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Determination of evapotranspiration and crop coefficient for cauliflower at Paraná northwest region

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Abstract
Evapotranspiration and the estimation of crop coefficient (Kc) are essential information for irrigation management, contributing to increase the water use efficiency and optimizing resources, mainly using local data. This study aimed to determine the water consumption and the crop coefficient of cauliflower (Barcelona hybrid) in the northwestern region of Paraná. The experiment was conducted in a greenhouse at the Technical Irrigation Center belonging to the State University of Maringá, in Maringá - PR. The crop evapotranspiration was determined using constant water table lysimeters, and the reference evapotranspiration was estimated by the Penman-Monteith method (FAO), using climatological data collected in an automatic meteorological station. The cultivation was carried out from April to July. The total water consumption by the cauliflower was 215.11 mm, a higher value than that available in the FAO recommendations. The crop coefficient (Kc) recommended values for local conditions are 0.74 for the initial stage, 1.86 for the intermediate stage, and 1.50 for the final stage.
Keywords: *Brassica oleracea* var. *botrytis*; irrigation management; lysimeter; water consumption.

Determinação da evapotranspiração e coeficiente da cultura da couve-flor na região noroeste do Paraná

Resumo
A evapotranspiração e a estimativa dos coeficientes da cultura (Kc) são informações fundamentais para o manejo da irrigação, contribuindo para o aumento da eficiência no uso da água e otimização dos recursos, principalmente a utilizar dados locais. O trabalho teve como objetivo determinar o consumo hídrico e o coeficiente da cultura da couve-flor (híbrido Barcelona) na região noroeste do Paraná. O experimento foi conduzido em casa de vegetação no Centro Técnico de Irrigação pertencente à Universidade Estadual de Maringá, em Maringá - PR. A evapotranspiração da cultura foi determinada utilizando lisímetros de lençol freático constante, e a evapotranspiração de referência foi estimada pelo método de Penman-Monteith (FAO), a partir de informações climatológicas coletadas em estação meteorológica automática. O cultivo foi realizado no período de abril a julho. O consumo total de água pela cultura da couve-flor foi de 215,11 mm, sendo um valor maior do que o disponível nas recomendações da FAO. Os valores recomendados de coeficiente da cultura (Kc) para as condições de cultivo são de 0,74 para o estádio inicial, 1,86 para o estádio intermediário e 1,50 para o estádio final.
Palavras-chave: *Brassica oleracea* var. *botrytis*; manejo da irrigação; lisímetro; consumo hídrico.

Introduction

Cauliflower (*Brassica oleracea* var. botrytis) is a species belonging to the Brassicaceae family. Environmental conditions, mainly temperature, are limiting factors for the production, and the South and Southeast are the major producers regions in Brazil. However, management practices enable cultivation in the mid-season and summer with satisfactory profitability (FERREIRA *et al.*, 2019; OLIVEIRA *et al.*, 2018; PEREIRA *et al.*, 2018).

Because of the superficial root system, cauliflower is intolerant to long periods of water deficit, which can compromise vegetative growth, causing a reduction of potential yield (MAY *et al.*, 2007). In hydric stress conditions, plants can show changes in morphological and physiological components, causing a direct impact on crop yield (FERREIRA *et al.*, 2019). Irrigation based on different technical criteria allows supply crop demands, decreasing environmental impact, and optimizing resource utilization (SANTOS *et al.*, 2018).

According to Coutinho *et al.* (2020), improper use of water by agricultural production shows a high impact on the productive sector and society. The determination of adequate amounts for irrigation is one relevant factor. One of the technical criteria to be used in an irrigated crop is the plant evapotranspiration supplied by the irrigation, conditioning crop to reach the maximum potential productivity (LOZANO *et al.*, 2017).

Different equations are utilized to estimate the reference evapotranspiration (ETo) based on climate data, being the Penman-Monteith method recommended by FAO (Food and Agriculture Organization). Crop evapotranspiration can be indirectly determined using reference evapotranspiration values and crop coefficient (Kc). Thus, the Kc presents great relevance to estimating crop water necessities (MANGAROTTI *et al.*, 2019).

The success of water utilization by irrigation depends, among other requirements, on accurate knowledge of crop demand. Thus, the use of adequate coefficients is necessary, especially Kc that is determined in function of crop evapotranspiration (ETc) and ETo.

The crop can be affected by several factors, stomatal resistance caused by adverse atmospheric conditions, plant morphology, soil fertility, the occurrence of pests and diseases, irrigation interval, water availability, soil characteristics, and sowing density (TAIZ; ZEIGER, 2017; SANTOS *et al.*, 2018). So this factors can affect the crop coefficient.

The Kc determination must be done in function of crop phenological stages, varying according to the location and climate where it is being assessed (BARBOSA *et al.*, 2015). Research about regional Kc determination is essential because it provides greater reliability in local evapotranspiration rates (LOZANO *et al.*, 2017; MARGAROTTI *et al.*, 2019; SANTOS *et al.*, 2020).

The present study aims to determine the hydric consumption and Kc on different phenological stages of cauliflower cultivated in a greenhouse at Paraná northwest region and compare with FAO irrigation and drainage paper 56.

Material and methods

The study was conducted at Irrigation Technical Center, from Maringá State University, situated at 23°25'S, 51°57' W, and altitude of 542 m (Maringá, state of Paraná). Climate is classified as Cfa (humid subtropical climate) according to Köppen classification, with annual precipitation of 1500 mm, average temperature between 28 °C and 29 °C (MONTANHER; MINAKI, 2020).

The experiment was conducted in a greenhouse, arched roof, covered with low-density polyethylene (thickness of 150 µm) and side protected by a nylon screen. Greenhouse dimension is 25 m long, 7 m wide, and 3.5 m headroom.

The soil of the experimental area is classified as NITOSSOLO VERMELHO Distroférrico corresponding to an Ultisol in the soil taxonomy classification (SANTOS *et al.*, 2018). Presenting as chemical characteristics: base saturation (V%) = 81.08; cation exchange capacity (CEC) = 12.95 $cmol_c$ dm^{-3}; water pH = 7.40; organic matter = 25.20 g dm^{-3}; P = 149.02 mg dm^{-3}; K = 0.25 $cmol_c$ dm^{-3}; Ca^{2+} = 7.55 $cmol_c$ dm^{-3}; Mg^{2+} = 2.24 mg dm^{-3}; S = 152.48 mg dm^{-3}; Cu = 17.77 mg dm^{-3}; Zn = 33.94 mg dm^{-3}; Mn = 103.70 mg dm^{-3}; Fe = 169.00 mg dm^{-3}; B = 4.10 mg dm^{-3}. As physical composition, the soil presented 122,60 g kg^{-1} of sand, 120,60 g kg^{-1} of silt, 756,80 g kg^{-1} of clay and soil bulk density of 1,34 Mg m^{-3}.

Base dressing was made based on the soil analysis and recommendations by Pauletti and Motta (2017). Urea, simple superphosphate, and potassium chloride were used as N, P, and K sources, respectively, besides 3 kg m^{-2} of tanned poultry manure. During the seedlings transplant, 15 and 30 days after transplant (DAT) boric acid (1 g L^{-1}) was applied (foliar spray) as the source of boron. At 15 DAT, ammonium molybdate (0.5 g L^{-1}) was applied (foliar spray) to provide molybdenum. Top-dressing was made with urea and potassium chloride at 15, 30, 45, and 60 DAT through fertigation.

After soil tillage and fertilizers incorporation, 48 plots were prepared inside the greenhouse, measuring 3 m long and 0.5 m wide. Seedlings were transplanted with the spacing of 1

m between rows and 0.5 m between plants. Irrigation was done using a drip irrigation system, where each plot contained 12 self-compensating drippers (flow rate of 4 L h^{-1}) spaced 0.25 m between each one. Seedlings were produced in 128-cell expanded polystyrene trays containing commercial substrate and using the 'Barcelona' cauliflower hybrid. When seedlings showed between three and four leaves, they were transplanted.

ETc was determined using three constants water table lysimeters installed inside the greenhouse. Lysimeters were built with polyvinyl chloride (PVC) boxes (1.05 m in diameter, 0.65 m deep, and 380 L capacity). To install, three circular trenches were opened, separating soil according to the different layers. At the bottom was placed a 0.50 m crushed stone layer with geotextiles to avoid the obstruction of water intake caused by soil particles. After this procedure, the soil was replaced inside the boxes respecting the same layer order when removed.

Each lysimeter was connected to an intermediate tank, made in a 200 mm PVC tube with 0.80 m high and the bottom sealed to prevent leaks. One float valve was installed, allowing water intake in the intermediate tank supplied by another tank (supply tank) used to measure the water volume consumed. Everyday water consumed was read in the supply tank, and the level water was replaced, keeping the water table constant.

Before crop installation, lysimeters were saturated and draining three times to guaranteed particle soil rearrangement. Two cauliflower plants were transplanted to each lysimeter, 0.5 m spaced. With crop development, evapotranspiration reduces the water table level supplied by the supply tank and changes the supply tank level. Assisted by a graduated ruler installed inside the supply tank, the water consumed was measured.

The read of supply tank level and the level of water replacement was made every day at 8:00 am. Evapotranspiration (ETc) was calculated using the difference between the current day read and last day read. The average of the three lysimeters determined the daily water consumption for the crop. ETo value was obtained by Penman-Monteith equation, according to the FAO recommendation (ALLEN *et al.*, 1998). Climate data used for ETo determination were registered by a weather station (Davis Instruments, Hayward, California, USA) installed 1.2 m high at the greenhouse center, data was stored in a datalogger. Cauliflower crop coefficient (Kc) was determined considering ETc without water restriction and ETo.

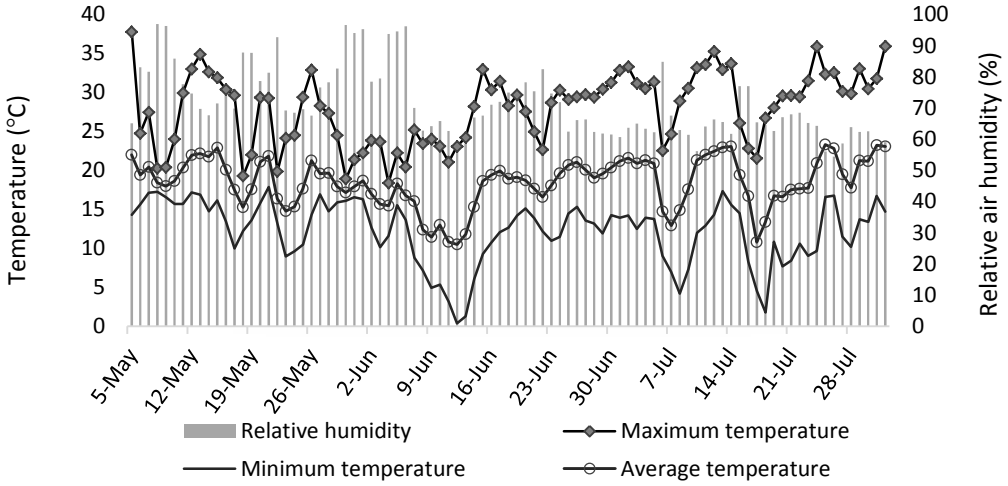
To calculate the mean Kc, the crop cycle was divided into three phenological stages defined by Allen *et al.* (1998): initial stage: from sowing to when plant presents between 7 and 10 leaves; intermediate stage: from 7-10 leaves to the appearance of inflorescence in the meristem; final stage: from the appearance of the inflorescence to the harvest. However, according to the field observation, the crop cycle was also divided into four phenological stages (ABDELKHALIK *et al.*, 2019). The intermediate stage was divided to do a better demonstration of water consumption during this stage.

This paper does not have treatments for being a deterministic analysis, so it is not necessary a statistical design. Using data collected, ETo, ETc, and Kc's values were determined using spreadsheet software Microsoft Excel®.

Results and discussion

During crop development, there were registered temperatures between 0.4 °C and 37.8 °C, and the mean temperature was 17.9 °C (Figure 1). Barcelona hybrid is classified as a midseason hybrid (MAY *et al.*, 2007), thus registered temperature was considered good to crop development.

Figure 1. Relative air humidity, minimum, maximum, and mean temperature inside the greenhouse.

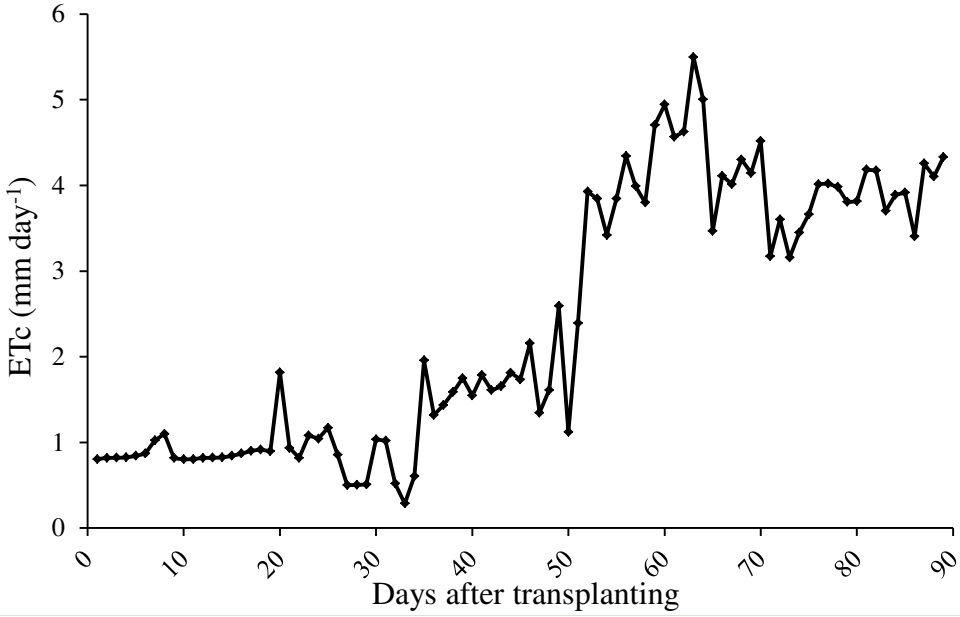


Midseason cultivars can tolerate higher temperatures during the development, therefore, temperature fluctuation is less prejudiced for this cultivar type than winter cultivars. According to MAY *et al.* (2007), the best temperature for cauliflower development is between 14 °C and 20 °C, above this temperature, physiological disorders can occur, affecting inflorescence quality and hindering commercialization. Temperatures below 14 °C affect plant growth.

With air temperature increase, molecule energy levels also increase and create a larger difference between vapor pressure and saturation pressure, resulting in evapotranspiration increase. When the relative humidity increase can decrease plant transpiration because the vapor concentration gradient between the stomatal cavity and the adjacent air to the leaf also decrease, caused by the reduction of air vapor saturation deficit (LOZANO *et al.*, 2017; TAIZ; ZEIGER, 2017).

Figure 2 represents the crop evapotranspiration demands during the crop cycle.

Figure 2. Crop evapotranspiration demands during the crop cycle of cauliflower, Maringá – PR.



Total water consumption was 215.11 mm during 92 cycle days after transplant. Mean evapotranspiration was 2.34 mm day^{-1}. The highest ETc value was observed between 50 DAT and 75 DAT, and 5.49 mm day^{-1} was the maximum value. Parekh (2014) evaluated the water consumption for cauliflower cultivated in the open field, obtaining a consumption of 237 mm.

Evapotranspiration demands for stage I (1 - 32 DAT) were 32.44 mm, where the minimum value was 0.41 mm dia^{-1} and maximum 1.80 mm day^{-1}. This phase can be understood as plant adaptation time to the ambient conditions. Crop roots will be developed along with the soil profile, demanding more nutrients and increasing the photosynthetic rate for vegetal development. According to Oliveira Gondin *et al.* (2011), roots represent the main part of vegetative mass increase when related with other cauliflowers parts until 30 DAT.

During stage II (33 - 61 DAT), occurred the increase in the number of leaves considering that the crop establishment has already happened. Water consumption was 61.12 mm, and 4.34 mm day^{-1} was the maximum consumption that was registered at the end of this stage. From 50 DAT, the water demand followed the leaf expansion (reach an average of 18 developed leaves) and the beginning of flower primordia appearance that presented a mean diameter of 2.1 cm. Barreto *et al.* (2017) and Sohail *et al.* (2018) affirm that the leaf area index (LAI) is related with the uptake of water and nutrients by the plants, the presence of limiting factors can affect this relationship.

Stage III (62 - 74 DAT) was characterized by the inflorescence growth, therefore, needing a larger water consumption. This stage lasted 13 days, and the total ETc was 51.17 mm (maximum value was 5.49 mm day^{-1}). The ETc differs between stage II and stage III was 9.95 mm. Still, stage III presented 16 days less, evidencing that inflorescence development demands more water, which is a critical stage during cauliflower development.

Stage IV (75 - 92 DAT) is the maturation period when the inflorescence growth ends, and the harvest begins. At this stage, the water demands stabilized, the maximum ETc was 4.14 mm day^{-1}. The crop cycle was 48 days less when compared to the cauliflower cycle determined by FAO. According to FAO (ALLEN *et al.*, 1998), the total cycle of cauliflower was 140 days, being 35, 60, and 45 days for stage I, II, and III, respectively.

Cauliflower Kc values, determined by the division between ETc and ETo, were higher than the reference values presented in the FAO Irrigation and drainage paper 56. According to Allen *et al.* (1998), under frequent wetting conditions, the Kc values can increase with high irrigation frequency or rain. Table 1 demonstrates the comparison between the Kc obtained and the Kc reported by FAO.

Table 1. Cauliflower crop coefficient (Kc) calculated and tabled Kc by FAO.

Phenological stage	Crop coefficient (Kc)	
	Calculated	FAO
Initial	0.74	0.65
Intermediate	1.86	1.05
Final	1.50	0.95

At all phenological stages, the Kc calculated was larger than Kc reported by FAO. Kc calculated was 0.74, 1.86, and 1.50 higher for the initial, intermediate, and final stages. According to Parekh (2013), the leaf area is small during the initial period, and the evapotranspiration is compound basically for water evaporation from the soil. The Kc can also increase when the soil is frequently wetted during the initial stage, this way, the Kc value can be higher due to soil conditions, which provide larger water evaporation. Parameters as a cultivar life cycle, planting location, and season also can influence the Kc calculated. The season and planting location influence the environmental conditions that will influence the crop life cycle; in this case, the life cycle was reduced, contributing to

increase the daily ETc and consequently increase the Kc.

It is possible to notice that Kc reported by FAO underestimates the value obtained experimentally. Using the Kc reported by FAO, the water volume applied during the irrigation will be smaller than real plant necessity, restricting water availability for the crop and causing production losses. The determination of the FAO kc is carried out in desert conditions in the United States, that is, in conditions totally different from those of the Brazilian regions (ALLEN *et al.*, 1998).

Thus, the values found locally for the plants shows the need for specific research on water consumption and the crop coefficient at the site and with the cultivar to be implanted. According to Yanglem and Tumbare (2014), when cauliflower is submitted to hydric stress, the evapotranspiration decrease happens caused by the stomatal conductance reduction. It will influence photosynthesis rates, consequently, the plant growth too. Under adequate soil humidity conditions, the plant can keep the photosynthesis rates, favoring the inflorescence growth, improving yield.

Lazzara and Rana (2010) reported that FAO reports underestimated the Kc for different crops such as cauliflower, red cabbage, lettuce, and melon. Therefore, it is essential to develop regional research, specifying the Kc values for different crops in all their phenological stages, considering that most references Kc were determined in the Mediterranean region. Besides, only 10% of main food-producing countries have a regionalized Kc value.

For López-Urrea *et al.* (2009), it is essential that there are local experiments for the determination of Kc, making the estimation of ETc more precise and, consequently, improving irrigation management. The author also points out that the equations' incapacity causes the differences between ETc values measured through lysimeters and the values calculated from the formulas provided by FAO irrigation and drainage paper 56 to capture the effect of all climate parameters combinations.

Although the higher Kc values obtained in the present study indicate a higher demand for irrigation water, yield also increases. Water use efficiency (WUE) is the variable that determines the efficiency of water management, which is if the water is being used well. When water is applied in quantity demanded by the crop, the yield tends to be maximum (if the other factors are adequately supplied), thus, the water use efficiency (LÓPEZ-URREA *et al.*, 2009). Wrongly estimating the Kc, it can overestimate the value and increase the use of water, decreasing production efficiency and change post-harvest aspects of the product (HACHMANN *et al.*, 2019; SHAMS; FARAG, 2019; WENNECK *et al.*, 2021).

The Kc values provided by FAO are useful as a reference in the absence of local data. Irrigation should be based on Kc values provided by FAO than to be carried out without criteria; however, whenever possible, local Kc values should be used, or at least values obtained for situations closer to cultivation condition.

Conclusions

According to the present study, the Kc values of cauliflower cultivated in a greenhouse under a humid subtropical climate are 0.74, 1.86, and 1.50 for the initial, intermediate and final stages, respectively. The water consumption was 32.44, 112.29, and 70.38 mm for the three stages, respectively, totalizing a water consumption of 215.11 mm.

Thus, it was possible to observe that the reference values of FAO irrigation and drainage paper 56 underestimate the values found locally for the Barcelona hybrid. This shows the need for specific research on water consumption and the crop coefficient at the site and with the cultivar to be implanted.

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