Water use, transpiration and crop coefficients for irrigated hedgerow olives grown in Southern Portugal

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Abstract

Olive trees are well adapted to the Mediterranean-type agro-ecosystems of southern Portugal and have traditionally been cultivated in areas with no irrigation. According to the 2009 agricultural census, the olive tree cultivation area was around 336,000 ha, of which 164,000 ha are in the southern province of Alentejo. In this southern region of semi arid Mediterranean climate where the erratic annual precipitation of around 300 to 550 mm is not enough to fulfil crop water requirements when needed, summer irrigation is a necessity to prevent crop water stress and ensure profitable yields. Hundreds of high and also very high tree-density hedgerow orchards of the Spanish cultivar Arbequina have recently been established in the region to take advantage of the European Commission decision 2000/406/CE (Official Journal L 154, 27/06/2000 P. 0033-0033) that allowed the expansion of Portuguese olive tree planting quota to 30,000 ha of new orchards. With enhanced olive production and yield depending on irrigation water supply and management, estimating hedgerow olive orchard water uptake in southern Portugal and appropriately scheduling irrigation have since been the primary concern of researchers, farmers and water resources managers. The objective of this study was to establish relationships between olive transpiration and crop transpiration coefficients of very high tree-density hedgerow orchard grown in Alentejo under well-irrigated treatment A (3.05 mm d^{-1}) and sustained deficit irrigation treatment B (2.12 mm d^{-1}) regimes, to understand and improve their irrigation management. On both treatments, daily transpiration at the stand scale (mm day^{-1}) was obtained by sap flow and by dividing the tree transpiration by the area of the planting pattern. The results were compared to the daily outputs obtained with the Penman-Monteith "big leaf" equation coupled with the Orgaz *et al.* (2007) specific model of bulk daily canopy conductance (G_c) for unstressed olive canopies. With the Willmott index of agreement IA and the root-mean-square error RMSE above 0.8 and below 0.4 mm d^{-1}, respectively (Willmott, 1982), the synthetic model proved sufficiently precise to be used as an appropriate simulation tool for predicting olive stand transpiration for the region. Crop and stress transpiration coefficients were proposed for both treatments.

Keywords: *Olea europaea*, transpiration, crop transpiration coefficient, hedgerow olive orchard, Arbequina

Uso da água, transpiração e coeficientes culturais para olivais regados e em sebe no sul de Portugal

Resumo

As oliveiras são árvores bem adaptadas ao clima Mediterrânico do sul de Portugal e têm sido cultivadas em áreas de sequeiro. De acordo com o censo agrícola de 2009, a área nacional de ocupação da oliveira estima-se em 336,000 ha, dos quais 164,000 ha estão distribuídos na região sul do Alentejo. Nesta região de clima semi-árido e em que a distribuição errática da precipitação anual entre 300 e 500 mm não é suficiente para a satisfação das necessidades hídricas da cultura, a rega de verão é uma necessidade real para prevenir deficiências de água e assegurar produções comerciais aceitáveis. Centenas de hectares de oliveiras de densidades de plantio alta a muito alta, com as últimas normalmente projetadas em sebe e baseadas na cultivar espanhola Arbequina, foram recentemente estabelecidas na região, aproveitando a decisão 2000/406/CE da Comissão Europeia (Jornal oficial L 154 de 27/06/2000 P. 0033-0033) que permitiu a expansão do olival nacional com mais 30,000 novos hectares. Com produções e rendimentos dependentes da rega e da sua adequada gestão, a estimativa das necessidades hídricas e consumos de água pelo olival super-intensivo em sebe no sul de Portugal, bem como a sua distribuição temporal, tornou-se desde então preocupação dominante de investigadores, empresários e gestores de recursos hídricos. O objectivo deste estudo foi establecer relações funcionais entre a transpiração e os coeficientes culturais para o olival superintensivo em sebe com regimes de rega plena (tratamento A, 3.05 mm d^{-1}) e rega deficitária sustentada (tratamento B, 2.12 mm d^{-1}), para melhor perceber e gerir a rega deste tipo de olival no Alentejo. Nos dois tratamentos, a transpiração do olival (mm d^{-1}) foi obtida pelo método de fluxo de seiva e relacionando a transpiração da árvore com a área de plantio. Os resultados diários da transpiração foram comparados com os obtidos através da aplicação do modelo “big leaf” de Penman-Monteith, incluindo neste a condutância estomática diária obtida com o “specific model of bulk daily canopy conductance (G_c) for unstressed olive canopies” de Orgaz *et al.* (2007). Com os índices de concordância IA e erro quadrado médio RSME acima de 0.8 e abaixo de 0.4 mm d^{-1}, respectivamente (Willmott, 1982), o modelo sintético provou ser suficientemente preciso para ser usado como instrumento de simulação na previsão da transpiração do olival em sebe na região Alentejo. No estudo são ainda propostos coeficientes culturais e de stress para os dois tratamentos.

Palavras-chave: *Olea europaea*, transpiração, coeficiente cultural, olival em sebe, Arbequina

Introduction

To improve yields and compete worldwide, newly and productive non-indigenous drip irrigated olive cultivars (Arbequina, Picual and Hojiblanca among others) have been introduced in southern Portugal, in the Alentejo region, particularly since year 2000, to take full advantage of the European Commission decision 2000/406/CE (Official Journal L 154, 27/06/2000 P. 0033- 0033) to expand the Portuguese olive tree planting quota to 30 000 ha of new orchards. In the process, hundreds of high (>300 trees/ha) and very high-density (>1700 trees/ha) drip irrigated orchards, mainly of the cultivar Arbequina, have been established. This abrupt change in olive planting technique and production in a region of severe low water availability prompted a regional debate over the need to increase the water use efficiency and the productivity of the irrigated orchards, with deficit irrigation management being advocated as a way out to better yields, oil quality and economic returns of the newly commercial orchards. The large demand for water rising from the increasing number of hectares devoted to olive orchards in southern Portugal make the optimal use of irrigation water critical for the long term sustainability of the commercial orchards. In this case, a precise estimation of transpiration under non-limiting conditions is required to set the upper limit of irrigation requirements, and to assess the opportunities of reducing transpiration via deficit irrigation (DI; Santos *et al*., 2007). Furthermore, crop coefficients are needed to help better schedule irrigation and water delivery. The objectives of this study were to: (1) determine and compare the actual differences in transpiration and water use of a hedge row olive orchard in southern Portugal under well-irrigated and an imposed deficit irrigation programme, (2) calculate and compare actual transpiration coefficient values based on the evaluated transpiration rates patterns, (3) estimate the maximum unstressed transpiration values for the orchard by using the conductance model of Orgaz *et al.* (2007), (4) compare the calculated PM-Orgaz model daily transpiration values with those obtained from the unstressed and deficit irrigation measurements, and (5) relate mean daily values of transpiration to variables such as radiation and vapor water pressure deficit.

Material and Methods

The research was conducted during 2012 in the region of Alentejo, Portugal, and in a commercial orchard at the Herdade da Azambuja, Monte do Trigo, near Évora (38º 24' 47.03" N, 7º 43' 38.36" W; alt. 75 m) in a Eutric Cambisoil (WRB, 1998). The average apparent bulk soil density was 1,67 Mg m^{-3}, and average volumetric soil water content at field capacity (i.e. at 0,03 MPa) was 0,36 m^3 m^{-3}, whereas it was 0,12 m^3 m^{-3} at wilting point (i.e. at 1,5 MPa). Using an orchard stand of 6 year-old olive trees (Olea europaea L. cv. Arbequina) planted on hedgerow in a 3,75 by 1,35 m spacing layout and drip irrigated, the trees were subject from mid-May to the end of October to one of two irrigation treatments: a treatment A with full-rate irrigation to the full soil water holding capacity and continuously replenished, a SDI treatment B with irrigation to trees to provide for approximately 70% of the water applied to treatment A. Reference evapotranspiration, ETo was calculated using the FAO-Penman–Monteith method and the procedures prescribed by Allen *et al*. (1998). Each tree of treatments A and B were supplied with water by a single drip line with emitters spaced 0,75 m apart throughout the entire length of the emitter line placed at the soil surface and laid out along each tree row, and serviced by 2,3 and 1,6 l h^{-1} emitters, respectively. The irrigation scheduling and time of water delivery to trees were the same to both treatments throughout the irrigation cycle. Half-hour averages of the meteorological parameters, wind speed, air temperature, solar radiation, precipitation and relative humidity were evaluated from data recorded in a nearby meteorological station. Half-hour averages of the net radiation above the canopy of the trees were measured using one NrLite net radiometer (Kipp & Konen, Holland) connected to a data logger (Delta-T, DL2e, Delta-T Devices, Cambridge, U.K). To evaluate sap flow rates and transpiration, three representative trees in each treatment were selected and their trunks implanted with one set of heat- pulse probes. Using the compensation heat-pulse technique (CHP) described in Santos *et al*. (2007), sap flow measurements were taken at 30min intervals and tree transpiration rates were estimated as average sap flow rates of the three probes. Photosynthetically active radiaton (PAR) where evaluated using a set of eight Quantum sensors (QPAR-02, 400 – 700 nm, Tranzflo, Palmerston, NZ) placed in a fixed grid around the trees and one at the top of the canopy. Measured daily transpiration values estimated from sap flow were compared to values obtained with the Penman-Monteith (PM) "big leaf" equation (1981) coupled with the Orgaz *et al.* (2007) specific model of bulk daily canopy conductance (G_c) for unstressed olive canopies (hereafter the PM-Orgaz model).

Results and Discussion

Average daily temperature was 22, 7 ºC during summer (1 June-30 September) while daytime average temperature for the same period was 26,3ºC (Table 1). Estimations of average daily and daytime net radiation (NR), vapour pressure deficit (D), and wind speed (U) are also shown in Table 1. Estimations of ETo for reference conditions (grass) were 5,0 mm d^{-1}, reflecting the prevailing weather conditions in Alentejo, of hot and dry summers with scarce or null rainfall. Total rainfall in the period was 29, 4 mm in 9 rainy days. Average daily and daytime values shown in Table 1 reflect the need of using daytime meteorological parameters in the Orgaz *et al*. (2007) model for calculating daily canopy conductance for water vapour (G_s) and daily olive tree transpiration (T).

Table 1. *Weather conditions during summer (1 June-30 September) for the experiment location. Values indicated in asterisk (*) are averages for the daytime period.*

Total rainfall (mm)	Rainy days (no.)	Average T (ºC)	Average D (kPa)	Average U (m s^{-1})	Average NR (W m^{-2})	Average ETo (mm d^{-1})
29,4	9	22,7	1,6	1,4	140	5
		26,3*	2,3*	1,6*	344*	

Transpiration rates estimated from sap flow were highly variable throughout the irrigation cycle (Figure 1), increasing in treatment A from spring to summer and then decreasing again in autumn. Average maximum and minimum daily treatment A canopy transpiration were 4,22 and 0,77 mm d^{-1}, respectively while corresponding values for treatment B were 2,34 and 0,67 mm d^{-1} (Figure 1). Total transpiration values for each treatment were 320 and 185 mm, respectively. For the unstressed treatment A, average maximum and minimum daily olive transpiration estimated with the PM-Orgaz model were 4,59 and 0, 145 mm d^{-1}, respectively, while the total transpiration was estimated as 294 mm, values that reflect the good match of the model to the seasonal pattern of treatment A transpiration rates (Figure 2). The high Willmott index of agreement IA of 0, 8 and the low root-mean-square error RMSE, of 0.4 mm d^{-1} (Willmott, 1982) confirm the goodness-of-fit and warrant treatment A as well-irrigated. Irrigation applied water for the period and for treatment A and B were 296 and

206 mm, respectively, a ratio of 0,7 as initially proposed. Decline of treatment B transpiration rates throughout the summer reflect such ratio.

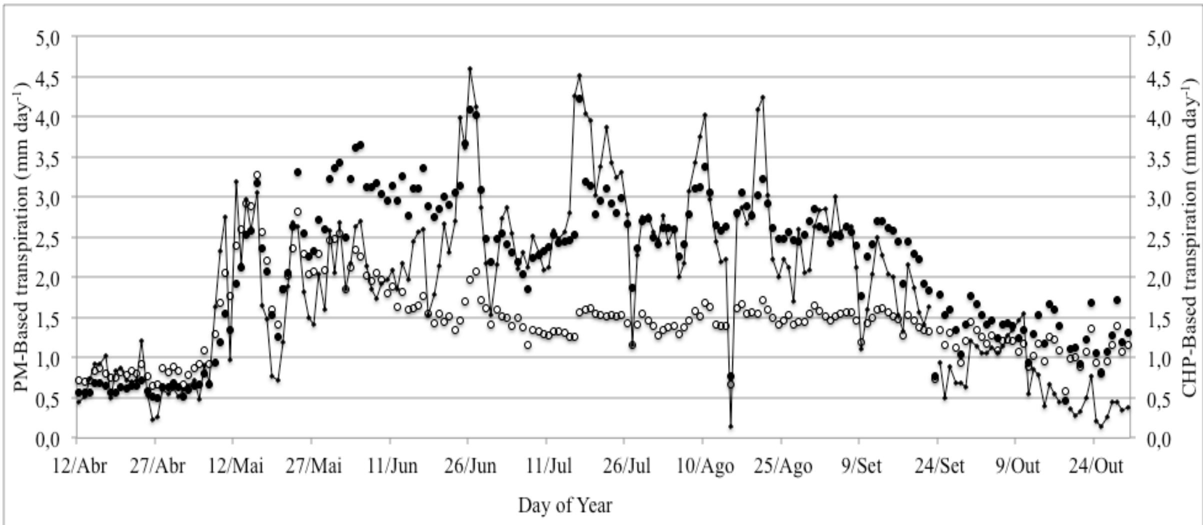

Figure 1. Time series of CHP-base olive transpiration (mm d^{-1}) for treatments A (solid circle) and B (open circle). The line is the transpiration rates calculated with the PM-Orgaz model.

Figure 2a establishes the relationships between CHP-based transpiration rates for treatments A and B and daily net radiation (NR), while Figure 2b establishes similar relationships with average vapour pressure deficit (D). The high goodness-of-fit (R^2=0,56 and 0,76, respectively) observed for treatment A suggests, as pointed out in Orgaz *at al.* (2007), that the PM-Orgaz model that critically bases its simulation of olive transpiration on those variables should be used solely for unstressed canopies.

a) b)

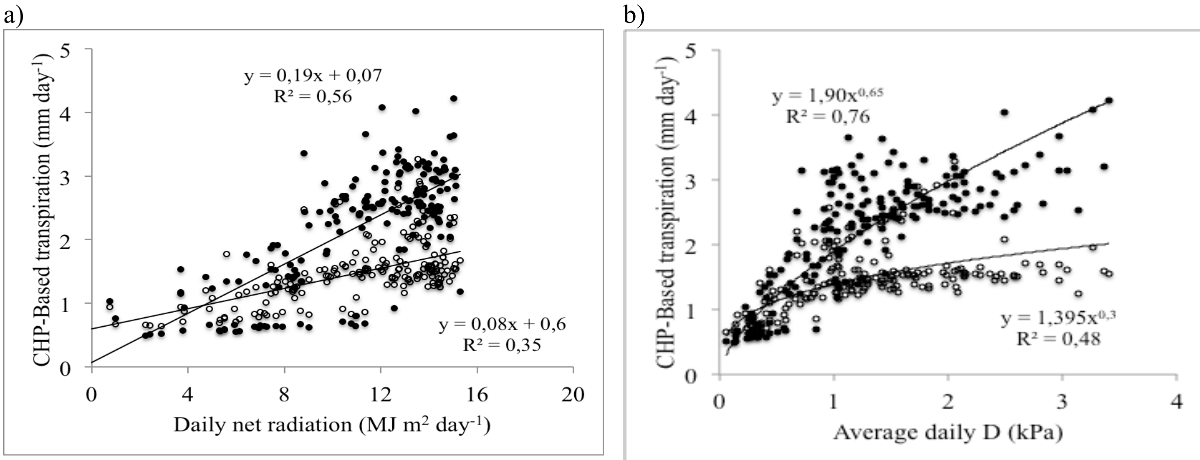

Figure 2. CHP-based olive transpiration (mm d^{-1}) relationship with a) daily net radiation (NR, MJ m^2 d^{-1}) and b) average daily vapour pressure deficit (D, kPa) for treatments A (solid circle) and B (open circle)

The average treatment A transpiration coefficient K_{cb} (the ratio of crop maximum transpiration over reference evapotranspiration, T_{max}/ETo) during summer (1 June to 30 September) was around 0,398, with a maximum of 0,975 and a minimum of 0,082, showing high variability during the period (Figure 3a). The U shape of the crop coefficient K_{cb} is a characteristic of olive trees and should be taken into account in the irrigation scheduling of olive orchards (Testi *et al.,* 2005). The variability of K_{cb} was also high during spring, closely following the variability of transpiration in the same period. A marked increase in its values was registered at the end of summer and onwards. When plants are under water stress the standard transpiration (T_{max}) is reduced and the crop coefficient K_{cb} is adjusted to those conditions using a water stress coefficient K_s (Allen et al., 1998). The adjusted transpiration rate (T_a) is the product of K_{cb}, K_s, and ETo. The crop stress coefficient K_s (the ratio of stressed to unstressed crop transpiration, T_a/T_m) is therefore often used to manage deficit irrigation by adjusting the upper limit of irrigation requirements (i.e. treatment A) to the soil water limiting conditions. Figure 3b plots the temporal evolution of K_s, recording an average K_s of 0,691 for the summer, and maximum and minimum of 0,92 and 0,462, respectively, to confirm the steadily decline in transpiration rates of treatment B from June to September, when its transpiration dropped to 59% of treatment A.

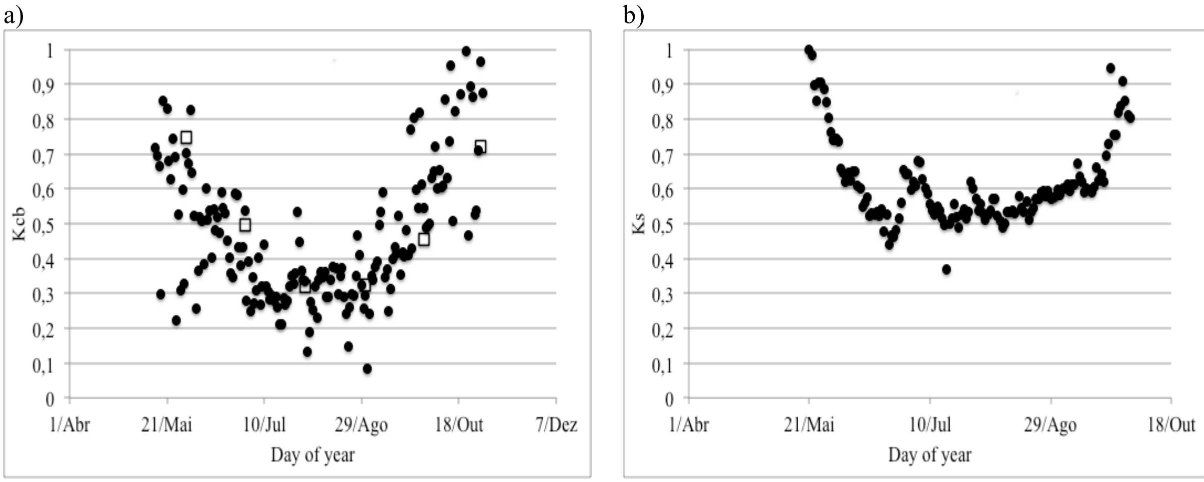

Figure 3. Time series of (a) coefficient of transpiration K_{cb} (the ratio of crop transpiration over reference evapotranspiration, or T/ETo) for the unstressed treatment A, and (b) the coefficient of stress K_s (the ratio of stressed to unstressed crop transpiration) for treatment B.

Conclusions

The irrigation regimes of treatment A and B were differently affected olive transpiration rates and crop coefficients. The low average K_{cb} coefficients obtained during summer suggest that hedgerow olive trees slow down their physiological processes in the period to improve their water use efficiency. Trees from deficit irrigation treatment B also showed a sharp decline in transpiration rates during summer reflected in their low K_s stress coefficients. The PM-Orgaz synthetic model accounted for the seasonal variability of treatment, proving sufficiently precise to be used as an appropriate simulation tool for predicting the upper limit of hedgerow olive stand transpiration rates for the region.

Acknowledgements

Financial support from the Fundação para a Ciência e a Tecnologia (FCT) and Instituto de Ciências Agrárias e Ambientais Mediterrânicas (ICAAM) for the projects PTDC/AGR-PRO/111717/2009 (H2Olive3S) and PEst-C/AGR/UI0115/2011, respectively, are gratefully acknowledged. Acknoweldgments are extended to the Estates Olivais do Sul for acess and research support in their commercial orchard at the Herdade da Azambuja.

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