# WATER ECONOMY BY ITALIA GRAPEVINES UNDER DIFFERENT IRRIGATION TREATMENTS IN A MEDITERRANEAN CLIMATE

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## Abstract

**Aims**: A study was conducted to compare traditional vineyard irrigation (TI) using one drip emitter per vine, and partial root zone drying irrigation (PRD) using two drip emitters per vine (one per each vine side), at 2 rates of water application (controlled deficit (TI4 and PRD4) and non limiting (TI8 and PRD8)).

**Methods and results**: Individual vine transpiration and vine water status were estimated from sap flow measurements by a stem heat balance method and midday stem water potential. The quality of the harvest was not significantly changed by the treatments. However, the vegetative growth was lower for the low irrigation rate treatments (TI4 and PRD4) and the PRD8 (compared to TI8). The total amount of water transpired by the vines during the season was estimated to 147 l/m$^2$ without water limitation. A limiting water supply (TI4) lessened vine water use and improved the fraction of supplied water trapped by the vines (81 % for TI4 and 66 % for TI8). PRD decreased the transpiration of the vines, but also the efficiency of use of irrigation water.

**Significance and impact of study**: Limited water supply saved water and improved the water capture efficiency by the roots of the vines. PRD irrigation saved water but the vine water capture efficiency was lower, limiting the practical interest of the method.

**Key words**: evapotranspiration, sap flow, water potential, *Vitis vinifera*, table grape

## Résumé

**Objectif** : Une expérimentation dans un vignoble commercial marocain a été conduite pour comparer l'irrigation traditionnelle (TI) avec un goutteur par cep et l'irrigation alternée (PRD) avec deux goutteurs disposés de part et d'autre des ceps sur le rang. Le régime d'irrigation était soit limitant (déficit hydrique contrôlé, TI4 et PRD4) ou non limitant (TI8 et PRD8).

**Résultats et conclusion** : La mesure du flux de sève de ceps représentatifs a permis d'estimer la transpiration des vignes. Leur statut hydrique a été évalué par la mesure du potentiel hydrique de tige à midi. La qualité des raisins à la récolte n'a pas été modifiée par le type et l'intensité de l'irrigation. Cependant la croissance végétative des vignes irriguée selon les modalités TI4 et PRD4 et PRD8 était diminuée comparé au traitement TI8. La quantité totale d'eau transpirée par les vignes irriguée sans limitations (TI8) de la nouaison à la récolte a été estimée à147 l/m$^2$. Avec une irrigation limitante (TI4) la vigne consomme moins d'eau et capte plus efficacement l'eau apportée par l'irrigation (81 % pour TI4 contre 66 % pour TI8). L'irrigation alternée réduit la consommation d'eau de la vigne mais l'efficacité d'utilisation de l'eau apportée est plus faible, ce qui limite l'intérêt de cette technique d'irrigation.

**Signification et impact de l'étude** : L'irrigation limitante permet une économie significative d'eau d'irrigation d'une vigne de raisins de table. L'irrigation alternée n'améliore pas la réponse de la vigne soumise à un déficit hydrique contrôlé. Un modèle de bilan hydrique publié précédemment a été validé dans cet essai pour l'irrigation traditionnelle. Il peut être utilisé pour programmer l'irrigation d'une vigne pour atteindre un déficit hydrique optimal qui permet d'économiser de l'eau et de préserver la qualité de la récolte.

**Mots clés** : evapotranspiration, potentiel hydrique, flux de sève, *Vitis vinifera*, raisin de table

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## INTRODUCTION

In a Mediterranean climate with hot and dry summer, irrigation is absolutely necessary for grapevine to secure the production (CIFRE *et al.*, 2005). Irrigation is especially beneficial to productivity and fruit quality of table grape. Table grape acreage in Morocco is constantly increasing due to growing demand of both the local market and the export market to Europe. However, irrigation is becoming a limiting factor, a consequence of limited water resources, increased planted surfaces and more frequent drought events. Therefore, grape growers need quantitative information to determine how much water is needed and how to increase water application efficiency (CHONÉ *et al.*, 2001; GIRONA *et al.*, 2006; KOUMANOV *et al.*, 2006, WILLIAMS and BAEZA, 2007). The research objectives for table grape vineyards are actually to save water without affecting the yield and berry quality. Controlled deficit irrigation (DI) and partial root drying (PRD) have emerged as promising techniques to save water in grape production (DRY *et al.*, 1996; SMITH *et al.*, 2000). However the improvement of the water economy in a commercial vineyard is still not fully demonstrated when PRD is compared to regulated deficit irrigation (BRAVDO, 2005; DOSSANTOS *et al.*, 2003; LANTZKE, 2004)

Deficit irrigation (DI) and partial root zone drying can improve the vine water use efficiency, keeping the normal fruit growth and impeding late grapevine vegetative growth (LOVEYS *et al.*, 2001; WAMPLE and SMITHYMAN, 2000). In DI, water is supplied to compensate for only a part of the potential transpiration of the vines. Soil moisture depletion causes shoot growth to slow down and stomatal closure in relation to the leaf predawn leaf water potential (SCHULTZ, 2000). As a consequence, grapevine transpiration rate decreases. It has been shown that a well fitted DI program is an effective way to control shoot growth before fruit maturation stage (before veraison) without negative effects on fruit development (CHAVEZ *et al.*, 2007). However, after veraison, DI may trigger excessive water stress in large canopy vineyards (WAMPLE and SMITHYMAN, 2000). When only a part of the grapevine root system is slowly dried whereas the remaining roots are kept well watered, a chemical signals produced by the drying roots decreases stomatal aperture and plant transpiration (DRY *et al.*, 2000a, b). An increase of abscisic acid (ABA) was observed in xylem sap, due to both a synthesis of ABA initiated in the drying roots and in situ ABA synthesis following a leaf water potential fall. Using split-root plant experiments it has been shown that the recovery of shoot function of partly dried grapevine roots occurred within 5 to 10 days, depending on the soil type, the size of the root system, the number of dried root tips, the rate of soil drying, the growth stage of the plants and the genotype (DRY *et al.*, 2000a). During the night, water flows from the roots of the irrigated side towards the 'dry' roots (DRY *et al.*, 2000b). The use of sap flow sensors installed on the roots of potted grapevines demonstrated that water movement does occur under the influence of the water potential gradient between the 2 root zones resulting from PRD irrigation (LOVEYS *et al.*, 2001).

The improvement of water use efficiency by applying DI or PRD irrigation is related to a lower stomatal conductance and consequently, a reduction of the plant transpiration from its crop coefficient value that is estimated from the solar radiation partition between the plants and the soil surface (RIOU *et al.*, 1994). In order to estimate precisely the vineyard water consumption, the stomatal control on transpiration must be taken into account. RITCHIE (1981) showed a relationship to exist between the crop water use and the fraction of the total transpirable soil water (FTSW). FTSW is calculated after evaluating the total soil water transpirable by the crop (TTSW) at the beginning of the growing season. FTSW is exponentially related to soil water potential (RAWLS *et al.*, 1982). A linear relationship between the soil water potential and the ratio of actual to potential transpiration of the canopy was used to modelize the transpiration control by the crop (PIERI and GAUDILLÈRE, 2005).

The relationship between FTSW and control of grapevine leaf transpiration rate has already been reported (SCHULTZ, 1997) and used in an integrated grapevine water use model (LEBON *et al.*, 2003). This model allows estimating rain fed vineyard water use all along the growing season, from bud burst to leaf fall. However the stomatal regulation function was not directly validated at the canopy level.

The objectives of the present study are: a) to quantify the grapevine water requirement for the main trellis system used in Morocco table grape vineyards, b) to test a water balance model suitable for scheduling irrigation, and c) to study the efficiency of different irrigation programs to improve water economy, promoting commercial productivity and fruit quality of Italia grapevines in Morocco.

## MATERIAL AND ANALYTICAL AND EXPERIMENTAL METHODS

The study was conducted in a drip irrigated commercial vineyard at Skhirate, close to the Atlantic coast and 20 km South of Rabat, Morocco (33° 75' N, 7° 08' W, altitude: 75 m). The soil was 55% sand and slightly acid (pH = 5.1). *Vitis vinifera* L., cv. Italia, 8 years old vines grafted on 110 Richter rootstock, were planted in South East - North West rows. Row and vine spacing were 3.0 and 1.5 m, respectively. The vines were head-trained at 0.7 m and pruned to four canes with 6 to 8 buds each. The trellis system in this vineyard was a double T. The lower crossarm was 0.4 m wide, at height 0.8 m above the soil whereas the upper crossarm was 0.8 m wide, 0.4 m above the first. The fruiting canes were tied to the lower crossarm.

The treatments were traditional irrigation (TI) using one drip emitter per vine, of 4 or 8 L/h (TI4 and TI8, respectively) and partial root zone drying irrigation (PRD), using two lines of drip emitters per vine, one on each vine side, 0.75cm apart from the row, of 4 or 8 L/h, (PRD4 and PRD8, respectively). These treatments were combined in a split-plot experimental design replicated four times, with irrigation practice as the main plot, and drip emitter as subplot. Each individual plot contained 16 vines. Water was delivered daily, simultaneously to all plots, during $^1/_2$ hour per day from day 90 to day 137 (0.45 and .90 mm/day) or 1 hour from day 137 to day 210, the harvest time (0.90 and 1.8 mm/day). For PRD treatments, water was applied to one side only of the vine for 14 days and then switched to the other side the next 14 days.

Vine transpiration was estimated from trunk sap flow rate measurements on four representative plants (one representative vine per treatment) along the days 102 to 185. A stem heat balance method (VALANCOGNE *et al.*, 2000; VALANCOGNE and NASR, 1993) was used. The measurements of temperature differences were obtained from thermocouple probes inserted into the stem. The outputs from the sensors were monitored by a Campbell Scientific CR10X data-logger at intervals of 10 s and the sap flow rates calculated from the temperature measurements were averaged every 15 min. The daily sap flow that was assumed to measure vine transpiration was computed by adding all sap flow rates measured during the day. The volumetric flux per vine in L/day was converted into mm/day (or L/($m^2$.day)) taking into account an area of 4.5 $m^2$ of ground per vine.

Solar radiation above the vineyard and canopy air temperature were monitored and stored in a data-logger, while relative humidity and wind speed were obtained from Institut Agronomique et Vétérinaire Hassan II (Rabat, Morocco) weather station, 20 km away, to calculate potential evapotranspiration (PET) using the modified Penman-Monteith equation (ALLEN *et al.*, 1998). The vine transpiration (TR) calculation was based on the solar radiation partition between the vine and the soil (LEBON *et al.*, 2003; RIOU *et al.*, 1989). The input parameters are the soil water reserve available to the plants (TTSW), the height, the width and the porosity of the foliage, the azimuth of the rows, the latitude of the plot and the date. Climatic data are daily mean temperature, potential evapotranspiration and rainfall. The model ran on a daily basis. Foliage size and porosity was determined weekly by measuring percent of shaded area beneath 10 representative vines (WILLIAMS, 2001; WILLIAMS and AYARS, 2005). Stomatal conductance was driven by the FTSW (RITCHIE, 1981; SMITH *et al.*, 2000), using a linear relationship between the soil water potential and the ratio of actual to potential transpiration rate of the canopy (PIERI and GAUDILLERE, 2005; RAWLS *et al.*, 1982). Considering the soil texture (RAWLS *et al.*, 1982) and the root depth, TTSW was estimated to 45 L/$m^2$ for all the treatments at the beginning of the growing season; it was therefore the same for the fully irrigated treatment. For deficit irrigation treatments (TI4 and PRD4) it was linearly reduced during the first irrigation regime (from day 90 to 125) to 27 L/$m^2$ due to the progressive soil dehydration and the decrease of the soil wet bulb size in the deficit irrigated plots. Derived from the daily calculation of FTSW by the model, the ratio of the actual transpiration of the vines (TR) to the transpiration of fully watered vines was calculated. This ratio (GWSI) measured the grapevines water satisfaction index, an indicator of the vine water status which varied from 1 (potential transpiration of the vines) to 0 (fully closed stomata).

Soil evaporation was modeled according to RITCHIE (1973). Water supplied by drip irrigation was supposed to feed only the root compartment and not the surface soil compartment.

Stem water potentials ($\Psi_s$) were measured weekly at midday with a Scholander pressure chamber (PMS Instrument Co., Corvallis, OR). The leaf water potential ($\Psi_l$) was measured on three fully expanded young leaves from sun-exposed shoots per treatment. To avoid evaporative loss, leaves were enclosed in a plastic bag before cutting the petiole and left covered throughout pressurization. $\Psi_s$ was measured on 3 shaded leaves per treatment, taken inside the canopy, and after having been placed in a plastic bag covered with aluminum foil for at least 90 min before the masurements, allowing $\Psi_l$ to equilibrate with $\Psi_s$ (NAOR, 1998). Midday leaf water potential data for each treatment were used to calculate the Water Stress Integral S($\Psi_l$), adapted from predawn $\Psi_l$ (MYERS, 1988), which integrates the intensity and duration of stress above a minimum value:

$$S(\Psi_l) = \left[\sum_{i=0}^{i=t}\left(\Psi_{i,i+1} - c\right) \times n\right] \qquad \text{(MPa day)}$$

$\Psi_{i,i+1}$ = mean of $\Psi_l$ in an interval i, i+1; c = maximum value of $\Psi_l$ measured during the study in all the treatments. The maximum c value was set to -0.62 MPa; and n= number of days in the interval. In this case, the intervals were of 7±3 days.

At harvest, crop yield and cluster number per vine were recorded and samples of 100 berries per replicate were randomly collected, and analyzed for berry weight, soluble solids (°Brix, temperature corrected), titratable acidity (determined by titration with 0.133N NaOH using phenolphthalein as indicator). The pruning weights were recorded at dormant season.

The data were analyzed using analysis of variance and Newman and Keuls test using Systat® software.

## RESULTS

### 1. Climate

Mean daily temperature before and after fruit set ranged from 15 to 20 °C, and from 20 to 25 °C, respectively (figure 1). Maximum and minimum temperatures during the measurement period (day 90 to 210) were 33.6 and 6.6 °C, respectively. Maximum daily global radiation at vineyard location ranged from 320 to 600 W/m$^2$ during the same period. Total rainfall was 53 mm; it occurred during the early period, with two events of 20 and 15 mm recorded after bloom, on April 22 and May 8, respectively. The daily light interception by the vines was estimated at 45 % of the incident radiation according to the method of Williams (2001) and RIOU *et al.* (1989).

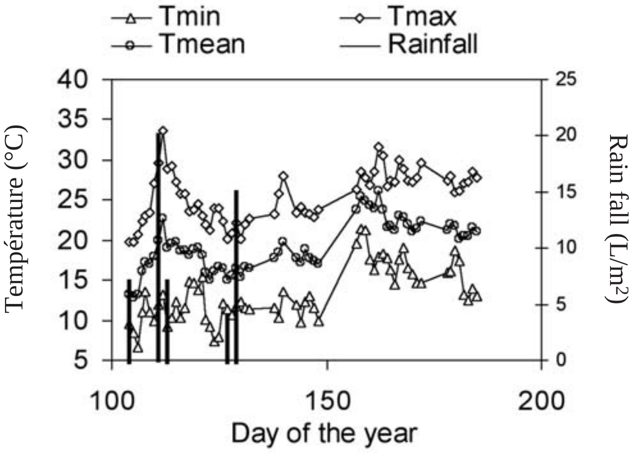

**Figure 1 - Climate recorded in the vineyard from flowering to harvest (Skhirate, Morocco, 2002).**

Based on the modified Penman-Monteith equation, reference evapotranspiration (PET) at the vineyard location varied between 1 and 5 L/(m$^2$.day) (4.5 to 22.5 L/(vine.day) before bloom and veraison, respectively. Cumulated PET between flowering and veraison was 1,200 L/m$^2$. The application of the water balance model to the irrigated vineyard according to TI4 and TI8 irrigation schedules, compared with the theoritical case of non irrigated vineyard is shown in figure 2A. The potential soil water reserve was adapted to the irrigation rate to take in account the difference in the size of the wet soil bulb according to the irrigation rate (see Material and Method). Without irrigation, transpirable soil water reserve would be totally emptied after day 170. The water supply with the TI8 schedule provided non limiting water availability in the vineyard. Conversely the TI4 schedule did not balance the water demand of the vineyard. The model foresaw a progressive depletion of the mean soil water content after the day 140. The GWSI (figure 2B) indicated a full water supply for the treatment TI8 all along the growing season. The treatment TI4 induced a progressive stress which became significant during maturation and at harvest (day 210). Then the vine water demand was satisfied at only 65 %.

### 2. Grapevine transpiration

The daily course of transpiration of the vines for the 4 treatments measured with sap-flow sensors, day 172, is shown in figure 3. Transpiration increased in the morning with the solar radiation in all the treatments.

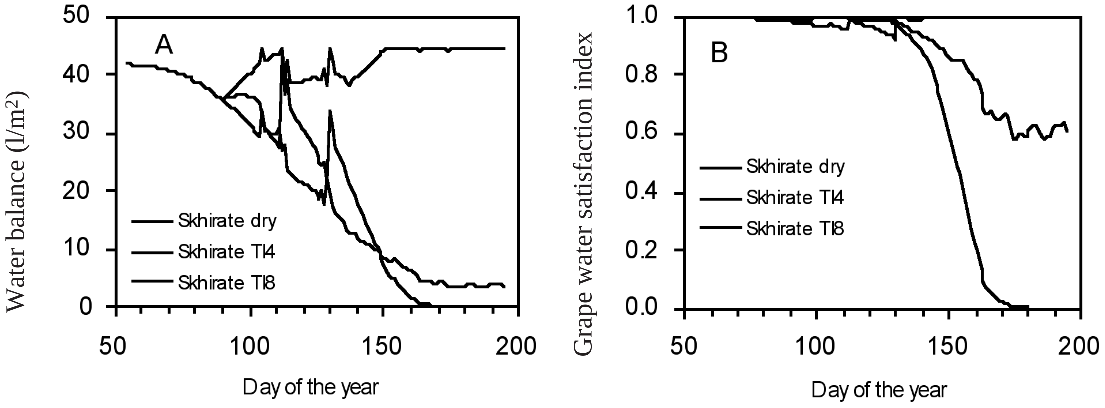

**Figure 2 - Model based water balance calculation with the climate and the architecture of the vineyard from budburst to harvest for the traditionally irrigated treatments (TI4 and TI8).**
Initial soil water reserve was set at 45 l/m$^2$. The dry condition is theoretical control because vines cannot survive without irrigation in this climate.

Then the sap flow was reduced by stomatal closure. This regulation was observed for all the treatments alike. Daily transpiration in the TI8 and PRD8 treatments was higher, relative to TI4 and PRD4 treatments. For both dripper-rates, traditional irrigation resulted in higher transpiration, relative to PRD irrigation. Maximum transpiration recorded during that day was 1.1; 0.9; 0.7; 0.5 L/h for TI8, PRD8, TI4 and PRD4 treatments, respectively.

Before fruit set, daily transpiration was similar for TI8 and PRD8 treatments (figure 4). Afterward, sap-flow measured for the TI8 vine reached a plateau when the PRD8 vine transpiration decreased. A similar pattern was observed for TI4 and PRD4 treatments (figure 4B). First TI4 and PRD4 water uses per vine were very similar, and then the PRD4 vines exhibited a lower transpiration rate. Transpiration of the TI4 vines reached a plateau lower than the TI8 vines (about 6 and 8 L/(day.vine), respectively). Average daily transpiration measured over the growing period for TI8 and PRD8 treatments was 6.2 (ranging from 0.85 to 10 L/vine ) and 4.7 L/vine (ranging from 0.54 to 7 L/vine), respectively. Average sap flow measured during the growing period for TI4 and PRD4 treatments was 4.5 (ranging from 0.5 to 6.9 L/vine) and 3.8 L/vine (ranging from 0.328 to 6.2 L/vine), respectively.

The vine crop coefficient (TR/PET), estimated from TI8 treatment, increased with the vegetative growth to reach a plateau (figure 5A). A decrease in actual transpiration rate was observed after day 150 for all the other treatments (figure 5B). This decrease was due to the regulation of stomata conductance initiated by water stress (decreasing GSWI), no leaf fall were observed. The water balance model allowed calculating the variations of actual transpiration rate, from the canopy light interception ratio and the values of FTSW and therefore GWSI. The model mimicked satisfactorily the actual transpiration rates of TI8 and TI4 treatments (figures 5A and 5B). However, it failed to describe the decrease after day 150, in PRD8 and PRD4.

## 3. Stem water potential

Midday stem water potential ($\psi_S$) was constant (0.4 MPa) before fruit set. Thereafter a continuous decrease throughout the season was observed for all the treatments (figure 6). The statistical comparison of stem water potential means between the treatments did not reveal any significant difference. The most negative seasonal $\psi_S$ was recorded after day 160; then, PRD4 treatment reached the lowest value of -1.17 MPa, followed by TI4, TI8, and PRD8 treatments with -1.14; -1.07; and -1.04 MPa. This trend in the water stress results was confirmed by the water stress integral calculated from $\psi_S$ values indicating the most intense stress was experienced by PRD4 (23 MPa.day), followed by TI4, PRD8 and TI8 with 20.2, 19.3, and 14.6 MPa.day, respectively.

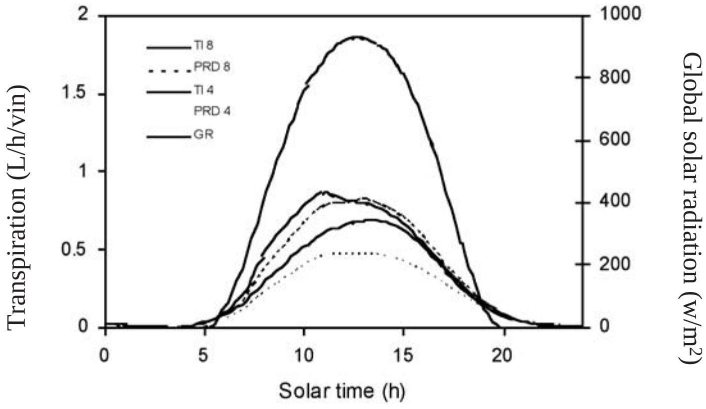

**Figure 3 - Daily variation vine transpiration (sap flow in the trunk) measured on representative vines of the 4 irrigation treatments by a clear day (day 172).**

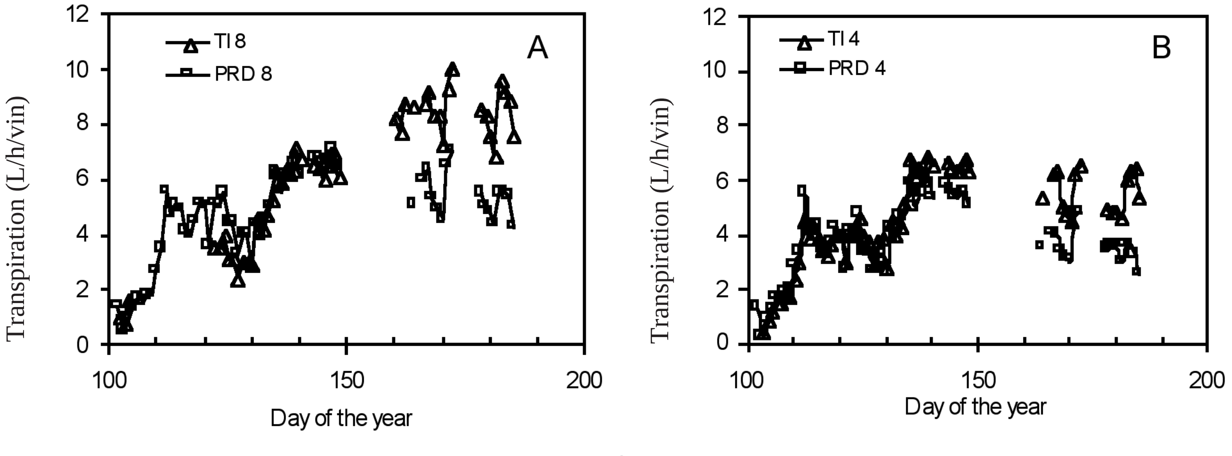

**Figure 4 - Seasonal vine transpiration (trunk sap flow) Water was daily delivered, TI: traditional irrigation, PRD: Partial root drying. A) TI8, PRD8: 0.9 mm/day from day 90 to day 137 and 1.8 mm/day from day 137 to day 210. B) TI4, PRD4: 0.45 mm/day from day 90 to day 137 and 0.9 mm/day from day 137 to day 210.**

PRD treatments did not increase the stem water potential compared to traditional irrigation. Midday leaf water potential followed the same pattern, with no difference between PRD and TI treatments and a significantly lower leaf potential in TI4 and PRD4 vines, compared to TI8 and PRD8 (data not shown).

### 4. Grape yield and quality

The yields per vine were significantly different in some treatments (table 1). The vines grown at TI8 showed a significant increase, averaging +21 % (+1 kg vine$^{-1}$). It was mainly due to a higher cluster mean weight in TI8 treatment. But there were no significant differences in berry weight among treatments. Fruit soluble solids concentration was not significantly affected by the irrigation schedule. However, higher soluble solids concentration was obtained in fruits from grapevines receiving traditional irrigation with 8 L/h drippers (table 1). Titratable acidity also was not affected by the irrigation treatment (table 1).

Vegetative growth was significantly higher in the TI8 treatment as shown by differences in pruning weight (table 1).

## DISCUSSION

This experiment allowed comparing fully irrigated grapevine (TI8) to deficit irrigation (TI4). This latter treatment supplied only 35 % of the total PET during the irrigation period, whereas the TI8 treatment supplied 60 %. This amount was considered not to be limiting for this vineyard since the vines intercepted a maximum of 45 % of the incident solar radiation, reducing the vine potential demand to 45 % of the total PET (RIOU *et al.*, 1994). The treatments TI4 or PRD4 therefore supplied about 70 % of the vine potential demand. The field measurement of the vine transpiration showed that all the treatments provided non limiting water untill day 135 (figure 4). Afterwards, a lower transpiration rate was observed with TI4, PRD 8 and PRD4. These treatments induced a mild water stress similar to that of a regulated deficit irrigation management (WAMPLE and SMITHYMAN, 2000).

The total amount of water transpired by the vines between the days 102 and 185 was estimated from the integrated transpiration curve (with interpolation to replace the missing points, figure 4). It was 113 $L/m^2$ and 91 $L/m^2$

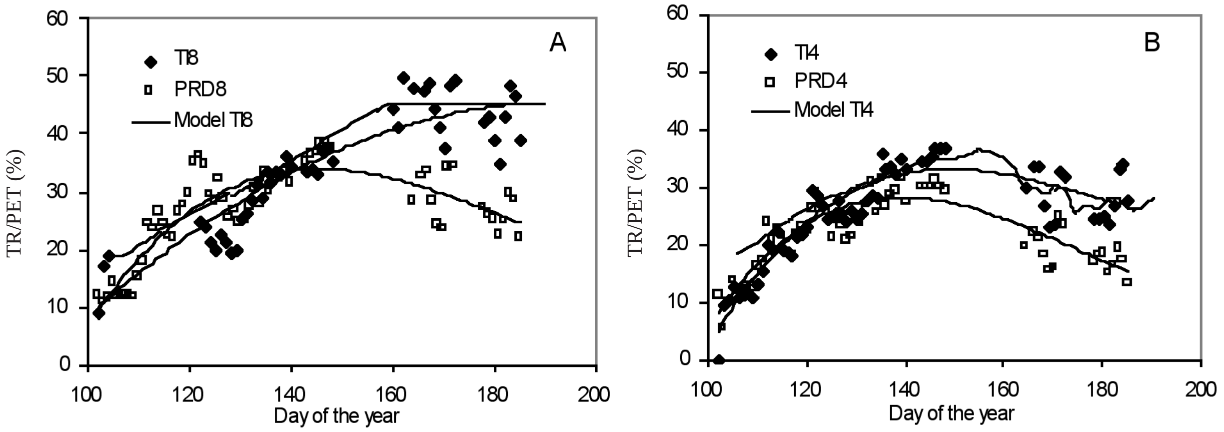

**Figure 5 - Crop coefficient (vine transpiration to potential evapotranspiration ratio) based on vine sap flow measurements. The bold curve is the crop coefficient calculated from the water balance model shown figure 2. A) TI8, PRD8: 0.9 mm/day from day 90 to day 137 and 1.8 mm/day from day 137 to day 210. B) TI4, PRD4: 0.45 mm/day from day 90 to day 137 and 0.9 mm/day from day 137 to day 210.**

**Table 1 - Effects of the four irrigation practices on yield, berry size, composition and vegetative growth (pruning weight) of grapevine cv Italia in 2002 at Skhirate (Morocco).**

Newman et Keuls test for the mean of 4 replications. PRD4/PRD8 and TI4/TI8: statistical comparison for the irrigation rate in each irrigation program; (PRD/TI): statistical comparison of the two irrigation programs [ *: probability <5 %, **, probability < 1 %]

| | PRD | | TI | | Statistics | | |
|---|---|---|---|---|---|---|---|
| | 4L/h | 8 L/h | 4L/h | 8 L/h | PRD4 / PRD8 | TI4 / TI8 | PRD / TI |
| Yield Kg/vine | 5,1 | 5,3 | 4,9 | 6,8 | NS | ** | * |
| Berry weight g | 6,9 | 7,4 | 6,9 | 6,6 | NS | NS | NS |
| ° Brix | 13,6 | 13,7 | 13,7 | 14,1 | NS | NS | NS |
| Titratable acidity Meq/L | 118 | 110 | 128 | 118 | NS | NS | NS |
| Pruning weight Kg/vine | 0,81 | 0,96 | 0,86 | 1,27 | ** | ** | * |

for TI8 and TI4, respectively. During the same period, the model estimated the grapevine water use to 103 and 85 l m-$^{2}$ for the two same treatments. This small underestimation by the model was probably due to the use of a simple regulation model of stomata conductance based on a gross estimation of the soil water status. But the difference could also be attributed to the unknown experimental error of measurements of grapevine sap flow. The most significant result is the ability of the model to fit both contrasting conditions, fully irrigated and water limited. The computed vine water use from day 90 to harvest was estimated by the model to 147 L/m$^{2}$ and 112 L/m$^{2}$ for the treatment TI8 and TI4 respectively. It is lower than in other vineyards (WILLIAMS *et al.*, 2003) of higherdensity training systems.

The difference of transpiration between TI and PRD treatment increased with time (figure 4). This effect could be explained by two hypotheses: PRD induced a root signal (ABA?) that triggered stomatal closure (STOLL *et al.*, 2000), or this irrigation practice made the water less available to the root system by lowering the mean soil-root hydraulic conductivity (PASSIOURA, 2002). Stem water potential did not exhibit any significant difference between the PRD and the traditional irrigation but PRD induced occasionally lower stem water potential during the driest periods (figure 6). Anyhow, it cannot be concluded that PRD generated a specific response of the vines,. The grapevine water balance model mimicked satisfactorily the daily crop coefficient for traditional irrigation (figure 5). A repeated pattern of the seasonal variation of the relative actual transpiration was observed. It increased during the vegetative growing period, and later decreased following soil water shortage and vine water stress when climatic water demand was higher than what the soil could afford. The regulation function of stomatal aperture was established in a temperate climate (LEBON *et al.*, 2003) but it was assumed sufficiently universal to be applied in a dry climate. The results confirm this assumption was valid: the model can be applied to traditional irrigation in dry conditions after fitting the total soil water available water (TTSW). However, the model failed to describe the treatments PRD8, PRD4, where grapevine transpiration was lower, compared to TI8 and TI4. By calibration process, a smaller TTSW was found appropriate for alternate irrigation treatments; then, the model can fit the experimental data satisfactorilt without introducing any additional physiological mechanism (results not shown). However, a larger available soil water reserve would be expected with the PRD treatments since the size of the active root volume is larger, compared to single dripper irrigation. No field data were available to support a reduction of the root zone in PRD irrigated crop. According to the literature stomatal conductance regulation would be controlled by a root signals from the dry zone (STOLL *et al.*, 2000) this mechanism must be added to the hydraulic signal related to the percentage of TTSW or the soil water potential.

The total amount of supplied water by irrigation during the same period was 140 and 229 l/m$^{2}$, respectively. The efficiency (ratio of vine transpiration to supplied water) of the traditional irrigation at high rate was low (65 % for TI8) but satisfactory in the limited water supply treatment (81 % for TI4). The 2 PRD treatments were less efficient (66 % and 55 % for PRD4 and PRD8 respectively). With the same water supply the amount of transpired water was lower (figure 4). Therefore, a significant fraction of water was lost. This finding has already been reported in a Portuguese vineyard (DOSSANTOS *et al.*, 2003). The relative inefficiency of the water supply under PRD may be related to an uneven root distribution in the soil and consequently an unbalanced amount of roots

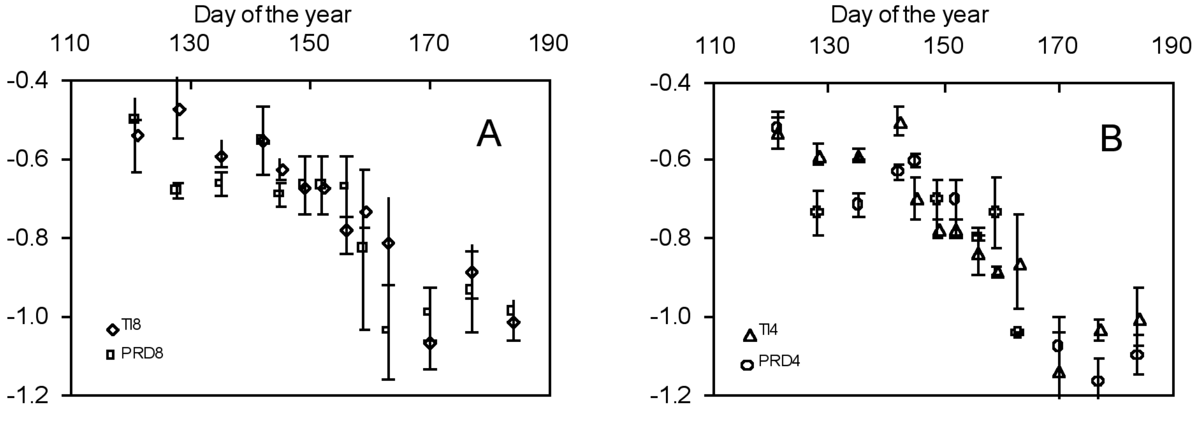

**Figure 6 - Seasonal pattern of stem water potential measured at noon (solar time).**
**A) TI8, PRD8: 0.9 mm/day from day 90 to day 137 and 1.8 mm/day from day 137 to day 210.**
**B) TI4, PRD4: 0.45 mm/day from day 90 to day 137 and 0.9 mm/day from day 137 to day 210.**

submitted to alternate dryness. Additionally, many additional environmental factors take part in the efficiency of the roots: hydraulic conductivity, mechanic properties, ions concentration, etc. (PASSIOURA, 2002). All these factors can interact in the root signal production mechanism (WILKINSON and DAVIES, 2002). In order to avoid unwanted water leakage due to drastic stomatal control, the amount of supplied water in a PRD system should probably require more attention and a finer tuning. Specifically, more information about root distribution would be necessary.

The water balance model cannot be applied in PRD irrigation because the soil water availability is difficult to estimate and because a model of the hormonal effect on stomata conductance is not available.

Grape quality was not affected by the PRD water supply. The yield of the TI8 treatment was significantly higher than of all the other treatments. This higher yield was mainly explained by a higher mean cluster weight. But as there was no significant effect of TI8 on the mean berry size, it was concluded that TI8 clusters contained more berries per cluster. Flowering and fruit set are early events which occurred (before day 100) when there was no sign of water stress. This effect was therefore barely explained by the irrigation treatment. The size and the representativeness of the sampling of berries used to assess the mean berry weight may be questioned.

The effect of PRD8 on vegetative growth estimated by the pruning weight (table 1), at full irrigation rate was an indication that PRD8 acted towards a limitation of the growth of vine tissues in a way similar to the TI4 and PRD4 treatments. It is well demonstrated that growth is very susceptible to the plant water status (BOYER, 1970). Therefore, from comparing PRD8 to TI8, it was concluded that PRD8 induced a water stress sufficiently strong to limit vegetative growth and sufficiently mild not to be revealed by mid-day stem water potential. An indirect effect may also have been present, of daily stomatal conductance regulation on the net carbon assimilation rate (DESOUZA *et al.*, 2003). This effect was suggested by sap flow measurements although the number of vines measured was insufficient to test this hypothesis. In any case, from a commercial perspective, PRD did not appear as a promising technique since the irrigation water efficiency was lower and the crop performances was not improved when compared to the traditional technique.

## CONCLUSION

After this experiment a quantitative evaluation of water use by a Moroccan commercial vineyard in a dry climate is now available. When the spatial pattern of the root system can be estimated with confidence, the maximal water need can be estimated using a grapevine water balance model. The model applies to a deficit irrigation system but not to partial root drying system. The water economy of the partial root drying technique was not efficient in our field conditions.

An operational model is now available to drive regulated deficit irrigation and improve water use efficiency in commercial table grape vineyards irrigated traditionally. It can be applied as alternative or complementary information, with stem water potential or soil humidity probing, to manage water supply in the vineyard.

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