evidence that night time transpiration

significantly affects plant water status (Rogiers *et al.*, 2009), the third objective of this study is to evaluate the use of the pressure chamber technique to quantify the contribution of night time transpiration to plant water status.

## MATERIALS AND METHODS

### 1. Experimental vineyard

The experiment was carried out during summer 2011 in a ten-year-old commercial vineyard located in the region of Ben Arous (lat. 36°39'N, long. 10°12'E), in Tunisia. Tonietto and Carbonneau (2004), in their climatic classification system for grape-growing regions, classify the Tunis-Carthage area, near the study site, as very warm on the heliothermal index, with very warm nights on the night cold index and very dry on the dryness index. The vines are *Vitis vinifera* L. cv ‘Italia’ grafted on 1103 P rootstock, planted in 2003 at a spacing of 2.5 x 2.5 m, and trained to the Italian “tendone” system. Plants were drip irrigated with two 8 L/h on-line pressure compensating emitters placed at 1.8 m height and using water with 3.12 dS m<sup>-1</sup> electrical conductivity. Vineyard soil was a homogenous deep fine silty clay (45 % clay: 20.5 % silt: 34.5 % sand), with 0.75 % organic matter, 11.9 % active CaCO<sub>3</sub>, a saturated paste electrical conductivity of 2.82 dS m<sup>-1</sup>, and pH of 8.75.

### 2. Experimental layout

Two rows of 41 vines each were used in this study to create two different irrigation regimes. The first row was equipped with 8 L/h emitters like the rest of the vineyard rows and considered as the “control”. The second row, “50 % Irrigation”, was equipped with 4 L/h emitters instead. The frequency and duration of irrigation were the same for both rows. In the vineyard, “control” and “50 % Irrigation” vines were separated by three rows (i.e., at a distance of 8 m from each other).

Because the experiment was set up in a commercial vineyard, the water regime could only be applied to the whole vine row. To eliminate any possible row vigor interference with the irrigation experiment results, vigor homogeneity of the vines of the two rows was tested in winter 2011 using the average cane diameter as vigor index (Champagnol, 1984). It was measured with a digital caliper on the fifth node of all the canes of each vine in the two irrigation regime rows. The results of the ANOVA (data not shown) clearly indicate that there is no significant difference between the two rows, in terms of vine vigor. Average cane diameters were 10.23 and 10.17 mm for “control” and “50 % Irrigation” vines, respectively.

### 3. Irrigation management

Irrigation management was achieved using a simplified water balance equation:  $I = Kc \times ET_0 - P$ , where  $I$  is the irrigation water supply on a daily basis,  $Kc$  is the crop coefficient for 'Italia' table grape trained to "tendone" system as proposed by Colapietra (2004),  $ET_0$  is the evapotranspiration calculated using the Penman-Monteith equation with climatic data from on site weather station (Oregon scientific® WM 918), and  $P$  is precipitation measured at the weather station. The quantity of irrigation water applied to the vineyard (i.e., "control" vines) was precisely measured using a Woltman type water meter. Figure 1 shows the evolution during the growing season of the simplified water balance parameters and points out the lack of water supply at the end of the growing season. Total amount of irrigation water for the considered growing season was 4947 m<sup>3</sup>/ha.

### 4. Water potential measurement

A pressure chamber PMS (Albany, USA) model 600 was used for water potential measurements. They were performed on fully expanded leaves chosen on primary shoots, just above the fruit zone and collected on the outer layer of the canopy on the shaded side, depending on sun position. This was made to reduce variation in leaf potential due to variations in direct sun-light exposition. For each irrigation regime, values of water potentials are means of five measurements collected on five randomly chosen separate vines.

Leaf water potentials were measured on uncovered leaves, while stem water potentials were measured on leaves that were covered several hours prior to measurement with both plastic sheet and aluminum foil.

Vine water potentials were assessed between the end of April and the end of September 2011. Measurements were done approximately once a week. In April and May, measurements were performed every two hours, from 0400 hr to 1600 hr. June to September measurements were performed only at 0400 hr and 1200 hr. The 0400 hr data of uncovered leaves was used as predawn leaf water potential ( $\psi_{L_{PD}}$ ) while that of covered leaves was used as predawn stem water potential ( $\psi_{S_{PD}}$ ). The 1200 hr data of uncovered leaves was used as midday leaf water potential ( $\psi_{L_M}$ ) while that of covered leaves was used as midday stem water potential ( $\psi_{S_M}$ ).

### 5. Vine growth measurement

The impact of water regime on vine growth was assessed using (1) shoot growth during spring and (2) average cane weight, both considered as vigor indices by Champagnol (1984). Shoot growth was measured on 10 marked shoots per irrigation regime chosen on 10 separate vines, once a week from the end of April to the beginning of June 2011.

Average cane weight was calculated as vine pruning weight divided by the number of cane per vine. It was determined on 38 vines per water regime in February

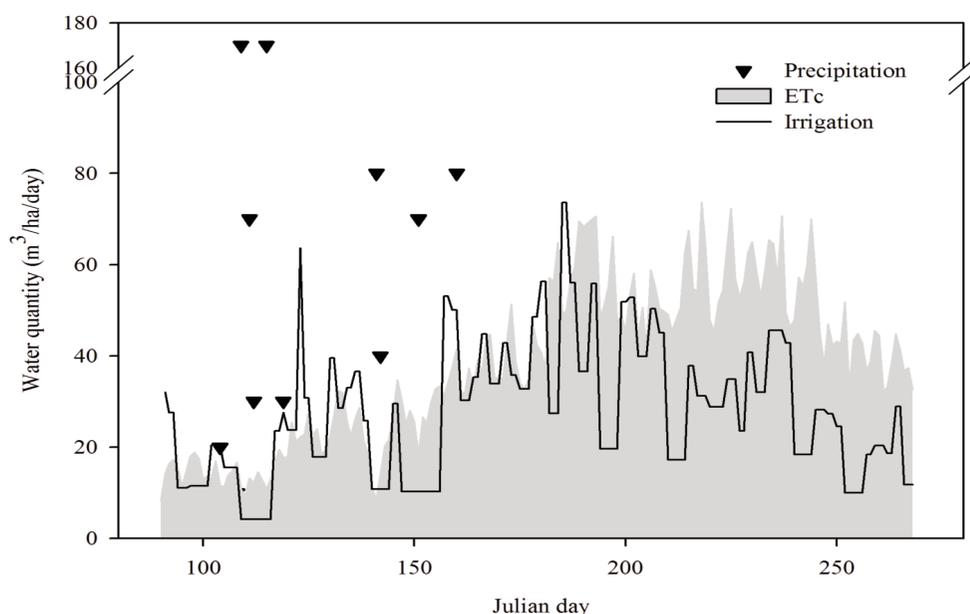


Figure 1. Vineyard (i.e., "control" vines) irrigation management during the growing season in 2011.

2012. Weight determination included main and lateral shoots.

### 6. Grape quality assessment

Grape ripeness was assessed from veraison until harvest at approximately one-week intervals. To determine berry quality, three to five berries from randomly selected clusters and vines were sampled to obtain a 200-berry sample for each irrigation regime. The total weight of the 200-berry samples was determined to estimate average berry weight during ripening. Then, each sample was hand pressed in a net and the juice was used to determine total soluble solids (°Brix) with an “Atago” RX-5000 digital refractometer. Titratable acidity (g/L tartaric acid) was determined by titration with 0.1 N NaOH using phenolphthalein as indicator.

At harvest, 10 random clusters per irrigation regime were selected to determine the average cluster weight and the number of berries per cluster. Average berry weight at harvest for each sampled cluster was finally calculated.

## RESULTS AND DISCUSSION

### 1. Diurnal evolution of water potentials

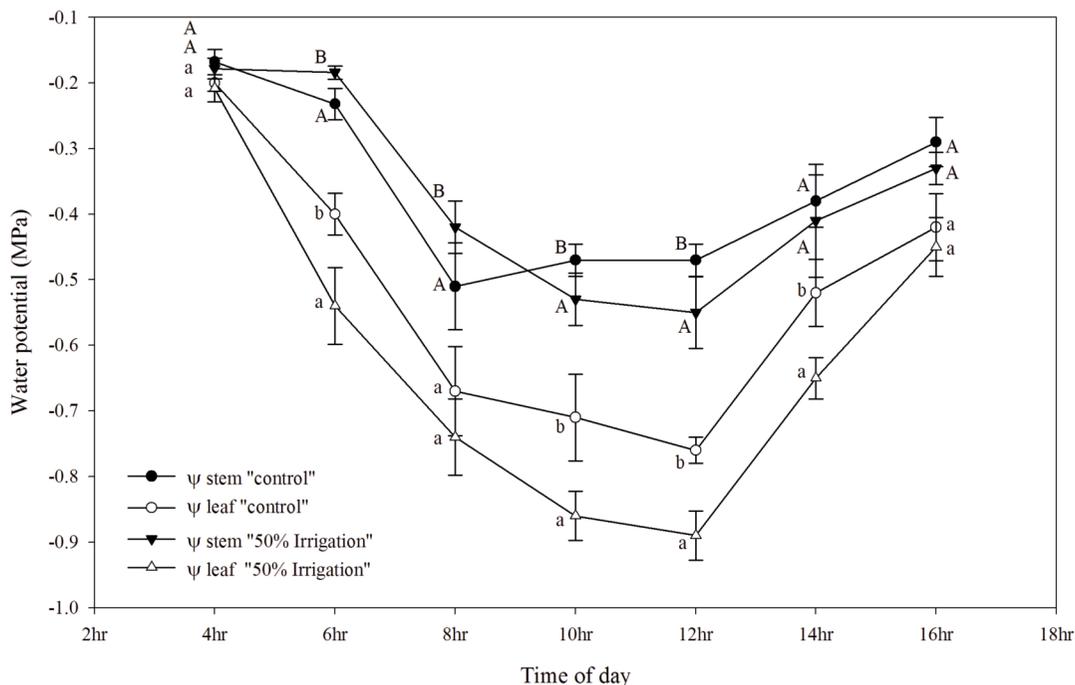
To give an example of typical diurnal evolution of vine water potentials, data of leaf and stem water potentials

measured throughout the day at the end of the flowering stage on 26 May 2011 are presented in Figure 2. The curves are typical and show significant differences between the two irrigation regimes. For leaf potentials, the “50 % Irrigation” vines had lower water potentials than “control” vines all day long. However, for stem potentials, the difference between “control” and “50 % Irrigation” vines was not so clear. The “50 % Irrigation” vines had a more favorable water status than the “control” vines, from sunrise to mid-morning, but this trend reversed during the rest of the day.

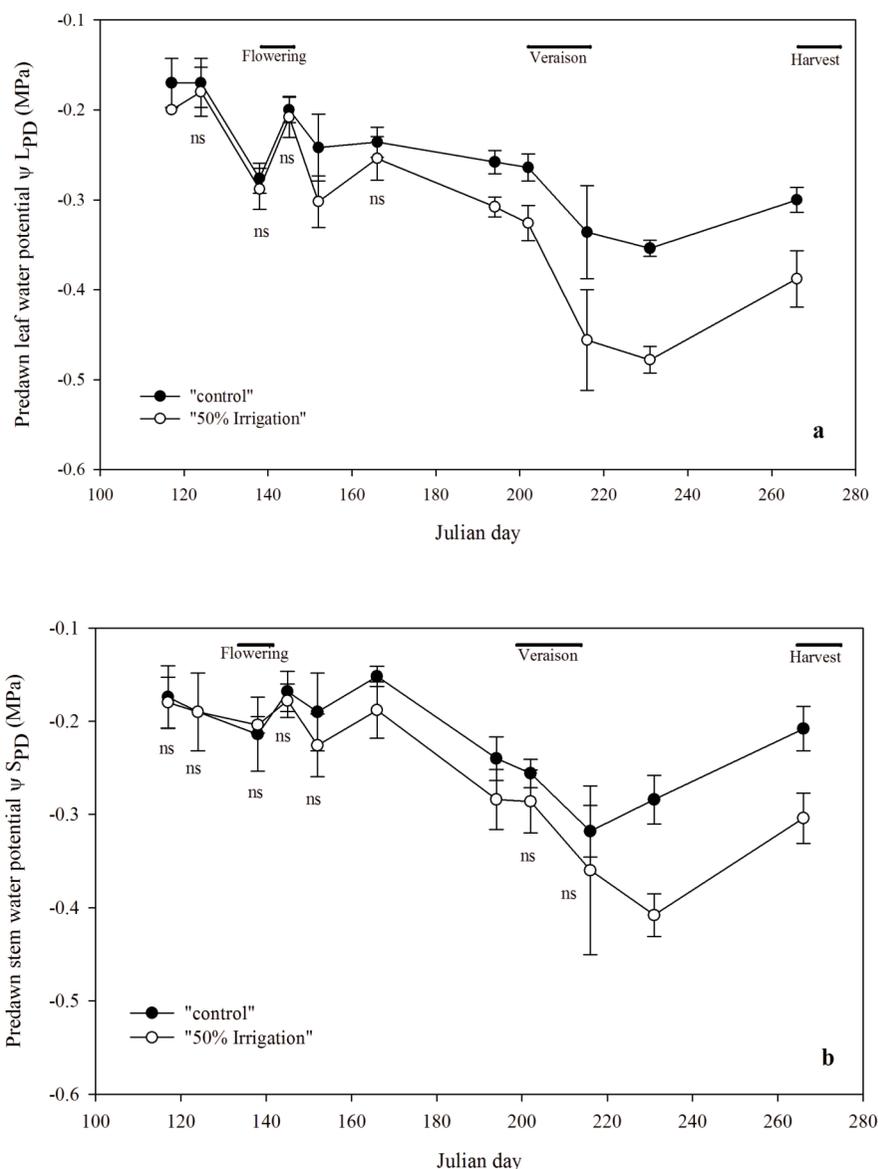
As expected, differences in water status during the day between the two irrigation regimes were easily detected with the pressure chamber technique. However, according to the review by Myburgh (2011), the water potential values measured in our study indicated no water stress for either irrigation regimes as  $\psi_{L_{PD}} > -0.2$  MPa and  $\psi_{L_M} > -1$  MPa.

### 2. Seasonal evolution of water potentials

In order to compare the water status of “control” and “50 % Irrigation” vines during the growing season, predawn water potentials ( $\psi_{L_{PD}}$  and  $\psi_{S_{PD}}$ ) are presented in Figure 3 and midday water potentials ( $\psi_{L_M}$  and  $\psi_{S_M}$ ) in Figure 4.



**Figure 2. Diurnal evolution of vine water potentials during flowering. Letters indicate significant difference between “control” and “50 % Irrigation” vines as derived from ANOVA at the 5 % probability level : lowercase letters for leaf potential, uppercase letters for stem potential.**



**Figure 3. Evolution of predawn leaf (a) and stem (b) water potentials over the season. “ns” not significant at the 5 % probability level.**

From Figure 3A and B, it can be concluded that differences in water status estimated by  $\psi_{L_{PD}}$  and  $\psi_{S_{PD}}$  could not be detected at the beginning of the growing season. This can be explained by high water availability due to spring rainfall (Figure 1). Later on, differences between the two water regimes appeared, especially for  $\psi_{L_{PD}}$ . Minimum seasonal  $\psi_{L_{PD}}$  values were -0.35 and -0.47 MPa for “control” and “50 % Irrigation” vines, respectively. This happened post-veraison, around mid-August.

Deloire *et al.* (2004) reported wine grape water stress thresholds using  $\psi_{L_{PD}}$  of -0.2, -0.4 and -0.6 MPa for mild, moderate and severe water stress, respectively.

Our values indicated that “control” vines experienced mild to moderate water stress, while “50 % Irrigation” vines experienced moderate to severe water stress. However, it should be pointed out that Deloire *et al.* (2004) references were developed for wine grapes, which are known to require less water than table grapes.

The differences between “control” and “50 % Irrigation” vine water status were also detectable using midday leaf ( $\psi_{L_M}$ ) and stem ( $\psi_{S_M}$ ) potentials (Figure 4A and B). Leaf water potential appeared to be a better indicator because differences between “control” and “50 % Irrigation” were greater.

Minimum seasonal  $\psi_{L_M}$  values (reached during fruit ripening) were -1.11 and -1.30 MPa for “control” and “50 % Irrigation” vines, respectively. According to Greenspan (2005) and Girona *et al.* (2006) cited by Myburgh (2011), this indicates a mild water stress for “control” vines and a moderate water stress for “50 % Irrigation” vines.

For  $\psi_{S_M}$ , minimum values during the season were 0.98 MPa for “control” and 1.03 MPa for “50 % Irrigation” vines, which indicated, according to Ojeda (2007), a favorable water status leading to moderate vine vigor and high quality grapes, in part due to a reduced berry weight.

The monitoring of predawn and midday water potentials during the growing season allowed us to notice that gradual water constraint was occurring in both irrigation regimes. The constraint increased around veraison, when the irrigation water supply became insufficient to counterbalance crop evapotranspiration (Figure 1). Its maximum was reached during grape ripening. Later on, water potentials rose gradually, in part thanks to autumn rainfall. This evolution during the season is in line with the theoretical model proposed by Ojeda (2007) for a precision qualitative irrigation. Therefore, plant water potentials can be used for the assessment of vine water status in table grape production.

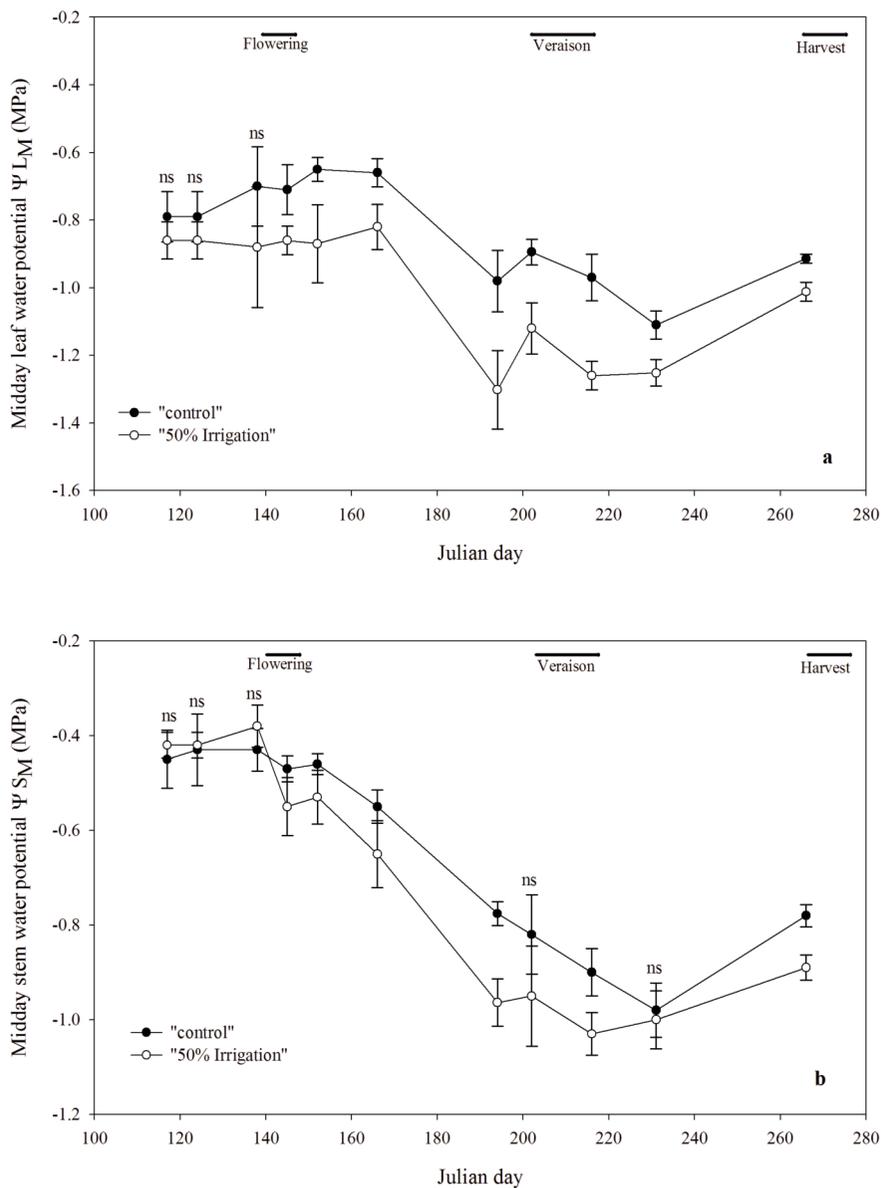


Figure 4. Evolution of midday leaf (a) and stem (b) water potentials over the season. “ns” not significant at the 5 % probability level.

For further investigation of  $\psi L_{PD}$ ,  $\psi L_M$ ,  $\psi S_{PD}$ , and  $\psi S_M$  effectiveness to differentiate between the two water regimes, the statistical difference between “control” and “50 % Irrigation” vines at each of the 11 dates of measurement was evaluated using ANOVA. The total count of significant differences between “control” and “50 % Irrigation” vines during the growing season was recorded. Then, the frequency of significant differences was calculated with regards to the 11 dates of measurement.

The results reported in Table 1 show that  $\psi S_{PD}$ ,  $\psi S_M$ ,  $\psi L_{PD}$  and  $\psi L_M$  water potentials were unable to detect differences between “control” and “50 % Irrigation” vines with a frequency of 36 %, 55 %, 64 % and 73 %, respectively. This clearly indicates that midday leaf water potential ( $\psi L_M$ ), as measured in this study on shaded outer leaves of the canopy, was the most reliable indicator of differences in table grape water status under the two irrigation regimes. Our results agree with those of Sousa *et al.* (2006) showing that midday leaf water potential together with sap flow and transpiration measurements are better correlated to soil water content than predawn leaf water potential. In contrast, Choné *et al.* (2000) found that midday leaf water potential was a less significant indicator of water constraint than midday stem water potential because the latter was more correlated to transpiration flow.

Patakas *et al.* (2005) came to similar conclusions, but these differences were not statistically tested.

It is worth mentioning that Williams and Araujo (2002) have demonstrated that predawn leaf water potential and midday leaf and stem water potentials are highly correlated and represent equally viable methods for assessing the water status of grapevines.

### 3. Cultivar adaptation to water stress

For Poni *et al.* (2007), the first criterion to classify grapevine genotypes as being isohydric or anisohydric is how their leaf water status responds to a soil water deficit treatment. According to this, the ‘Malagouzia’ cultivar was considered isohydric by Patakas *et al.* (2005) because irrigated and stressed grapevines in an experiment in Greece showed no leaf water potential differences. In our case, we believe that the ‘Italia’ cultivar is anisohydric as “50 % Irrigation” vines had significantly lower plant water potentials than “control” vines.

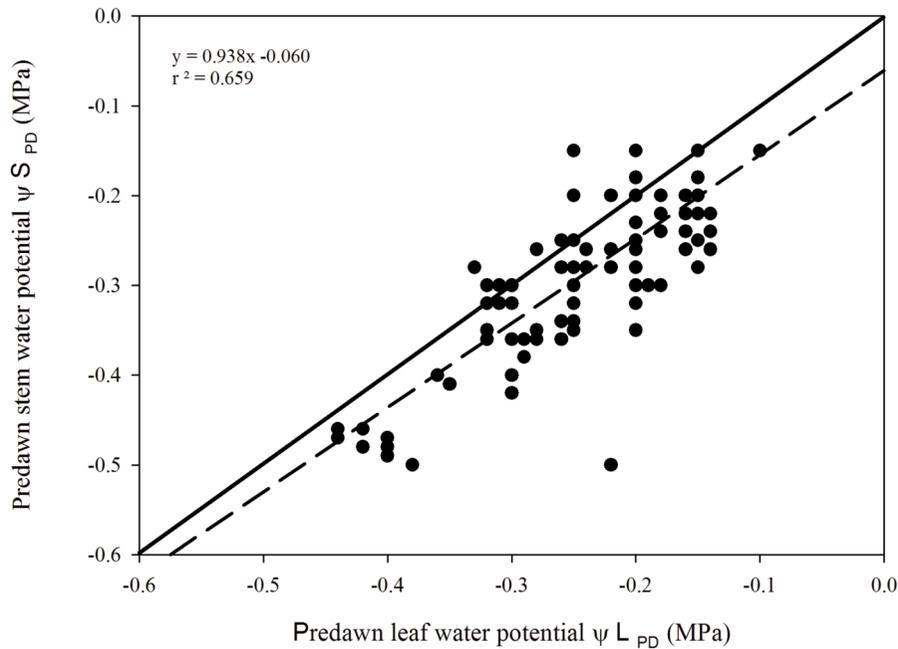
### 4. Evidence for night time transpiration

For each measurement date, the  $\psi L_{PD}$  and  $\psi S_{PD}$  values determined on five “control” and five “50 % Irrigation” vines (i.e., a set of 110 measurements) were compared (Figure 5). The highly significant determination coefficient ( $r^2 = 0.659$ ) indicates a

**Table 1. Statistical differences between “control” and “50 % Irrigation” vines relative to the various plant water potentials**

Julian day	Phenology	Plant water parameters			
		$\psi S_{PD}$	$\psi S_M$	$\psi L_{PD}$	$\psi L_M$
117		0,764	0,346	0,039	0,127
124	Flowering	1	0,788	0,579	0,127
138		0,598	0,115	0,37	0,096
145		0,449	0,028	0,523	0,004
152		0,172	0,033	0,02	0,003
166		0,037	0,022	0,207	0,001
194		0,038	***	***	***
202	Véraison	0,106	0,063	***	***
216		0,35	0,002	0,007	***
231		***	0,607	***	***
266	Harvest	***	***	***	***
Total count of significant differences		4	6	7	8
Frequency of significant differences		36%	55%	64%	73%

\*\*\*  $P < 0.0001$  (ANOVA),  $\psi S_{PD}$ : predawn stem potential,  $\psi S_M$ : midday stem potential,  $\psi L_{PD}$ : predawn leaf potential and  $\psi L_M$ : midday leaf potential



**Figure 5. Correlation between predawn leaf and stem water potentials. Data used are those of “control” and “50 % Irrigation” measurements.**

strong positive correlation between predawn leaf and stem water potentials. However, the linear regression shows clearly that  $\psi L_{PD}$  was always lower than  $\psi S_{PD}$ . The former was measured on uncovered transpiring leaves, while the latter was measured on covered non-transpiring leaves. The average  $\psi L_{PD}$  and  $\psi S_{PD}$  values over the growing season were -0.235 and -0.281 MPa, respectively. The average difference between  $\psi L_{PD}$  and  $\psi S_{PD}$  was 0.046 MPa. This difference is likely to be due to night time transpiration. In our case study, night time transpiration induced a decrease of 19.5 % in predawn leaf water potential, under the Tunisian semiarid climate classified by Tonietto and Carbonneau (2004) as very dry with very warm nights.

Rogiers *et al.* (2009) have demonstrated that the anisohydric cultivar ‘Sémillon’ has higher values of night time transpiration than other wine grape varieties grown in Australia. For this particular cultivar, this has been shown to be the result of insufficient stomatal regulation. These findings support our classification of ‘Italia’ as an anisohydric cultivar for which night time transpiration decreases predawn water potential.

## 5. Impact of water regime on vine growth and grape quality

### *Vine growth*

As expected, different water regimes resulted in different vine shoot growth during spring (Figure 6).

These differences appeared prior to flowering. At that stage, only midday leaf water potential ( $\psi L_M$ ) was able to detect differences between “control” and “50 % Irrigation” vines. This is additional evidence that  $\psi L_M$  is an effective water status indicator.

Water regime also affected vine vigor in this study. Average cane weights measured at the end of the growing season were 119 and 84 g for “control” and “50 % Irrigation” vines, respectively. This difference was statistically significant ( $P = 0.000074$ ). So, a reduction of 50 % in the irrigation water amount induced a decrease of 29.4 % in vine vigor. Gouveia *et al.* (2011) reported similar results for the wine grape cultivar ‘Touriga Nacional’ in a deficit irrigation experiment. Average cane weight was reduced by 7.6 %, decreasing from 7.9 to 7.3 g for full irrigation and 50 % irrigation, respectively.

### *Grape quality*

At harvest, several table grape quality parameters were investigated. The “control” vines had an average cluster weight of 995 g compared to 901 g for the “50 % Irrigation” vines, but this difference was not significant ( $P = 0.192$ ). The number of berries per cluster was also not significantly different ( $P = 0.346$ ): 142 for “control” and 154 for “50 % Irrigation” vines. In contrast, the difference in average berry weight at harvest was significant ( $P = 0.047$ ): 6.9 and 6.1 g for “control” and “50 % Irrigation”, respectively. So, the 50 % reduction in the amount of

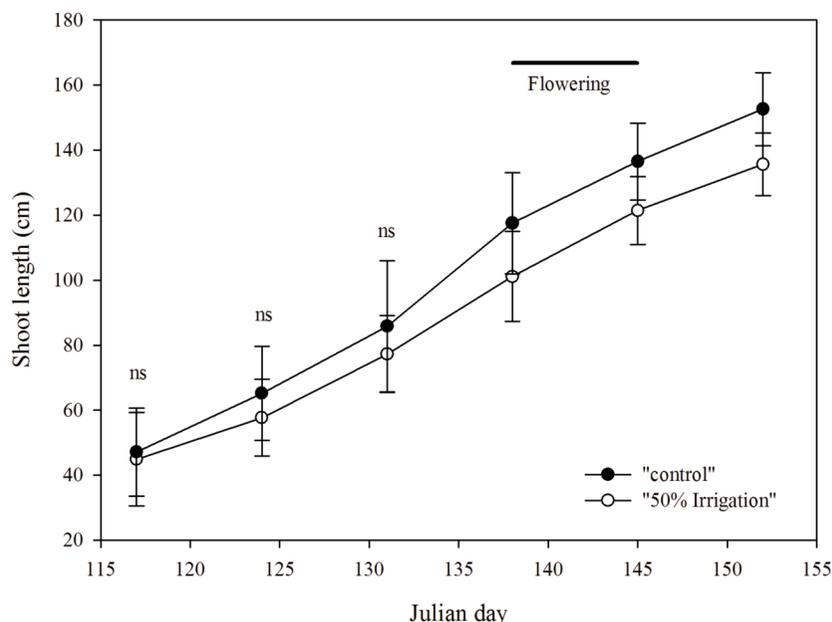


Figure 6. Vine shoot growth during spring 2011. “ns” not significant at the 5 % probability level.

water supply resulted in a decrease of 11.5 % in berry weight. This difference in berry weight appeared soon after veraison and persisted until harvest (Figure 7A). As berry weight is a crucial qualitative character in table grape production (Mattheou *et al.*, 1995), reducing water supply in this experiment had a negative impact on grape quality even though total soluble sugar and titratable acidity were equivalent for “control” and “50 % Irrigation” vines (Figure 7B).

## CONCLUSION

Our results show that the various water potentials measured with the pressure chamber technique can be used to assess the vine water status in a table grape vineyard. Midday leaf potential ( $\psi_{LM}$ ) appeared to be the most reliable indicator. Thus, the pressure chamber can be an effective device for irrigation management in commercial vineyards.

Some evidence in this study suggests that the ‘Italia’ cultivar has an anisohydric behavior. This hypothesis should be confirmed by a study of stomatal response of ‘Italia’ to soil water status and air vapor pressure deficit.

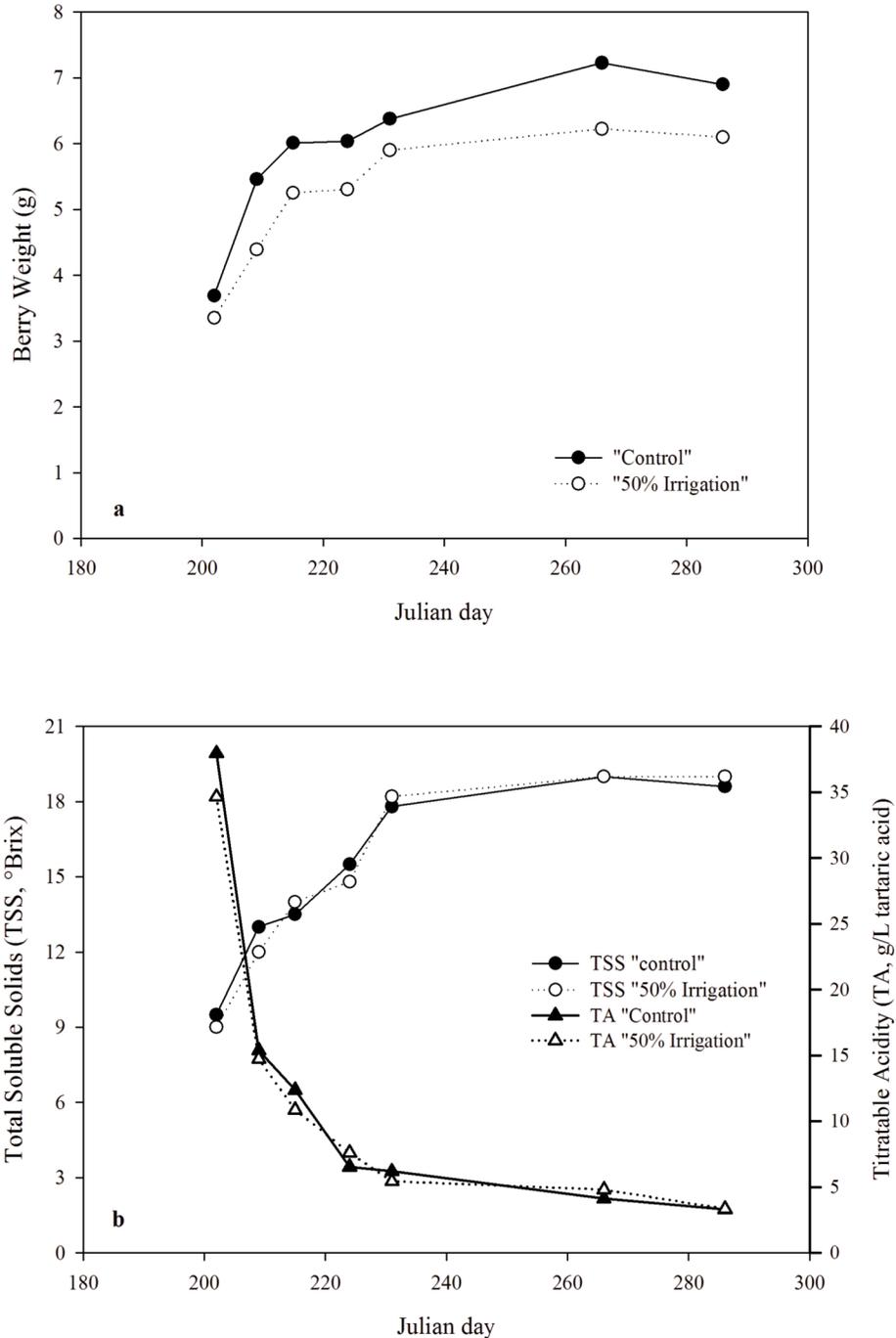
In our environmental conditions, night time transpiration occurring in ‘Italia’ induced a decrease of predawn leaf potential. Thus, nocturnal transpiration can be a significant component of the vine daily total water consumption. This should be considered when estimating vine water requirements under semiarid climates.

So far, the only available water stress thresholds were developed for wine grape. Taking into account our results on the impact of induced water stress on vine water potentials and grape quality parameters, the minimum midday leaf water potential threshold to produce high quality table grape would be -0.8 and -1.1 MPa for pre- and post-veraison, respectively. Further investigations are needed to confirm these threshold values in connection with physiological parameters (e.g., photosynthesis and transpiration rates) as well as quality parameters (e.g., berry color, firmness, etc.).

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**Figure 7. Evolution of grape quality parameters during summer 2011. (a) Berry weight and (b) Berry sugar content and titratable acidity.**

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