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SOCIEDADE DE CIÊNCIAS
AGRÁRIAS DE PORTUGAL

Comparing approaches for evapotranspiration partitioning: single vs. dual crop coefficients

Avaliação da partição da evapotranspiração: comparação de dois métodos baseados no coeficiente cultural simples e coeficiente cultural dual

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https://doi.org/10.19084/rca.38548

Received/recebido: 2024.08.31
Accepted/aceite: 2024.10.25

ABSTRACT

Soil evaporation and crop transpiration are fundamental processes in modelling water transport, which is crucial for irrigation planning and scheduling. This study compares two methods to determine these components of crop evapotranspiration: (i) the straightforward single crop coefficient method, and (ii) the dual crop coefficient method, which may be more suiTable for daily irrigation scheduling. Experimental data were collected from a spinach crop grown in pots between June and September 2022, using drip irrigation with three different soils (two sandy loams and one loam), inside a polytunnel, during two growth cycles. Meteorological data, plant height, and root depth were measured onsite. The particle size distribution was used to obtain soil hydraulic properties for dual crop coefficient method. Soil cover fraction was obtained with the *Canopeo* software. The results showed that crop evapotranspiration and its partitioning in evaporation and transpiration differ between the two methods. The single crop coefficient method resulted in overall lower crop evapotranspiration throughout the growth cycles, while attributing a relatively larger proportion of evapotranspiration to evaporation, particularly after the midpoint of the growth cycles.

Keywords: soil evaporation, crop transpiration, crop coefficient, soil cover factor, irrigation scheduling.

RESUMO

A evaporação do solo e a transpiração das plantas são processos fundamentais na modelação do transporte de água, essencial para o planeamento da rega. Este estudo compara dois métodos para determinar esses componentes partindo da evapotranspiração cultural: (i) o coeficiente cultural simples e (ii) o coeficiente cultural dual, que pode ser mais adequado para a programação diária da irrigação. Foram usados dados experimentais de uma cultura de espinafre cultivada em vasos entre junho e setembro de 2022, usando rega por gota-a-gota em três tipos diferentes de solo (dois solos franco-arenosos e um solo franco), dentro de uma estufa, durante dois ciclos de crescimento. Os dados meteorológicos, a altura das plantas e profundidade das raízes foram medidos durante a experiência. As propriedades hidráulicas do solo para o método do coeficiente cultural dual foram estimadas por funções pedo-transferência com base na distribuição do tamanho das partículas do solo. As estimativas da fração coberta do solo foram obtidas com o software *Canopeo*. Os resultados mostraram que o método do coeficiente de cultural simples resultou numa menor transpiração ao longo dos ciclos de crescimento e atribuiu uma proporção relativamente maior da evapotranspiração à evaporação, especialmente após o meio dos ciclos de crescimento.

Palavras-chave: evaporação do solo, transpiração cultural, coeficientes culturais, fração coberta do solo, planeamento da rega.

INTRODUCTION

Soil evaporation (*E*) and crop transpiration *(T)* are fundamental processes in modeling water transport in soil, which is essential for effective irrigation planning and scheduling. The combination of these two processes constitutes crop evapotranspiration, which is influenced by weather conditions, crop characteristics, and management practices. These factors must be considered when assessing evapotranspiration from crops grown over large areas. Crop evapotranspiration under standard conditions (ET_c) represents the water demand of crops grown under optimal conditions, with sufficient soil water, effective management, and favourable environmental conditions, ensuring maximum production for the given climatic conditions (Allen *et al*., 1998).

ET_c is calculated using reference evapotranspiration (ET_o) and a crop coefficient, which accounts for differences between the field crops and the reference grass used in ET_o calculations. This can be done by integrating differences in *E* and *T* into a single crop coefficient (K_c) or separated them into two coefficients: a basal crop coefficient (K_{cb}) and a soil evaporation coefficient (K_e). The choice of method depends on the purpose of the calculation, the required accuracy, and the data availability. The single K_c method is straightforward and requires less data, while the dual crop coefficient method is computationally more intensive but more adequate for analysing the effects of specific wetting events and for scheduling high-frequency irrigation (Allen *et al*., 1998).

The aim of this study was to compare the results from the single and dual crop coefficient methods to determine ET_c and partitioning it into its two components, *E* and *T*, using experimental data from a spinach crop grown in pots in a polytunnel during two growth cycles.

MATERIAL AND METHODS

Experimental data

The data used in this study was collected in an experiment conducted between June and September 2022 at Lincoln University, in Lincoln, UK. In the trial, spinach was grown in large-scale pots with a height of 0.4 m and a diameter of 0.3 m. The pots had drainage holes at the bottom to facilitate free water drainage. The pots were placed inside a polytunnel and filled with three different soil types soils (two sandy loams and one loam), with and no additional fertilization applied. Each soil type was represented by five replicate pots, and the three pots with the most similar spinach growth were selected for modelling. In each pot, five spinach plants were seeded. Due to the short growth cycle of spinach, two consecutive growth cycles were conducted to extend the monitoring period. All the pots were irrigated using a drip system, while precipitation was simulated using a sprinkler.

Daily meteorological data relative to air temperature, wind speed, and relative humidity were collected at the experimental site. The plant height and the root depth were measured at the end of the growth cycle and linear growth was assumed during the cycle. Soil particle size distribution was determined to calculate the readily evaporable water (*REW*) and the total evaporable water (*TEW*) using pedo-transfer functions. Soil cover fraction (*SCF*) was obtained with the *Canopeo* software.

Single crop coefficient method

Both the single and dual crop coefficient determination methods were applied as described by Allen *et al*. (1998). In the single crop coefficient approach, ET_c [mmd^{-1}] is calculated according to Equation 1:

$$ET_c = ET_o \times K_c \qquad \text{Equation 1}$$

where ET_o was calculated according to the Hagreaves-Samani equation (Hargreaves & Samani, 1985) using a transmissibility factor, measured onsite, to account for differences between radiation outside and inside the polytunnel, according Fernández *et al.* (2010). K_c was obtained from reference values for spinach for the four growth stages: initial, crop development, midseason, and late season. The duration of the stages was defined by the *SCF* according to Allen *et al.* (1998). The K_c of midseason and late season was adjusted for the specific weather conditions according to Equation 2.

$$K_c = K_{c(Tab)} + [0.04(u_2 - 2) - 0{,}004(RH_{min} - 45)](\frac{h_e}{3})^{0.3} \qquad \text{Equation 2}$$

where $K_{c(Tab)}$ is the reference value for spinach by Allen *et al.* (1998), u_2 is wind speed measured at 2 m height, RH_{min} is minimum relative humidity, and h_e is the plant height. The soil cover fraction (*SCF*) was used to partition ET_c into *E* and *T*, as proposed by Ritchie (1972), according to Equations 3 and 4:

$$T = ET_c \times SCF \quad \text{Equation 3}$$

$$E = ET_c \times (1 - SCF) \quad \text{Equation 4}$$

Dual crop coefficient method

In the dual crop coefficient method, K_c is split into two factors that separately describe *E* and *T*, according to equation 5.

$$ET_c = ET_o \times (K_{cb} + K_e) \quad \text{Equation 5}$$

K_{cb} is defined as the ratio between ET_c/ET_o when the soil surface is dry but transpiration is occurring at a potential rate. K_{cb} was obtained from reference values for spinach by Allen *et al.* (1998) and adjusted according to equation 6:

$$K_{cb} = K_{cb(Tab)} + [0.04(u_2 - 2) - 0{,}004(RH_{min} - 45)](\frac{h_e}{3})^{0.3}$$

Equation 6

K_e describes the evaporation component of ET_c and is calculated according to equation 7:

$$K_e = K_r\,(Kc_{max} - K_{cb}) \leq f_{ew}\,Kc_{max} \quad \text{Equation 7}$$

where K_r is dimensionless evaporation reduction coefficient, Kc_{max} is maximum value of K_c following rain or irrigation, and f_{ew} the soil fraction that is both exposed and wetted. Following rain or irrigation K_r is 1 and evaporation is maximal. As the soil surface dries, K_r is < 1 and evaporation is reduced. K_r is zero when no water is left for evaporation in the upper soil layer. K_r is calculated by equation 8:

$$K_r = \frac{TEW - D_{e,i-1}}{TEW - REW} \quad \text{Equation 8}$$

where *TEW* is total evaporable water, *REW* is the readily evaporable water and $D_{e,\ i-1}$ is the cumulative evaporative depletion of the previous day. This equation is used when *TEW* is lower than $D_{e,\ i-1}$, otherwise K_r is considered to be 1. TEW and REW were calculated from the field capacity and wilting point (Allen *et al.*, 2005), which were obtained with the particle size distribution with pedotransfer functions presented by Ramos *et al.* (2014). The Kc_{max} and f_{ew} are calculated according to equations 9 and 10:

$$Kc_{max} = (\{1{,}2 + [0{,}04(u_2 - 2) - 0{,}004(RH_{min} - 45)](\frac{h_e}{3})^{0.3}\}, (K_{cb} + 0.05))$$

Equation 9

$$f_{ew} = \min\,(1 - SCF, f_w) \quad \text{Equation 10}$$

where f_w is fraction of soil surface wetted by irrigation or precipitation. $D_{e,\ i-1}$ and f_w were also calculated according to the equations presented by Allen *et al.* (1998). Finally, *T* and *E* can be calculated by equations 11 and 12 respectively:

$$T_r = ET_O \times K_{cb} \quad \text{Equation 11}$$

$$E = ET_O \times K_e \quad \text{Equation 12}$$

All the results were obtained by implementing the equations in a spreadsheet.

Determination of the soil cover fraction (SCF)

An important variable in both approaches is *SCF*. To estimate SCF, the *Canopeo* software was used (Patrignani & Ochsner, 2015). This application is based on the ratio of red to green (R/G) and blue to green (B/G) colours in each pixel, as well as an excess green index (2G-R-B). The R/G and B/G ratios must be lower than 0.95 and the excess green index must be higher than 20 to classify the pixel as green. Figure 1 shows the processing of a spinach pot picture by *Canopeo* to estimate *SCF*.

Figure 1 - Spinach pot picture processed by Canopeo. In this example, resulted in a SCF of 56,9%.

RESULTS AND DISCUSSION

Figure 2 shows the crop coefficients used in both methods, namely the K_c corrected to meteorological conditions, and K_{cb} and K_e obtained with Equations 6 and 7. In this Figure and the following, the results are shown for one of the studied sandy loam soils, with similar outcomes for the other two soil types, which are therefore not presented. Figure 2 shows that K_{cb} is lower than K_c, as K_{cb} is related only to the crop's transpiration. The main difference between K_c and K_{cb} occurs during the initial stages in both growth cycles, when the spinach is small and water losses are mainly due to soil evaporation, related to by K_e. As the spinach *SCF* increases, K_e decreases. The K_{cb} and K_c become nearly identical at the midseason and late season stages. K_e peaks after an irrigation or precipitation event, but as the layer dries, K_e gradually decreases.

Figure 3 shows ET_c resulting from the single and the dual crop coefficient methods, for a sandy loam soil. The single crop coefficient approach resulted in lower ET_c across the entire cycle, which indicates that the sum of K_{cb} and K_e is higher than K_c. In average,, ET_c was 1,50 mm/day lower in the single crop coefficient approach than in the dual crop coefficient, during the entire period.

Figure 4 shows *E* and *T* resulting from both methods, in same sandy loam soil. Over the entire

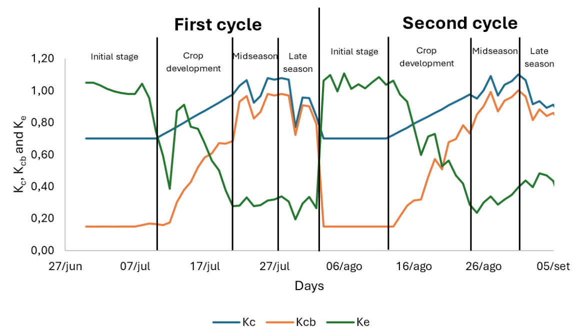

Figure 2 - The single crop coefficient (K_{cb}), the basal crop coefficient (K_{cb}), and the evaporation coefficient (K_e) for the two spinach growth cycles, in a sandy loam soil.

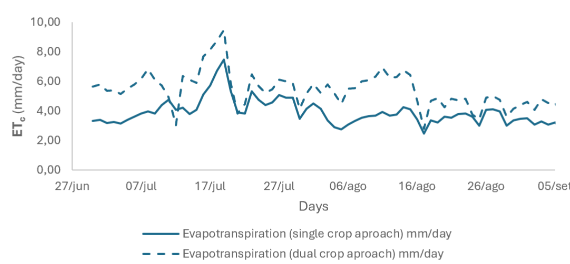

Figure 3 - Crop evapotranspiration (ET_c) determined with the single and dual crop coefficient methods in a sandy loam soil.

period, *T* was 54,26 mm for single crop coefficient method and 159,32 mm for the dual crop coefficient method. This is partly because the SCF used for

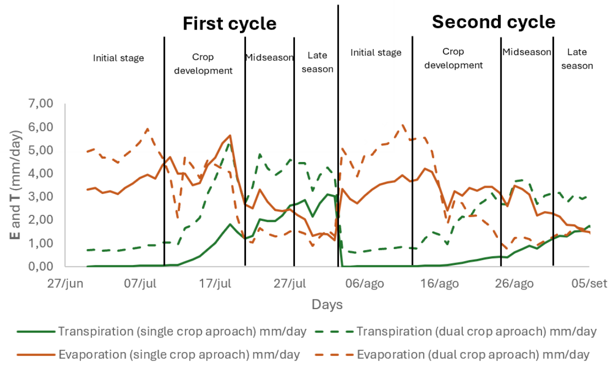

Figure 4 - Evaporation (*E*) and transpiration (*T*) determined with the single and dual crop coefficient methods in a sandy loam soil.

calculating T in Equation 3 is zero during the initial stage of the growth cycles, whereas K_{cb} never drops to such a low value. The single crop coefficient approach resulted in lower *E* during the initial stage of the growth cycles, but it increased and surpassed the values from the dual crop coefficient approach after the midpoint of the growth cycles. Over the entire period, *E* was 214,38 mm for the single crop coefficient approach and 212,89 mm for the dual crop coefficient approach.

These results show that the two methods not only result in different absolute value of ET_c (Figure 2) but also differ in how they partition ET_c into *E* and *T*, resulting in different proportions for each component along the growth cycle. Specifically, in the single crop coefficient approach, a relatively larger proportion of ET_c was attributed to *E*, particularly after the midpoint of the growth cycles.

CONCLUSIONS

Crop evapotranspiration and its partitioning in *E* and *T* differ between the two approaches. Namely, the single crop coefficient approach results in a lower ET_c throughout the entire growth cycles, while attributing a relatively larger proportion of ET_c to E, particularly after the midpoint of the growth cycles. These differences are primarily due to the use of a daily adjusted K_e and K_{cb} in the dual crop approach, compared to a K_c within each crop stage in the single crop approach. Future research should compare the results from both approaches with measured values of ET_c, *E*, and *T*.

AKNOWLEGMENTS

This work was carried out within the project *SoilSalAdapt* (DOI: 10.54499/EJPSoils/0003/2021) funded Biology and Biological Sciences Research Council, the Research Council of Norway, and Fundação para a Ciência e a Tecnologia.

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