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Transpiration and water stress effects on water use, in relation to estimations from NDVI: Application in a vineyard in SE Portugal

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Abstract. Remote sensing can give contributions to answer the classical questions in irrigation management: when to irrigate and how much (irrigation depth). In order to compare with estimations partially derived from remote sensing, evapotranspiration (ET) and its components (transpiration, T and soil evaporation, Es) as well as selected water stress indicators were measured in a commercial vineyard with deficit irrigation, in SE Portugal. A combination of micrometeorological, sapflow and microlysimeter methods were used to measure water flux densities. The seasonal results reported (2009) are explored in relation to T obtained from practical models based on meteorological data (reference ET, ETo), crop basal coefficients (Kcb) and stress coefficients (Ks) where the use of the normalized difference vegetation index (NDVI) is included. Results from stress cycles (2010) confirm the selection of predawn leaf water potential (PLWP) as water tress indicator for the purpose of the analysis. A preliminary conclusion, confirmed later, on the meaning of NDVI in the conditions of this study (-0.2 MPa>PLWP>-0.7 MPa), suggested that it is not affected by short term but by long term water stress. Kcb measured and estimated from NDVI agreed generally well, with exceptions. The comparison between T measured and estimated from ETo.Kcb.Ks (being Ks obtained from PLWP) highlights the importance of Ks on T estimation. For practical uses, alternative tools to obtain Ks are proposed.

Keywords. Basal crop coefficient – NDVI – *Vitis vinifera,* L. – Water stress.

Transpiration et effets du stress hydrique en relation avec des estimations à partir de télédétection : application sur une vigne dans le SE du Portugal

Résumé. *La télédétection peut contribuer à répondre aux questions classiques de la gestion de l'irrigation : quand irriguer et quelle quantité apporter. L'évapotranspiration (ET) et ses composantes (transpiration, T et l'évaporation du sol, Es), ainsi que certains indicateurs de stress hydrique ont été mesurés dans un vignoble commercial soumis à une irrigation déficitaire, dans le sud-est du Portugal, afin de les comparer avec des estimations partiellement obtenues par télédétection. Une combinaison de méthodes de mesures micrométéorologiques, de flux de sève et par microlysimètres a été utilisée pour mesurer les densités de flux d'eau. Les résultats saisonniers (2009) sont analysés par rapport à T obtenu à partir de modèles pratiques basés sur les données météorologiques (ET de référence, ETo), les coefficients culturaux de base (Kcb) et les coefficients de stress (Ks) incluant l'utilisation de NDVI. Les résultats obtenus à partir de cycles de stress (2010) confirment la pertinence du potentiel des feuilles avant l'aube (PLWP) comme indicateur du stress hydrique pour cette analyse. Une conclusion préliminaire, confirmée ultérieurement, sur la signification de NDVI dans les conditions de cette étude (-0,2 MPa> PLWP> -0,7 MPa), suggère qu'il est affecté par un stress hydrique de long terme et non de court terme. La concordance entre Kcb mesuré et Kcb estimé à partir de NDVI est généralement bonne, avec des exceptions. La comparaison entre T mesurée et T estimée à partir de ETo.Kcb.Ks (Ks étant obtenu de PLWP) souligne l'importance de Ks dans l'estimation de T. Pour des utilisations pratiques, des outils alternatifs pour obtenir Ks sont proposés.*

Mots-clés. *Coefficient de stress basal – NDVI –* Vitis vinifera, *L. – Stress hydrique.*

I – Introduction

The need for adequate water management increases with water scarcity and the impacts of excessive use of water and agrochemicals in soil and underground water. In order to manage irrigation, there are three questions to solve: when, how much and how to apply water, the last being related to equipment and efficiency of irrigation. The answer to the two first questions can be related to each other or not, depending on irrigation frequency and irrigation scheduling method.

In the following, the nomenclature used is approximately the one used in FAO Irrigation and Drainage paper 56 (Allen *et al*. 1998):

ET: evapotranspiration or actual ET

ETo: reference ET

T: transpiration (in general or actual T)

Es_ water evaporated directly from soil surface

Kc: crop coefficient (=ET_m/ETo)

ET_c or ET_m: ET for a certain well irrigated crop

Kcb: basal crop coefficient (=T_m/ETo)

T_m: T of a well irrigated crop (=ETo.Kcb)

Ks: stress coefficient (=T/T_m)

With daily irrigation, the main question is to calculate irrigation depth. In case of a so-called well watered crop, the user refills the water reservoir (for the layers where roots are found). Therefore, irrigation depth corresponds to the water consumption or actual evapotranspiration (ET≈ ETo. Kcb+Es) of last day, adding an extra to account for the application losses. In deficit irrigation, the user may want to keep a lower soil water status and the irrigation depth will reflect that choice. In this case, a stress coefficient is applied (ET≈ ETo.Kcb.Ks+Es).

If irrigation is applied at intervals of several days, it is necessary to identify when to apply water, to prevent critical water stress implications on yield. Usually, a water status indicator (soil, plant or atmosphere) is selected, using a certain pre-determined threshold value. If using water balance to estimate soil water depletion, a certain percentage of soil water content or a percentage of readily accessible water can be used, for instance. There is a remarkable cumulated experience on indicators and their threshold values, which includes tables of critical percentages of readily accessible water (for the last, e.g. the FAO Irrigation and Drainage papers 24 and 56). Irrigation opportunity and depth are linked: the more irrigation is delayed, the higher is irrigation depth. Traditional irrigation science and practice provide the means for such determinations which work satisfactorily for well irrigated low crops that fully cover the soil.

There are stands and conditions where irrigation is more difficult to manage, even if they are homogeneous. This includes (i) stands submitted to deficit irrigation, where T is reduced as a consequence of water stress, and Ks has to be included in T estimation, (ii) woody crops, for which not only (due to methodological reasons) there is less information on crop coefficients (Kc and Kcb) but also, in Mediterranean areas, soil water balance is difficult to estimate due to deep root systems, (iii) anisotropic stands, where crop coefficients are highly dependent on plant density and architecture or (iv) the combination of 1 to 3.

Further difficulties are related to soil and water application heterogeneities at plot scale. In land use planning and water management in large areas, there are other limitations related to unknowns in mixed or less controlled areas, i.e., heterogeneities at larger space scales. Remote sensing tools have been studied aiming to access water use, support irrigation scheduling and stress diagnosis, with lower costs and higher efficiency in all these situations.

When using remote sensing tools for ET estimation, a common approach is to calculate NDVI (normalized difference vegetation index) to obtain Kcb. When the crop is under water stress, the same approach can be used, if considering a stress coefficient (Ks), T being estimated from Kcb×Ks×ETo. We intend to verify the reliability of this approach using ground truth seasonal data and assuming a linear relationship between Kcb and NDVI (Calera *et al*., 2001). A first step is to answer the following: to which extent is NDVI affected by short term and/or long term water stress, in the conditions of our study? If the ratio between T measured and ETo×Kcb (being Kcb estimated from NDVI) can be identified with Ks, this means that NDVI is not affected by short term water stress. In that case, will NDVI be influenced by long term stress impacting Kcb? In order to analyze these preliminary aspects, the ratio between T measured and ETo×Kcb was first related to a selected water stress indicator. In a second step, Kcb measured was compared to Kcb estimated from NDVI. In a third step, T measured (2009) is compared to T estimated using an equation for Ks (from a water status indicator) derived during a stress cycle experiment performed in 2010.

II – Materials and methods

1. Experimental site

The experimental plot is located in a commercial irrigated vineyard (*Vitis vinifera* L. Aragonez 'syn. Tempranillo', grafted on '1103P') with 6.0 ha, situated within a continuous area of a 30 ha vineyard, with fetch above 300 m, near Beja (38º 02' 59'' N, 7º 55' 15''W, 200 m above sea level), in the warmest and driest region of Portugal (Alentejo): 606 mm precipitation and 1775 mm ETo (average 30 yrs). Plants were spaced 2.8 m x 1.1 m. The training system was vertical shoot positioning. The grapevines were spur pruned on a bilateral Royat cordon with 16 buds per vine. The mean grapevines height and canopy width were about 1.8 m and 1.0 m, respectively. The row orientation was approximately N-S. Beneath the canopy and between the rows the soil was bare, not mobilized and mobilized respectively. The soil is a shallow clay vertisol with abundant gravels and few stones, profile type Ap-Bw-C-R derived from basic rocks. Main root zone depth is about 0.6 m; some fine roots explored rock fissures up to 1.5 m depth. The vineyard was drip irrigated, with emitters for each 1.0 m (flow 2.4 l/h), suspended above the ground in the vine row. The nominal flow was 2.4 l/h.

The experimental work took place between flowering and the end of the vegetative cycle (May to October) from 2008 to 2010. During summer 2010, several sub-plots were temporarily irrigated with different strategies, being a well irrigated sub-plot used as a reference (Tm), in order to study the relationship between Ks and plant water status.

2. Evapotranspiration measurements

The eddy covariance technique (EC) was used to measure convection heat flux densities: sensible (H) and latent heat flux (LE) or evapotranspiration (ET_{EC}). The sensors were a CSAT 3-D sonic anemometer and a KH20 krypton hygrometer (Campbell Scientific, Inc. Logan, UT, USA), placed on a metallic tower at a height of 3.2 m, oriented into the dominant wind direction (NW, N). The data were stored (30 min averages) in a CR23X data logger (Campbell Scientific, Inc. Logan, UT, USA). LE was corrected using WPL correction and for oxygen absorption. A wind vane (W200P, Vector Instruments, Rhyl, United Kingdom) as well as a capacitive sensor (air temperature and humidity) were installed at the tower and used for EC corrections and footprint analysis. Net radiation (Rn) was measured with a net radiometer (model NR2, Kipp & Zonen, Delft, Netherlands) 3.2 m above the ground. Seven soil heat flux plates (HFT-3.1, Rebs, Seattle, USA) were placed in a transept at a depth of 0.05 m. Soil heat storage above plates was calculated from soil temperature (0.025 m deep) and water content dependent soil parameters. Soil heat flux (G), was calculated using the soil heat flux densities and the variation in heat storage. Data were stored in a CR10X data logger (Campbell Scientific, Inc. Logan, UT, USA). G, H and Rn were measured to verify the energy balance closure contributing to the evaluation of the EC data quality. Other details and references on corrections can be found in Conceição *et al*. (2011).

EC data could not be obtained with rain, dew or when the wind turned from dominant direction The EC data served to transform the seasonal SF data into reliable absolute T values.

3. Sap flow measurement and transpiration calculation

Sap flow (SF) was monitored with 1.0 and 0.5 cm long radial sap flow sensors (heat dissipation method, Granier 1985), (UP, Germany) installed at 0.30 to 0.45 m from soil. The temperature difference between the heated (downstream) and non-heated (upstream) probes was measured every 60 s and averaged every 30 min (CR10X with an AM416 relay multiplexer, Campbell Scientific, Inc. Logan, UT, USA). Transpiration during the whole season was obtained from SF data after calibration from EC using periods of negligible Es (when ET≈T) or from the relationship ET_{EC}-Es versus SF data, when Es was obtained from a model adjusted from lysimeter measurements (data not shown).

4. Measured and estimated basal crop coefficient

Measured basal crop coefficients (Kcb) were obtained from the relationship T/(ETo.Ks) for the periods were it could be assumed that Ks=1. The data to support this assumption were obtained during the 2010 experiments with stress cycles (not shown).

Estimated basal crop coefficient (Kcb_{NDVI}) was derived from NDVI as Kcb=1.36×NDVI-0.066, according to Calera *et al*. (2001), Project DEMETER. NDVI maps were obtained from LANDSAT 5 TM images (geometrical and atmospheric corrections). NDVI was calculated as NDVI = (IRC - R) / (IRC + R) as described in Conceição *et al*. (2011).

5. Other measurements

Leaf water potential at pre-dawn (PLWP) was measured in at least 9 leaves with a pressure chamber (PMS Instruments, Corvallis, Oregon, USA). Ks was obtained from T/(Kcb.ETo). Meteorological data from a nearby station belonging to COTR [*Centro Operativo e de Tecnologia de Regadio* (www.cotr.pt)], located at Beja (38º 02’ 15’’ N, 07º 53’ 06’’ W, ca. 206 m height above sea level) were used to calculate ETo with Penman-Monteith equation using the crop parameters of a well irrigated healthy grass (0.12 m height, 70 $s.m^{-1}$ surface resistance and 0.23 of albedo, according to Allen *et al*. 1998).

III – Results and discussion

1. Impact of short or long term stress on NDVI

By short term stress effect, we mean a stress effect that can be rapidly recovered with irrigation; it is related to Ks. Conversely, long term stress means that it cannot be resumed by a few irrigation events: the long term stress affects leaf area and therefore the capacity to transpire even if enough water was suddenly provided. It can be assumed that it affects Kcb.

Ks was first estimated as T/(ETo×Kcb_{NDVI}) and related with PLWP. The results (Conceição *et al*. 2011) are similar to the relationship between Ks and PLWP obtained from independent Ks measurements (not shown). This fact suggests that the assumption that NDVI was not affected by short term stress was correct, for -0.2 MPa >PLWP> -0.7 MPa. Otherwise, the value estimated for Kcb_{NDVI} would have been underestimated and thus Ks overestimated in relation to the correspondent output from the relationship obtained in 2010 (from direct measurements).

As a consequence of this first result, values of Kcb and Kcb_{NDVI} could be compared using the 2009 Kcb seasonal course (Fig. 1). The values compare well, except for the two last points. This fact can be explained by the loss of basal leaves (documented by photos) due to long term stress (impacting on leaf area but not significantly on ground cover or NDVI).

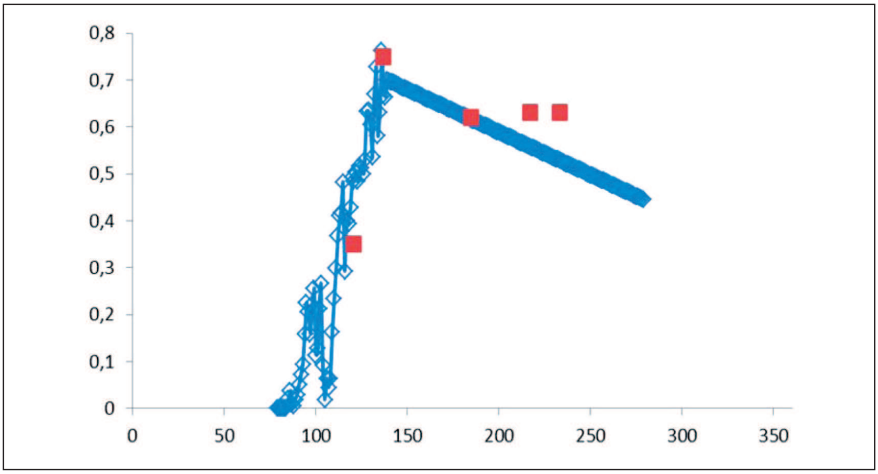

Fig. 1. Seasonal course (DOY 2009) of Kcb (adimensional) measured (blue line) and estimated from NDVI (red quares) Beja, Portugal.

2. Transpiration estimated and importance of the stress coefficient

T estimated from ETo.Kcb.Ks (where Ks was not measured but calculated from PLWP measurements, using the independent relationship obtained in 2010) was compared to T measured. Kcb was either estimated from NDVI or measured.

Fig. 2 shows the seasonal course of ETo, T measured and T estimated using the relationship between Ks and PLWP obtained during the 2010 stress cycles experiments. These results show

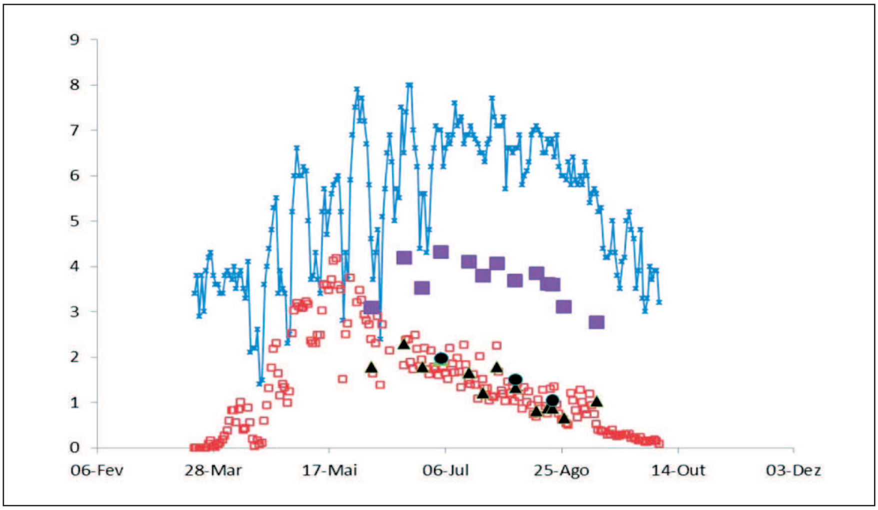

Fig. 2. Seasonal course during 2009 of daily ETo (line), Tm (filled squares), T measured (open squares), T estimated from ETo.Kcb.Ks and ETo.Kcb_{NVDI}.Ks (respectively black triangles and circles) with Ks always estimated from the Ks vs PLWP relationship obtained in 2010 (mm/day). Beja, Portugal.

that (i) the T values calculated as ETo.Kcb.Ks with Kcb from direct measurements or calculated from NDVI are remarkably similar, (ii) after late spring, T measured was much lower than Tm obtained from ETo.Kcb (1 to 3, at the end of dry summer) emphasising the importance of Ks estimation in this irrigated vineyard. The relationship between Ks and automated water status indicators (e.g. stem diameter variations, differences in surface temperature from remote sensing) was not successful. Further data analysis will follow on alternatives, such as soil water depletion estimated from cumulated ET since last irrigation (Ferreira *et al*., 1989, 2008) or others derived from on-going field studies in the frame of a Ph D thesis (2^{nd} author).

IV – Conclusions

Reliable values of T during the seasonal course obtained using a combination of methods served as reference to evaluate the meaning and validity of Kcb estimations from NDVI.

The results suggest that Kcb was not affected by short term stress. Kcb from direct measurements or Kcb calculated from NDVI were remarkably similar, except for the late season. T measured was much lower than Tm obtained from ETo.Kcb, emphasising the importance of Ks estimation in stands submitted to deficit irrigation. After late spring, T values calculated as ETo.Kcb.Ks (with Ks estimated from PLWP) compared very well with T measured.

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References

Allen R.G., Pereira L.S., Raes D. and Smith M., 1998. Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. *FAO Irrigation and Drainage Paper 56*. FAO, Rome, Italy.

Calera A., Martínez C. and González-Piqueras J., 2001. Integration from multiscale satellites, DAIS and Landsat, applying a linear model to the NDVI values in La Mancha (Spain). In: *Proceedings ESA Workshop*, 15-16th March 2001.

Conceição N., Ferreira M.I., Fabião M., Boteta L., Silvestre J. and Pacheco C.A., 2011. Transpiration measured and estimated from ETo, NDVI and predawn leaf water potential for a vineyard in South Portugal. In: *Acta Hort.* (in press).

Ferreira M.I., Itier B. and Katerji N., 1989. In: *Modelação Matemática em Hidr. e Rec. Hídricos (Proc. 4º Simp. Luso-Brasileiro em Hidráulica e Recursos Hídricos)*, APRH, Lisboa.

Ferreira M.I., Paço T.A., Silvestre J. and Silva R.M., 2008. Evapotranspiration estimates and water stress indicators for irrigation scheduling in woody plants. In: ML Sorensen (ed.) *Agricultural Water Management Research Trends*. Nova Science Publishers, Inc., New York. p. 129-170.

Granier, A., 1985. Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. In: *Annales des Sciences Forestières*, 42, p. 193-200.