DAILY EVOLUTION OF THE COMPONENTS OF THE BALANCE OF RADIATION OF VINES IN A VINEYARD IN THE DÃO REGION

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Summary

In order to validate a model of vine transpiration based on radiative surface temperature a field trial was conducted in a vineyard in the Dão region, centre of Portugal, with the cultivar "Touriga Nacional". The model is based on the partition of net radiation between the components of the canopy (vines, soil, and grass cover), considering that the vines and the undercover (soil plus grass cover) act separately and in parallel. Thus, the latent heat flux from the vines to the atmosphere (λT_c) is determined from vine net radiation (Rn_c) and sensible heat flux (H_c). The partition of net radiation (Rn) between the undercover (Rn_s) and the vines (Rn_c) is made considering the exponential form for radiation extinction, with the coefficient of extinction being corrected with a factor dependent on the zenital solar angle (φ) while leaf area index (*LAI*) is corrected with a clumping factor, Ω(φ). Sensible heat flux from the vines (H_c) is calculated from radiative temperature (T_c) considering that the fluxes from the different origins are independent and that there are two resistances in series between the canopy and the atmosphere: the leaf boundary layer resistance (r_{aHc}) and the aerodynamic resistance of the crop (r_{aH}). Besides the estimation of the daily values of transpiration, the model allows to study the evolution of the different components of the radiation balance throughout the day. The daily evolution of the evaporation fraction from the vines (FE_c) can be approximated by a concave curve. Values of $FE_c > 1$ show that, under certain circumstances and periods of the day, energy used for transpiration (λT_c) is greater than crop net radiation, which indicates that there are exchanges of energy between the several components of the surface, namely when evaporative demand from the atmosphere is high and there are no soil water restrictions. The model also shows that, regardless of the soil water status, transpiration is a big part of *Rn* when these values are low (in the beginning of the morning and late afternoon).

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INTRODUCTION

Measurement of water use by vines is fundamental in water relations studies, identification of limiting factors, irrigation scheduling or selection of varieties based on water use efficiency (Silvestre, 2003). A perfect monitoring of plant water status during the cycle is also essential for the evaluation of productivity and must quality. However, evapotranspiration measurement often requires the use of complex instrumentation and methodologies, as well as a high technical competence. Therefore, the development of models for estimating evapotranspiration, which are less demanding and thus less expensive, is of outmost importance.

Energy partition in a vegetated surface can be evaluated through the ratio between the latent and sensible heat fluxes ($H/\lambda E$), better known as the Bowen ratio (β), and/or evaporation fraction (*FE*). This latter one has been studied in different crops, mainly aiming at the estimation of daily evapotranspiration from its average value measured at mid-day and daily net radiation (*Rn*-*G*). Crago (1996) reports that, in clear sky conditions, and due to the steady evolution of the daily values of radiation, temperature and air humidity, the components of the energy balance vary slowly and as a consequence the coefficients of energy partition, namely *FE*, show little variation throughout the day. However, Lhomme and Elguero (1999) showed that *FE* changes throughout the day, with this daily evolution showing a concave shape but with relatively stable values at midday.

The present work was carried out at the Dão region, in the center of Portugal, with the "Touriga Nacional" variety. The objective is to analyze the diurnal evolution of the components of the energy balance of the vines using a double-layer model whose inputs are radiative infrared temperature and simple meteorological variables.

MATERIAL AND METHODS

The model used in this work to estimate the components of the energy balance of vines makes the partition of net radiation between the components of the canopy (vines and soil surface plus grass cover) based on the assumption that these components act independently and in parallel. Based on this assumption, latent heat flux from the vines (λE_c) can therefore be determined as a residual term from plant surface net radiation (Rn_c) and sensible heat flux (H_c). The partition of the whole canopy net radiation (Rn) between the undercover (Rn_s) and the vines (Rn_c) is made based on the exponential radiation extinction, Beer's law, as modified by Anderson *et al.* (1997), with the extinction coefficient being corrected with a term that depends on solar zenital angle (φ). As vineyards are a heterogeneous canopy, leaf area index (*LAI*) is corrected by a "clumping factor" $\Omega(\varphi)$ as proposed by Campbell and Norman (1998). The estimation of the sensible heat fluxes from the vines (H_c), from measured infrared temperature (T_c), is done assuming that the fluxes that originate in the different canopy components are independent (Norman *et al*., 1995) and considering two resistances in series from the leaves up to the reference height in the atmosphere: the leaf boundary resistance (r_{aHc}) and the aerodynamic resistance of the canopy (r_{aH}) (Lhomme and Monteny, 1993). In practice, the general equation for the determination of the sensible heat flux is used but with the aerodynamic temperature (T_0) being substituted by the radiative crop temperature (T_c) and introducing an additional resistance (r_{aHv}), as proposed by Choudhury and Monteith (1988). More details regarding this model can be found in Rodrigues *et al*. (2010).

The field trial was carried out at the Centro de Estudos Vitivinícolas do Dão, at Nelas, Portugal, with the variety Touriga Nacional, in the Dão region (latitude 40º 31´ N, longitude 7º 51´ W , altitude 440 m), from 2004 to 2007, in two plots whose characteristics can be found in Table 1.

The trial consisted in a split plot design, with different irrigation regimes and several repetitions. In one treatment the crop was irrigated in order to maintain the plants in optimum water conditions (full irrigation – FI). In another treatment, plants received no irrigation (NI) and the other two treatments were deficit irrigated (DI30 and DI50). Irrigation was made with a drip irrigation system.

In each experimental unit, soil water was monitored with a capacitive probe in two profiles, one in the line of vines, between two plants, close to the dripper (profile 2), and the other at half distance between the lines (profile 1).

In one of the experimental units, surface temperature of the vines was measured, at 10 minutes interval, with an infrared thermometer placed above the plants in such a way as to ensure that the width of measurement was slightly smaller than the width of the line of plants. At the same time, meteorological variables (air temperature and humidity, wind velocity, incoming solar radiation, net radiation and rainfall) were measured at an automated meteorological station installed in the middle of the field.

Leaf area was determined using the methodology described by Lopes and Pinto (2005), from the measurements made in vine shoots of selected plants throughout the crop cycle.

The extinction coefficient of radiation (k_e) was determined from the values of photosynthetic active radiation (PAR) measured at the top of the canopy and at the soil level at solar noon, when the shading of the soil by the plants is minimum. A ceptometer was used, placed perpendicularly to the lines of vines, at the same dates and same plants used for leaf area measurement.

The energy partition of the vines was characterized by the Bowen ratio and the evaporative fraction, as:

$$\beta_c = \frac{H_c}{\lambda E_c} \qquad [1]$$

and

$$FE_c = \frac{\lambda E_c}{Rn_c} = \frac{\lambda E_c}{\lambda E_c + H_c} \qquad [2]$$

These two indices are directly related, since $FE_c = 1/(\beta_c + 1)$.

Table 1. Characteristics of the plots used in the field trials

Year	Plot	Soil texture	Planting year	Rootstock	Planting density (vines/ha)	Training system	Pruning system	Trunk height (m)	Canopy height (m)
2004 and 2005	1-A	Loamy sand	1989	SO4	3636	Vertical Shoot Positioning	Double Guyot	0.6	1.3
2006 and 2007	5-A	Loamy sand	2000	110 R	4545	Vertical Shoot Positioning	Bilateral Royat Cordon	0.6	1.2

RESULTS AND DISCUSSION

The diurnal evolution of the energy partition coefficients in DOY 194 to 198 of 2004 for treatments FI and DI50 is presented in Figure 1. It can be seen that, when soil water availability is high (FI treatment), β_c and FE_c are practically constant during a big part of the daytime (10:00 to 18:00). When, on the contrary, available soil water is low (DI50 treatment), β_c shows a daily evolution with an inverted "V" shape, that is, values of β_c vary significantly throughout the day. When soil water is low, plants close their stomata as the evaporative demand of the atmosphere increases in order to slow their water losses and, as a consequence, available energy is directed mainly to sensible heat loss. Li *et al.* (2009) also registered a similar daily evolution of the Bowen ratio (β) in a vineyard (plants + undercover) and concluded that, in clear sky conditions, it depends on soil humidity.

In general, the diurnal evolution of FE_c can be described by a concave curve, with more or less constant values during a short period of time at midday, when transpiration is low. Values of $FE_c > 1$ indicate that the energy used in plant transpiration (λE_c) is greater than net radiation of the plant cover (Rn_c). Yunusa *et al.* (2004) also observed that, in short periods of time, advection of sensible heat from the naked soil acted as a source of energy for transpiration. In some days they observed evaporative fractions of the whole vineyard (*FE*) of 0.51 to 0.58, corresponding to plant evaporative fractions (FE_c) of 1.01 to 1.23. Heilman *et al.* (1996), for daily values of *FE* between 0.46 and 0.71, observed daily values of FE_c between 0.9 and 1.57. These results show that while the plants only use a part of the energy balance of the whole canopy (*Rn*-*G*) for transpiration, they can use more than its own energy balance (Rn_c), due to energy transfers between the different components of the canopy (plants / undercover).

Figure 1 also shows that in plants fully irrigated advection of sensible heat from the soil is a big source for transpiration during most of the daytime, namely after mid morning. When available soil water is low, this phenomenon only occurs at the end of the daytime.

Besides the influence of soil water, daily evolution of FE_c is also determined by meteorological variables, namely vapour pressure deficit (*VPD*).

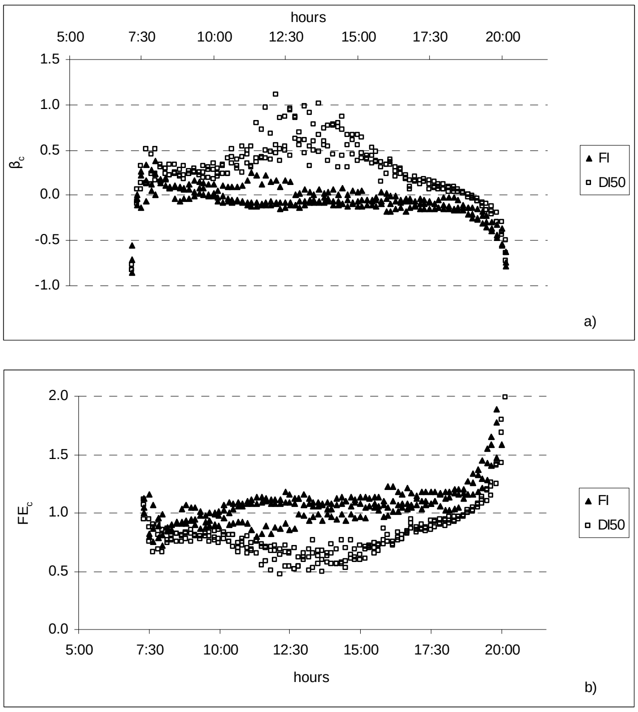

Figure 1. Diurnal evolution of the Bowen ratio, β_c (a) and evaporative fraction, FE_c (b) of plants in DOY 194 to 198, 2004, for the FI and DI50 treatments**.**

Figure 2 shows the diurnal evolution of FE_c in DOY 215 to 218, 2005, in treatments NI and FI. These were clear sky days but very different in terms of values of *VPD* (Figure 3). The corresponding mean available soil water fraction (*FTSW)* to 200 cm deep in treatment NI was 10% (Figure 4 b). During this period, an irrigation was made in treatment FI, and therefore mean soil water availability to 130 cm deep changed, ranging from 62% (DOY 213) to 86% (DOY 217) (Figure 4 a).

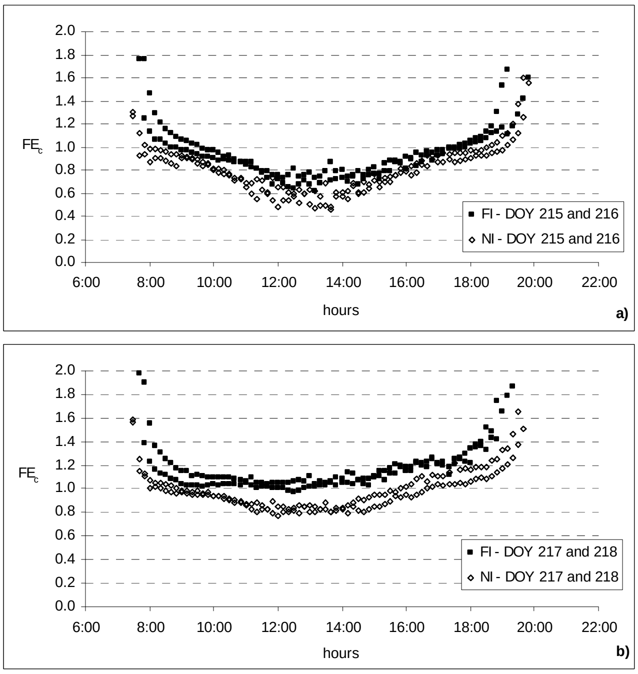

Figure 2. Diurnal evolution of the evaporative fraction of the plants (FE_c) in DOY 215 and 216 (a) and DOY 217 and 218 (b), 2005, FI e NI treatments**.**

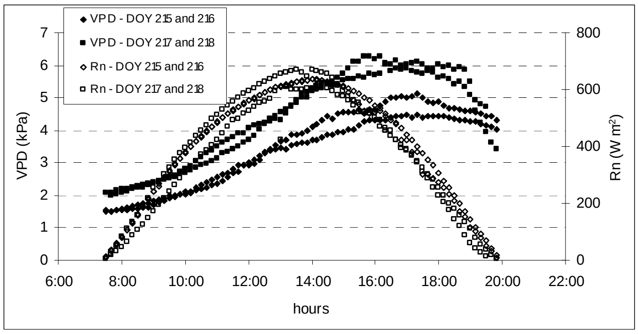

Figure 3. Diurnal evolution of net radiation (*Rn*) and vapour pressure deficit (*VPD*) between DOY 215 and 218, 2005.

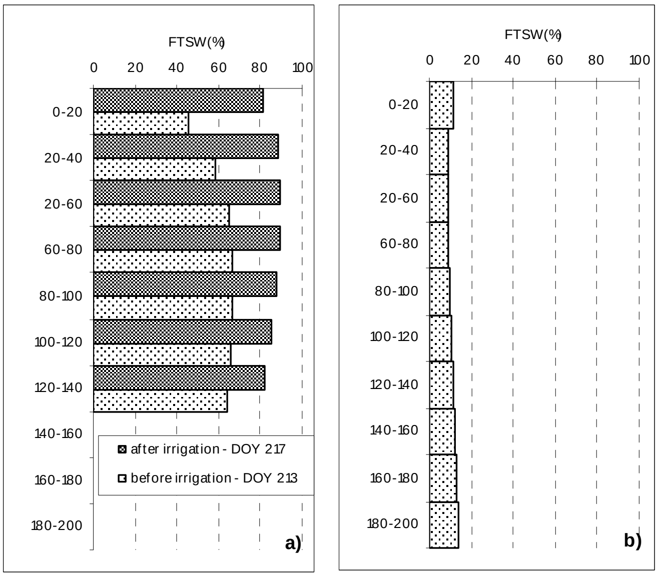

Figure 4. Profile of the available soil water fraction (*FTSW*) measured at the access tube in the line of vines (profile 2), before (DOY 213) and after (DOY 217) irrigation in treatment FI (a) and in DOY 216 in the non irrigated treatment (NI) (b), 2005**.**

As expected, the fraction of available energy used in the transpiration process is always higher when *VPD* is high, independently of the level of available soil water. Even so, it's important to stress that in treatment FI, and despite the high availability of soil water, FE_c is less than 1 during most part of the day in DOY 215 and 216 (low *VPD*), while in DOY 217 and 218 (higher *VPD*) FE_c is almost always bigger than 1, which indicates, as referred previously, advection of sensible heat from the soil. As to the deficit irrigation treatment, advection only occurs at the beginning and at the end of the daylight period. It can therefore be concluded that sensible heat advection occurs when a combination of factors are present, namely high available soil water and high atmospheric evaporative demand.

Figure 5 shows the relationship between the plant evaporative fraction (FE_c) and net radiation of the whole canopy (*Rn*) in treatments FI and NI, in DOY 218 of 2005, during the morning (until 13 h) and afternoon. It can be seen that, in both soil water conditions, FE_c grows rapidly when *Rn* decreases, for *Rn* values lower than about 150 W m^{-2}. Rowntree (1991) cited by Li *et al*. (2008) refers that *FE* of plant cover of a vineyard is very sensitive to variations in available energy (*Rn*-*G*) when these values are low, and registered a big increase in *FE* at the end of the afternoon, for *Rn*-*G* values lower than 200 W m^{-2}. These results indicate that there is a strong energy “investment” in plant transpiration when available energy is low.

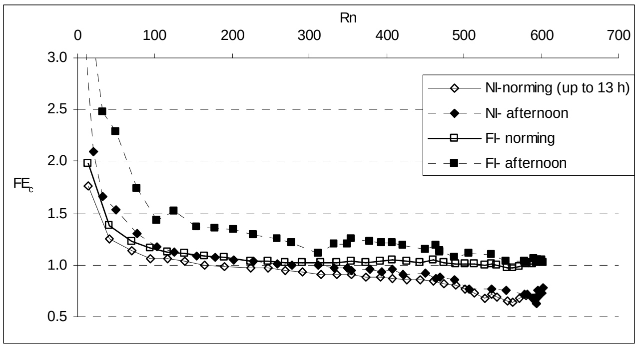

Figure 5. Evaporative fraction of the plant cover (*FE_c*) as a function of whole canopy net radiation (*Rn*), in treatments FI and NI, DOY 218, 2005, in the morning (up to 13 h) and in the afternoon.

The relationship between the evaporative fraction of the plant cover and net radiation, in both periods of the day (morning and afternoon) show hysteresis, that is, for the same level of *Rn*, FE_c is always higher in the afternoon than it is in the morning, with the biggest difference between the two values being observed in the plants that are free from water stress. This is mainly due to the fact that the driving meteorological factors (air temperature and VPD) are also hysteretic relative to net radiation (Alves, 1995). It’s also important to verify that during the first hours of daytime (*Rn* < 350 W m^{-2}) the fraction of energy used in transpiration is very similar in the two treatments, but very rapidly (after 10 h) soil humidity determines the energetic partition of the plant cover.

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