Estimation of water use and crop coefficients for an intensive olive orchard using sapflow measurements and modeled data

Estimativa de uso da água e coeficientes culturais de um olival intensivo através de sensores de fluxo de seiva e modelação

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Abstract

Olive tree sap flow measurements were collected in an intensive orchard near Évora, Portugal, during the irrigation seasons of 2013 and 2014, to calculate daily tree transpiration rates (T_SF). Meteorological variables were also collected to calculate reference evapotranspiration (ETo). Both data were used to assess values of basal crop coefficient (Kcb) for the period of the sap flow observations. The soil water balance model SIMDualKc was calibrated with soil, biophysical ground data and sap flow measurements collected in 2013. Validated in 2014 with collected sap flow observations, the model was used to provide estimates of dual e single crop coefficients for 2014 crop growing season. Good agreement between model simulated daily transpiration rates and those obtained with sapflow measurements was observed for 2014 (R^2=0.76, RMSE=0.20 mm d^{-1}), the year of validation, with an estimation average absolute error (AAE) of 0.20 mm d^{-1}. Olive modeled daily actual evapotranspiration resulted in atual ETc values of 0.87, 2.05 and 0.77 mm d^{-1} for 2014 initial, mid- and end-season, respectively. Actual crop coefficient (Kc act) values of 0.51, 0.43 and 0.67 were also obtained for the same periods, respectively. Higher Kc values during spring (initial stage) and autumn (end-stage) were published in FAO56, varying between 0.65 for Kc ini and 0.70 for Kc end. The lower Kc mid value of 0.43 obtained for the summer (mid-season) is also inconsistent with the FAO56 expected Kc mid value of 0.70 for the period. The modeled Kc results are more consistent with the ones published by Allen & Pereira [1] for olive orchards with effective ground cover of 0.25 to 0.5, which vary between 0.40 and 0.80 for Kc ini, 0.40–0.60 for Kc mid with no active ground cover, and 0.35–0.75 for Kc end, depending on ground cover. The SIMDualKc simulation model proved to be appropriate for obtaining evapotranspiration and crop coefficient values for our intensive olive orchard in southern Portugal.

Keywords: Olive transpiration, dual crop coefficients, SIMDualKc, sap flow, Kc modelling

Resumo

Medições de fluxo de seiva foram efetuadas num olival intensivo perto de Évora, Portugal, durante os períodos de rega de 2013 e 2014 e os resultados utilizados para calcular os valores diários de transpiração (T_SF) do olival para esses anos. Dados meteorológicos, bem como os resultados da taxa de transpiração do olival obtidos do fluxos de seiva foram usados para calcular a evapotranspiração de referência (ETo), e os coeficientes culturais de base (Kcb) para os mesmos perídos. Igualmente, calibrou-se o modelo de balanço de água no solo, SIMDualKc, com os dados biofísicos e de solo recolhidos em 2013, e com os valores de transpiração derivados das medições de fluxo de seiva. A validação do model para 201 foi efetuada com os resultados da transpiração do olival obtidos com os sensores de fluxo de seiva, tendo-se estabelecido para esse ano de 2014, o ano de validação, uma boa correlação entre os valores de transpiração modelados e avaliados no campo, resultando num coeficiente de determinação, R^2, de 0.76, num erro quadrático médio (EQM) de 0.20 mm d^{-1}, e um erro médio absoluto (EMA) de 0.20 mm d^{-1}. Após a validação, o modelo foi utilizado para obter informação sobre a evapotranspiração atual do olival, e sobre os coeficientes culturais (Kc) para os diversos períodos de crescimento. Para 2014 observaram-se valores diários de evapotranpiração atual (ETc act) de 0.87, 2.05 and 0.77 mm d^{-1}, respetivamente para o período inicial, meia estação e período final. Valores atuais de Kc de 0.51, 0.43 and 0.67 foram também obtidos com o modelo para os mesmos perídos. Valores mais elevados de Kc foram tabelados na publicação FAO56 para os períodos de primavera (Kc ini) e outono (Kc end), de 0.65 e 0.70, respetivamente. O valor de 0.43 obtido para Kc mid é também inferior ao de 0.70 tabelado pela FAO56 para o mesmo período. Os valores de Kc obtidos com o modelo são mais congruentes com os Kc publicados por Allen & Pereira [1] para olivais com cobertura de solo efectiva entre 0.25 e 0.50, e que variam entre 0.40 e 0.80 para Kc ini, 0.40 e 0.60 para Kc mid e 0.35 e 0.75 para Kc end, dependendo neste último caso do enrelvamento do solo. O modelo SIMDualKc mostrou-se adequado para obter a evapotranspiração atual e os respetivos coeficientes culturais para o olival intensivo em estudo no sul de Portugal.

Palavras-chave: Transpiração da oliveira, coeficiente cultural de base, SIMDualKc, fluxo de seiva, modelação de Kc.

Introduction

Operational tools for precise quantification of actual olive evapotranspiration (ETc) under field conditions are important and required for better irrigation management, as they relate to crop water requirements, irrigation delivery and scheduling, canopy performance and thus productivity [1]. The development of such operational tools requires using appropriate corrections to the standard potential crop coefficients (Kc) values that are defined and tabulated for a wide range of agricultural crops [2], as they generally vary with plant height, fraction of ground covered and the amount of stomatal regulation under moist soil conditions. The values of Kc for conditions of low soil water availability are generally determined by reducing Kc estimates via a stress coefficient (Ks). This is best done by a daily soil water balance model as the value specified for the soil water threshold at which water stress begins does impact Kc estimations and the whole process needs to be determined locally [1]. The FAO-56 procedure for estimating actual crop coefficients (Kc) for orchards as a function of fraction of ground cover, plant height and stomatal regulation is formalized in the dual crop coefficient approach of Allen and Pereira [1], and adopted in the SIMDualKc soil water balance model [3]. In the present study we provide information on 2014 atual ETc and Kc for an intensive olive orchard by considering the physical characteristics of the orchard and the SIMDualKc soil water balance model [3], calibrated and validated with transpiration data derived from sapflow measurements obtained in the orchard during 2013 and 2014, respectively.

Material and Methods

Study site and measurements

The experiment was conducted during the growing season of 2013 and 2014 at the Herdade Álamo de Cima, near Évora (38º 29' 49.44'' N, 7º 45' 8.83'' W; alt. 75 m) in southern Alentejo, Portugal. The orchard was established with 10-year old trees in grids of 8.0 x 4.2 m (300 trees ha^{-1}) in the E-W direction and conducted on a shallow sandy loam Regosoil Haplic soil of weakly developed and unconsolidated materials [4]. The climate is semi-arid, temperate Mediterranean.

In this approximately 12 hectares orchard, a plot with 130 central trees surrounded by 260 border trees was selected and all measurements were taken in the central row of trees. From mid-May to the end of September the orchard was drip irrigated to provide trees with approximately 70% of ETc. As described in [5], three randomly selected representative trees were selected and instrumented in 2013 and 2014 with two set of heat-pulse sap flow probes and continuously monitored from May to the end of September, to obtain daily tree transpiration rates on a ground area basis (mm day^{-1}) by the Compensation Heat Pulse method [6]. Sap flow measurements were used to calibrate and validate the soil water balance model SIMDualKc (vide below). Water applied in each irrigation event was obtained by directly measuring the amount of water collected in rain gauges placed underneath selected emitters and connected to recording data loggers.

SIMDualKc soil water balance model

The soil water balance model simulates ETc, and the basal (Kcb) and soil evaporation coefficients (Ke) that relate to crop transpiration (Tc) and soil evaporation (Es), respectively, as:

$$ETc = Tc + Es = (Kcb + Ke)ETo = KcbETo + KeETo \quad (1)$$

where ETc is crop evapotranspiration for no stress conditions. When water stress occurs, ETc is adjusted as a function of the available soil water in the root zone by considering a stress coefficient (Ks), thus providing ETc act (mm d^{-1}), which is the actual evapotranspiration.

$$ETc\,act = Tc + Es = (KsKcb + Ke)ETo = KsKcbETo + KeETo \quad (2)$$

where Ks, the water stress coefficient, is an indicator of the relative intensity of the stress effect on a specific growth process and growth stage. Ks in essence are modifiers of the parameter Kcb and range in value from one (no stress) to zero (full stress). The coefficient is often used to adjust ETc to reflect the soil water conditions [1, 3], and is computed by SIMDualKc through a daily soil water balance algorithm. Concerning crop coefficients, the model takes into account plant density and height through a density coefficient Kd, to better adjust the final computations of Kc or Kcb.

$$Kcb = Kcb\min + Kd(Kcbfull - Kc\min) \qquad (3)$$

where Kcfull is the estimated basal Kcb during the peak plant growth for conditions of full ground cover, and Kcmin is the minimum Kc for bare soil [1,7]. Kd is estimated from the effective fraction of ground cover as:

$$Kd = \min(1, M_L f_{c\,eff}, f_{c\,eff}^{(1/1+h)}) \qquad (4)$$

where $f_{c\ eff}$ is the effective fraction of ground covered or shaded by vegetation near solar noon, M_L is a multiplier on $f_{c\ eff}$ describing the effect of canopy density on shading and on maximum relative ETc per fraction of ground shaded, and h (m) is the mean height of the vegetation [1,7]. As previously referred, measured sapflow data (T_SF) from 2013 was used to calibrate the SIMDualKc model and validation was performed with 2014 collected T_SF data. The calibration and validation we used the methodologies described in Rosa *et al*. [3], and Paço *et al.* [7], Calibration was essentially performed by progressively changing crop, evaporation, runoff, and percolation parameters to minimize the differences between observed (T_SF) and simulated transpiration (T_SDual).

Results and discussion

Climatic characterization

Reference evapotranspiration (ETo) spanning from June to September was 770 mm in 2014, the year of model validation, while annual ETo was 1209 mm, respectively. Total rainfall for the same irrigation period and year was 130 mm, while annual rainfall was 766 mm, respectively, showing that the irrigation season from June to September was provided with 17% of the total annual rainfall and 64% of the total annual ETo.

Irrigation and water use efficiency

An average of 271 mm of irrigation water was applied during the irrigation period of May 6th to October 5th. Seasonal tree water uptake and use obtained by monitored sap flow transpiration rates was of 202 mm, for a water use efficiency (WUE, ratio of water used to irrigation-water applied) of 0.75.

Average transpiration rates

For the irrigation period between June to August, Tc was estimated as 1.92 mm d^{-1} while it was estimated as 1.38 mm d^{-1} for the month of September. ETo for the periods was of 5.88 mm d^{-1} and of 3.27 mm d^{-1}, respectively. Figure 1 presents the evolution of sap flow olive transpiration and ETo during the irrigation period.

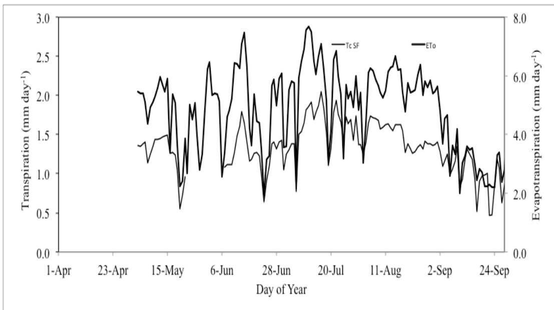

Fig. 1 – Time evolution of olive transpiration evaluated with sapflow observations (SF) for the irrigation period of 2014. Presented are the reference evapotranspiration rates (ETo) for the same irrigation period.

Sapflow transpiration rates closely followed the pattern of reference evapotranspiration, with a maximum ETo of 7.7 mm d^{-1} occurring in July 11th (DOY 192) and maximum T_SF in July 16th (DOY 197).

SIMDualKc validation with sapflow data

The model SIMDualKc was calibrated with T_SF data collected in 2013 (data not shown) and validated with T_SF data collected in 2014. Figure 2 presents the time evolution of olive transpiration modeled with SIMDualKc (T_SDual) and transpiration derived from sapflow observations (T_SF), as well as ETo, and the rainfall and irrigation water applied. Data plots show the pattern of evaluation of T_SF and T_Sdual, indicating that the model reproduced quite well observed transpiration rate estimates with minimal deviations. The goodness of fit assessed with a linear regression forced through the origin provided a slope, b, of 0.97, very close to one. The determination coefficient R^2 was 0.76, for a root mean square error (RMSE) of 0.2 mm d^{-1}. Similarly, the average absolute error (AAE) was estimated as 0.2 mm d^{-1}.

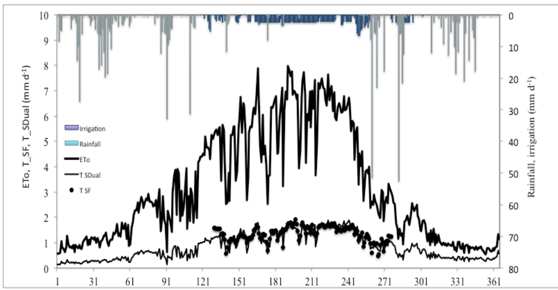

Fig. 2 – Time evolution of olive transpiration modeled with SIMDualKc (T_SDual) and transpiration derived from sapflow observations (T_SF). Reference evapotranspiration is also presented as well as rainfall and irrigation depths.

Olive SIMDualKc modeled daily actual evapotranspiration and resulted in ETc act values for the 2014 irrigation season of 0.87, 2.05 and 0.77 mm d^{-1} for the crop initial, mid- and end crop development stages, respectively.

Actual crop coefficients

Actual crop coefficient (Kc act) values of 0.51, 0.43 and 0.67 were obtained for the initial, mid- and end crop development stages, respectively. Higher Kc values during spring (initial stage) and autumn (end-stage) were published in FAO56, varying between 0.65 for Kc ini and 0.70 for Kc end. The lower Kc mid value of 0.43 obtained for the summer (mid-season) is also inconsistent with the FAO56 expected Kc mid value of 0.70 for the same period. The modeled Kc results are more consistent with the ones published by Allen & Pereira [1] for effective ground cover of 0.25 to 0.5, which vary between 0.40 and 0.80 for the Kc ini, 0.40–0.60 for the Kc mid with no active ground cover, and 0.35–0.75 for the Kc end, depending on the ground cover.

Conclusions

The SIMDualKc simulation procedure proved to be appropriate for obtaining adequate evapotranspiration and crop coefficient values for our intensive olive orchard in southern Portugal. The actual Kc results were lower than the tabulated FAO56 Kc values, reflecting the local conditions of soil and crop development and the required adjustments needed. Such tunings were successfully implemented with the SIMDualKc model.

Acknowledgments

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