Olive water use and crop coefficients from energy balance and radiometric canopy temperatures

Uso da água e coeficientes culturais de um olival através do balanço de energia e de temperaturas radiométricas da copa

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Abstract

Biophysical and meteorological variables as well as radiometric canopy temperatures were collected in an intensive orchard near Évora, Portugal, with 28% ground cover by canopy and combined in a simplified two-source energy balance model (STSEB) to independently calculate the olive tree transpiration (T_STSEB) component of the total evapotranspiration (ETc). Sap flow observations were simultaneously taken in the same orchard allowing also for independent calculations of tree transpiration (T_SF). Model water use results were compared with water use estimates from the sap flow measurements. Good agreement was observed (R^2=0.86, RMSE=0.20 mm d^{-1}), with an estimation average absolute error (AAE) of 0.17 mm d^{-1}. From June to August, on average olive water use were 1.92 and 1.89 mm d^{-1} for sap flow and STSEB model respectively, and 1.38 and 1.58 mm d^{-1} for the month of September. Results were also used to assess the olive basal crop coefficients (Kcb). Kcb estimates of 0.33 were obtained for sap flow and STSEB model, respectively, for June to August, and of 0.44 and 0.53 for the month of September. Basal crop coefficients were lower than the suggested FAO56 average Kcb values of 0.65 for June to August, the crop mid-season growth stage, and of 0.65 for the month of September, the end-season.

Keywords: Olive transpiration, energy balance, STSEB, sap flow, olive crop coeficient

Resumo

Dados biofísicos e meteorológicos, e temperaturas radiométricas da copa foram obtidos num olival intensivo perto de Évora, Portugal, com uma cobertura de solo de cerca de 28% e combinados num modelo simplificado de balanço de energia (STSEB) para independentemente se calcular a componente transpiração (T_STSEB) da evapotranspiração total das árvores. Medições com sensores de fluxo de seiva foram também simultaneamente efetuadas no olival, para o cálculo independente da transpiração (T_SF). Os resultados de uso de água do olival obtidos com o modelo foram comparados com as estimativas de transpiração estabelecidas com os sensores de fluxo de seiva, tendo-se observado uma boa correlação entre esses valores, resultando num coeficiente de determinação, R^2, de 0.86, um erro quadrático médio (EQM) de 0.20 mm d^{-1}, e num erro médio absoluto (EMA) de 0.17 mm d^{-1}. De junho a agosto, o uso médio de água do olival estimado com os fluxos de seiva e o modelo STSEB foram de 1.92 e 1.89 mm d^{-1}, respetivamente, e de 1.38 e 1.58 mm d^{-1} para o mês de setembro. Os resultados de uso de água foram também utilisados para obter coeficientes culturais de base (Kcb) para o olival. De junho a agosto o valor de Kcb obtido foi de 0.33 para o fluxo de seiva e o STSEB, e de 0.44 e 0.53 com os mesmos métodos para o mês de setembro, respetivamente. Estes valores são inferiores ao Kcb_{mid} de 0.65 para os meses de junho a agosto e Kcb_{end} de 0.65 para o mês de setembro tabelados pela FAO56 para olivais com cobertura do solo entre 40 e 60%.

Palavras-chave: Transpiração da oliveira, balanço de energia, STSEB, fluxo de seiva, coeficiente cultural da oliveira.

Introduction

Estimates of crop water requirements and crop coefficients are important for the improvement of crop water use and irrigation scheduling. This is of particular importance for olive trees in Mediterranean regions of increased water scarcity due to climate change and irrigated agriculture pressures. A common approach for the estimation of crop water requirements is the Kc-ETo methodology adopted by FAO 56 [1] where a reference crop evapotranspiration (ETo) is multiplied by a crop coefficient (Kc) for obtaining crop evapotranspiration, ETc. A single or dual Kc approach may be used [2]. Another approach for estimating crop ETc is the energy balance, based on surface energy balance models that use remote sensing thermal infrared observations [3], and biophysical and meteorological data to extract the latent heat flux, and derive crop transpiration rates. In particular, the simplified version of the two-source energy balance [4] allows the separate estimation of soil evaporation, Es, and transpiration, Tc, by establishing a separate balance for soil and canopy components, in a specific target. Sap flow measurements [5] also provide for independent estimations of plant transpiration, with microlysimeters [6] providing for soil evaporation. In this paper we use direct radiometric canopy temperature measurements and the simplified version of the two-source configuration (STSEB), as well as sap flow observations, to obtain daily olive transpiration rates, and assess basal crop coefficient values (Kcb) for olive trees. Evaluated basal crop coefficients are compared to FAO56 tabulated values.

Material and Methods

Study site and measurements

The experiment was conducted during the growing season of 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 [7]. 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 representative trees were selected and instrumented 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 [8]. Water applied in each irrigation event was obtained by directly measuring the amount collected in rain gauges placed underneath selected emitters, and connected to recording data loggers.

Radiometric surface temperatures of the canopy were obtained with one Apogee S-111 thermal Infrared Radiometer (IRT) placed 5 m above the canopy level and looking at its surface with nadir view. To evaluate sky brightness temperature for the atmospheric correction of the surface temperature [4], a second radiometer was also placed above the canopy and pointing at the sky with an angle of 53º.

Simplified energy balance

The energy balance uses as input direct radiometric canopy and soil temperature measurements to predict the net radiation partitioning between soil and vegetation [4]. According to this simplified approach the energy required for canopy transpiration, λT (W m^{-2}), is [4]:

$$\lambda T = R_{nc} - H_c \qquad (1)$$

where R_{nc} is the contribution of canopy to the total net radiation flux (W m^{-2}), and H_c is the contribution of canopy to the total sensible heat flux (W m^{-2}). H_c and R_{nc} are expressed as:

$$H_c = \rho C_p \frac{T_c - T_a}{r_a^h} \quad (2)$$

$$R_{nc} = (1-\alpha_c)S + \varepsilon_c L_{sky} - \varepsilon_c \sigma T_c^4 \quad (3)$$

where ρC_p is the volumetric heat capacity of air (J K^{-1} m^{-3}), T_c is the canopy temperature (ºK), r_a^h is the aerodynamic resistance to heat transfer between the surface and the air (s m^{-1}), as a function of wind speed and canopy height (z), α is the albedo, ε is the emissivity, σ is the Stefan-Boltzmann constant, L_{sky} is the incoming long-wave radiation (W m^{-2}), and S is the solar global radiation (W m^{-2}). A complete description of the simplified energy balance approach is found in [4], with a complete summary of the expressions to estimate the required aerodynamic resistances (s m^{-1}) to heat transfer between the canopy and the reference height described in [9].

Results and discussion

Climatic characterization

Reference evapotranspiration (ETo) spanning from June to September was 770 mm in 2014, 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 in 2014 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. Such circumstances make commercially irrigated olive orchards in Alentejo particularly vulnerable to climatic and water demand pressures, and requires from grower an appropriate irrigation management of their orchards.

Irrigation and water use efficiency

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

Average transpiration rates

Average daily transpiration rate for the irrigation period was estimated as 1.77±0.31 mm d^{-1}. For the irrigation period between June to August, Tc was estimated as 1.89 and 1.92 mm d^{-1} with the STSEB model (T_STSEB) and sap flow (T_SF), respectively, and 1.60 and 1.38 mm d^{-1} for the month of September. T_STSEB values for this latter month were higher than sap flow derived T_SF values, reflecting probably overestimation of T_STSEB in wetter months of the irrigation period. The values of T_STSEB and T_SF are plotted in Fig. 1. When compared, a high determination coefficient was obtained (R^2=0.86), together with a regression coefficient of 0.99, very close to 1.0. A root mean square error (RMSE) of 0.20 mm d^{-1} was also obtained together with a quite small average absolute error (AAE) of 0.17 mm d^{-1}. Despite such good agreement estimates, discrepancies were observed for the wetter month of September. Figure 1 reflects such discrepancies. Total crop transpiration for the first period, from June to August, was 147 mm for STSEB and 150 mm for sap flow measurements, respectively, while it was 47 mm for STSEB and 42 mm for sap flow during the month of September. ETo for the first period of June to August was 5.9 mm d^{-1} and 3.3 mm d^{-1} in September, respectively.

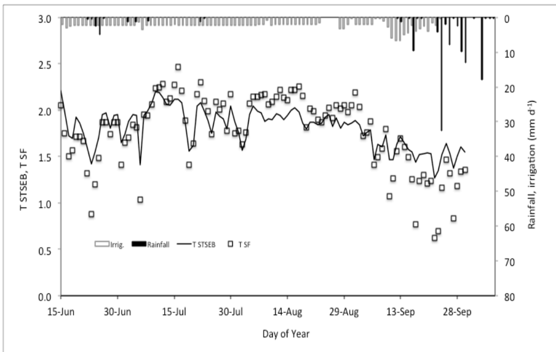

Fig. 1 – Time evolution of olive transpiration evaluated with the simplified two-source energy balance model (STSEB) and sap flow observations (SF) for the irrigation period of 2014. Presented is the rainfall and irrigation applied rates for the same irrigation period.

Average basal crop coefficients

Figure 2 shows the seasonal variation of daily Kcb obtained with the STSEB model and sap flow measurements, respectively, from June to the end of September. Results show that the actual Kcb_STSEB values match quite well Kcb_SF observed values in the months of June to August, with an average of 0.33. Kcb values for the month of September reflect the above-mentioned Tc variability during the month, with a Kcb_STEB of 0.52 and a Kcb_SF of 0.44 estimated for the month. Higher FAO56 [1] and Allen & Pereira [2] of 0.65 are tabulated for the two periods. In either case, the higher Kcb values tabulated for the month of September are credited to higher crop water uptake due to rainfall added soil water.

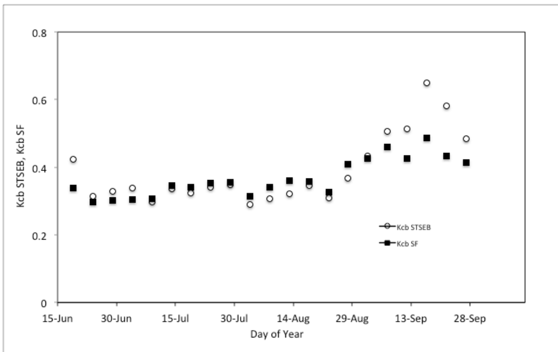

Fig. 2 – Time evolution of olive basal crop coefficients evaluated with the simplified two-source energy balance model (STSEB) and sap flow observations (SF) for the irrigation period of 2014.

Conclusions

The simplified two-source energy balance model (STSEB) used in this work provided independent estimations transpiration and basal crop coefficients for our olive orchad during the months of June to September of 2014 when simple radiometric canopy temperatures were taken. Independent estimations of olive transpiration were also obtained for the same period with sapflow measurements. Good agreement was observed between both estimations (R^2=0.86, RMSE=0.20 mm d^{-1}), with an estimation average absolute error (AAE) of 0.17 mm d^{-1}. From June to August, olive water use was on average of 1.92 and 1.89 mm d^{-1} for sap flow and STSEB model respectively, and 1.38 and 1.58 mm d^{-1} for the month of September. Some discrepancies are shown when comparing their calculated transpiration values for the wetter month of September. Results were also used to assess olive basal crop coefficient (Kcb) values. Kcb estimates of 0.33 were obtained from June to August for sap flow and STSEB model, and of 0.44 and 0.53 for the month of September, respectively. Discrepancies were observed when comparing calculated basal crop coefficients with those proposed by FAO56. They were lower than the suggested FAO56 average Kcb of 0.65 for June to August, the crop mid-season growth stage, and of 0.65 for the month of September, the end-season.

Acknowledgments

This work is supported by Foundation for Science and Technology (FCT) through the program SFRH/BSAB/113589/2015

References

[1] Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration: Guide- lines for Computing Crop Water Requirements. FAO, Rome, Irrigation and Drainage Paper, 56.

[2] Allen, R.G., Pereira, L.S., 2009. Estimating crop coefficients from fraction of ground cover and height. IRRIG SCI 28, 17–34.

[3] Kustas, W.P., Norman, J.M., 2000. A two-source energy balance approach using direc- tional radiometric temperature observations for sparse canopy covered surfaces. AGRON J 92, 847–854.

[4] Sánchez, J.M., López-Urrea, R., Rubio, González-Piqueras, Caselles V., 2014. Assessing crop coefficients of sunflowe and canola using two-source energy balance and thermal radiometry. AGR WAT MANAG 173:23-29.

[5] Santos, F.L., Valverde, P.C., Ramos, A.F., Reis, J.L., Castanheira, N.L., 2007. Water use and response of a dry-farmed olive orchard recently converted to irrigation. BIOSYST ENG 98 (1):102–114.

[6] López-Urrea, R., Martín de Santa Olalla, F., Fabeiro, C., Moratalla, A., 2006. Testing evapotranspiration equations using lysimeter observations in a semiarid climate. AGRIC WATER MANAGE 85, 15–26.

[7] WRB, 2006. World Reference Base for Soil Resources. World Soil Resources Report 84. FAO, Rome.

[8] Green, S.R., Clothier, B.E., Jardine, B., 2003. Theory and practical application of heat pulse to measure sap flow. AGRONOMY JOURNAL *95*:1371–1379.

[9] Sánchez, J.M., Kustas, W.P., Caselles, V., Anderson M., 2008. Modelling surface energy fluxes over maize using a two-source patch model and radiometric soil and canopy temperature observations. REMOTE SENS ENVIRON 112, 1130-1143.