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Estimatation of evapotranspiration and crop coefficient of melon cultivated in protected environment

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Key words:
Cucumis melo L.
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lysimeter

ABSTRACT
The objective of this work was to determine the water consumption and the crop coefficient of melon in a protected environment. The experiment was conducted in a greenhouse at the Technical Center of Irrigation of the State University of Maringá, in Maringá, PR. The melon hybrid used was Sunrise and the irrigations were performed daily by drip irrigation. Crop water requirement was quantified based on its evapotranspiration directly measured through constant water table lysimeters. Weather information was collected in an automatic weather station, installed inside the protected environment, which allowed to calculate the reference evapotranspiration by the Penman-Monteith method. The total water consumption of the melon crop was 295 mm, reaching maximum crop evapotranspiration of 5.16 mm d^{-1}. The phenological stages were shorter in the initial, growth and intermediate phases, compared with the data from FAO. The determined crop coefficients were 0.87, 1.15 and 0.64 for the initial, intermediate and final stages, respectively.

Palavras-chave:
Cucumis melo L.
irrigação
lisímetro

Estimativa da evapotranspiração e do coeficiente de cultura do melão rendilhado cultivado em ambiente protegido

RESUMO
Objetivou-se, neste trabalho, determinar o consumo de água e o coeficiente de cultura do melão rendilhado em ambiente protegido. O experimento foi conduzido em casa de vegetação no Centro Técnico de Irrigação da Universidade Estadual de Maringá, em Maringá, PR. O híbrido de melão utilizado foi Sunrise e as irrigações foram realizadas diariamente via gotejamento. A necessidade de água da cultura foi quantificada por meio da evapotranspiração da cultura medida diretamente através de lisímetros de lençol freático constante. As informações climatológicas foram coletadas em estação meteorológica automática, instalada no interior do ambiente protegido, que deram subsídio ao cálculo da evapotranspiração de referência pelo método de Penman-Monteith. O consumo total de água da cultura do melão foi de 295 mm, atingindo a evapotranspiração da cultura máxima de 5,16 mm d^{-1}. As durações dos estádios fenológicos foram menores na fase inicial, de desenvolvimento e intermediária, quando comparados a FAO. Os coeficientes da cultura determinados foram 0,87; 1,15 e 0,64 para o estádio inicial, intermediário e final, respectivamente.

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Introduction

Melon (*Cucumis melo* L.), belonging to the Cucurbitaceae family, has great importance in the Brazilian economy, because it is highly appreciated fresh and in the form of soft drinks, besides being one of the crops of highest growth in the exportations of vegetable products by the country (Dalastra et al., 2016).

Some varieties are grown in protected environment in the South and Southeast regions due to the climate and the possibility to obtain better market prices, producing in the offseason of the Northeastern producing states (Queiroga et al., 2008). When a protected environment is used, irrigation becomes necessary; however, due to the reduction in water availability and high cost of electric power nowadays, it is indispensable to adopt an irrigation management (Oliveira et al., 2011).

Studies related to evapotranspiration and estimation of crop coefficients (Kc) are fundamental for a good management (Fernández et al., 2010). Experimental values of Kc are found in the literature (Allen et al., 1998). However, due to the climatic differences from one place to another, these values may vary and, consequently, overestimate or underestimate water consumption by plants (Carvalho et al., 2006). The Kc values determined by Miranda et al. (2004) for the watermelon crop in Ceará and by Peres et al. (2013) for the melon crop in São Paulo were higher than those recommended in the literature, which highlights the importance of determining Kc at a regional level.

Given the lack of research on melon Kc in the Southern region of the country, this study aimed to determine water consumption and crop coefficient of the melon crop grown in protected environment, under the edaphoclimatic conditions of Maringá, PR.

Material and Methods

The experiment was carried out from November 12, 2015, to February 19, 2016, in a protected environment at the Technical Center of Irrigation (CTI) of the State University of Maringá (UEM), in Maringá, PR (23º 25' S and 51º 57' W, at altitude of 542 m). The local climate, according to Köppen's classification, is Cfa, subtropical mesothermal. The protected environment had an arched roof, covered with polyethylene film (150 μm) and white shade screen on the sides.

The soil of the experimental area is classified as distroferric Red Nitosol with clayey texture (EMBRAPA, 2013) and its chemical characterization according to methodologies described in EMBRAPA (2009) showed the following results: pH $CaCl_2$ = 6.4; pH H_2O = 7.20; OM = 15.55 g dm^3; C = 9.02 g dm^3; P = 46.77 mg dm^3; K = 0.30 $cmol_c dm^3$; Ca^{+2} = 11.99 $cmol_c dm^3$; Mg^{+2} = 2.50 $cmol_c dm^3$; H^+Al^{+3} = 2.54 $cmol_c dm^3$; SB = 14.80 $cmol_c dm^3$; CEC = 17.34 $cmol_c dm^3$; V (%) = 85.35; Cu = 18.71 mg dm^3; Zn = 20.34 mg dm^3; Fe = 68.97 mg dm^3; Mn = 94.61 mg dm^3; Na^+ = 32.58 mg dm^3; B = 0.18 mg dm^3.

The soil was turned, allowing the construction of 60 beds (3 m long and 0.5 m wide). Fertilization was performed according to soil chemical analysis and crop requirements.

The experiment used the melon hybrid Sunrise and the seedlings were produced on expanded polyethylene trays with 50 cells, containing commercial substrate, and maintained in a greenhouse until transplanting, when they showed three true leaves.

The plants were arranged on the beds at spacing of 1 m between rows and 0.5 m between plants, vertically trained using one single stake and narrow plastic strips until the height of 1.90 m. After flower production, manual pollination was performed, leaving one fruit per plant. The harvesting point was defined by the change of color and formation of the abscission zone of the fruit (Dalastra et al., 2016).

A drip micro-irrigation system was used, composed of drip lines with diameter of 16 mm, 12 pressure-compensating drippers spaced by 0.25 m and flow rate of 8 L h^{-1}, operating at pressure of 10 mwc. Irrigations were applied with a frequency of one day. The Christiansen uniformity coefficient (CUC) was 96%, which is considered as excellent (Frizzone et al., 2012).

Crop water requirement was quantified based on crop evapotranspiration (ETc), measured using two constant water table lysimeters, installed in the center of the protected environment. The lysimeters were built using PVC boxes with capacity for 310 L, diameter of 1.05 m and depth of 0.54 m. The lysimeter was equipped with an auxiliary device made of PVC tube (200 mm), a float valve and a water supply system with known volume, connected by a flexible tube.

Two plants were transplanted to each lysimeter, spaced by 0.5 m, similar to the conditions of the beds, so that the extracted water volume was automatically replaced by the system. Water replacement in the supply tank was daily performed, at 7:00 a.m., based on a level indicator attached to the external wall of the tank. A container with capacity for 5 L and a digital scale (0.1 g) were used. The water of the tank was replaced until the increase in the level and the difference of mass of the full container in relation to the mass after the replacement indicated the water consumption.

Reference evapotranspiration (ET_o) was determined using a DAVIS weather station and the data were recorded in a data logger placed in a weather instrument shelter positioned in the center of the protected environment.

The agroclimatic model used to determine ET_o was FAO Penman-Monteith (Allen et al., 1998) according to Eq. 1:

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{Tmed + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where:

ET_o - reference evapotranspiration, mm d^{-1};
Δ - slope of the vapor pressure curve, kPa $^oC^{-1}$;
Rn - daily net radiation, MJ m^{-2} d^{-1};
G - daily heat flow in the soil, MJ m^{-2} d^{-1};
γ - psychrometric constant, kPa $^oC^{-1}$;
T - daily mean air temperature, ^oC;
U_2 - daily mean wind speed at height of 2 m, m s^{-1};
e_s - daily mean water vapor saturation pressure, kPa; and,
e_a - daily mean water vapor pressure, kPa.

Crop coefficients were calculated from the values of crop evapotranspiration (ETc) and reference evapotranspiration (ET_o), Eq. 2:

$$Kc = \frac{ETc}{ET_o} \quad (2)$$

To calculate the mean Kc, the crop cycle was divided into four phenological stages: I) initial stage, II) growth stage, III) intermediate stage and IV) final stage (Allen et al., 1998).

The experiment is a deterministic analysis and does not fit to a statistical design, since it did not test treatments, only readings of evapotranspiration.

Results and Discussion

Water consumption or crop evapotranspiration (ETc) of the melon crop in the period from transplanting to harvest was 295 mm, according to Figure 1.

The increase and reduction of ETc along the melon crop cycle can be attributed to the climatic conditions and the development of the plants. According to Figure 1, the lowest values of ETc occurred in the initial and final stages, and it is important to point out that in initial stage the melon crop has small development of the shoots and its water demand is due to water evaporation from the soil, superficial moisture, irrigation frequency and atmospheric evaporation demand, while in the final stage this reduction in ETc is due to the natural process of senescence (Allen et al., 1998). The maximum water consumption, in turn, occurred in the intermediate stage, with ETc of 5.16 mm d^{-1}, which can also be due to the increase in leaf area along with the development of the fruits.

In a study conducted by Miranda et al. (2004) with watermelon, Crimson Sweet variety, in the region of Paraipaba, CE, using weighing lysimeters for ETc quantification, the authors observed that the intermediate stage showed consumption of 6.5 mm d^{-1}, and the highest value was recorded in a 70-day cycle. Silva et al. (2015), determining the ETc of watermelon, Sugar Baby cultivar, in the region of Juazeiro-BA, using water table lysimeters, observed that the highest ETc values occurred in the intermediate stage, reaching up to 10.4 mm d^{-1} in a 60-day cycle.

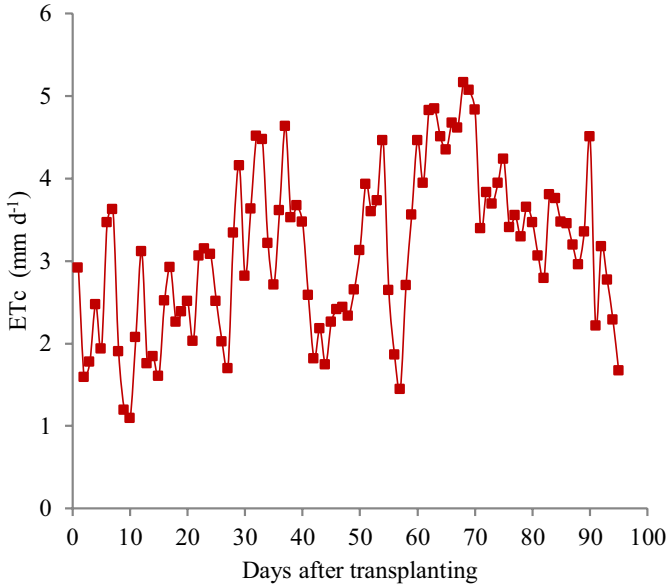

Figure 1. Melon crop evapotranspiration along the experimental period

Soares (2001), determining water consumption of the melon hybrid Don Carlos with a weighing lysimeter in protected environment in the municipality of Piracicaba, SP, observed crop evapotranspiration of 280 mm in a 100-day cycle. The result of this author corroborates with those of the present study, probably because the climatic conditions of both regions are similar.

Valnir Júnior et al. (2013), working with water management, found the consumption of a volume of 266 mm during the 55-day cycle of the melon crop in the open field, in the Northern region of the Ceará state, thus revealing the large influence that the climate has on the water consumption of the melon crop.

The main climatic variables that affect ETc are air temperature, relative air humidity, solar radiation and wind (Lemos Filho et al., 2010), as presented in Table 1.

The mean variation of air temperature inside the protected environment remained within the critical limits for the crop. According to Brandão Filho & Callegari (1999), melon vegetative growth is damaged by air temperatures lower than 13 °C and higher than 40 °C, and the range from 25 to 32 °C is considered as optimal.

Temperature influences the process of evapotranspiration because the solar radiation absorbed by the atmosphere and the heat emitted by the cultivated surface causes air temperature to increase. The heated air close to the plants transfers energy to the crop in the form of sensible heat, increasing the evapotranspiration rates (Ismael Filho et al., 2015).

According to Brandão Filho & Callegari (1999), the relative air humidity considered as ideal during the vegetative growth of the melon crop is from 65 to 75%. Based on Table 1, in the months of November and December, the values were above the desirable. This variable can affect ETc due to the interactions with photosynthesis and dry matter production, negatively reflecting in the leaf area index or modifying stomatal conductance (Jolliet, 1994).

It is noted that, as temperature increases, the values of relative air humidity decrease, representing an increment in the saturation deficit. With the increase in air temperature, there is an increase in the energetic level of the molecules and in the difference between the actual vapor pressure and saturation pressure, consequently resulting in an increment of evaporation or evapotranspiration. More water molecules leave the evapotranspiring surface and are incorporated into the air (Pereira et al., 1997).

Global solar radiation is closely related to the variation in crop evapotranspiration, being proportional. When there is an increase in global solar radiation, ETc values also increase (Figure 2).

Global solar radiation can be considered as the main source of energy to the plants and part of this energy is converted

Table 1. Mean climatic conditions observed in protected environment during the experimental period

Month	Temperature (°C)			Relative air humidity (%)	Solar radiation (MJ m^{-2} d^{-1})
	Maximum	Mean	Minimum		
November	31.8	25.5	19.2	79.4	8.35
December	34.8	27.8	20.8	76.4	11.03
January	37.0	28.8	20.7	71.7	13.91
February	40.7	31.2	21.5	69.5	13.03

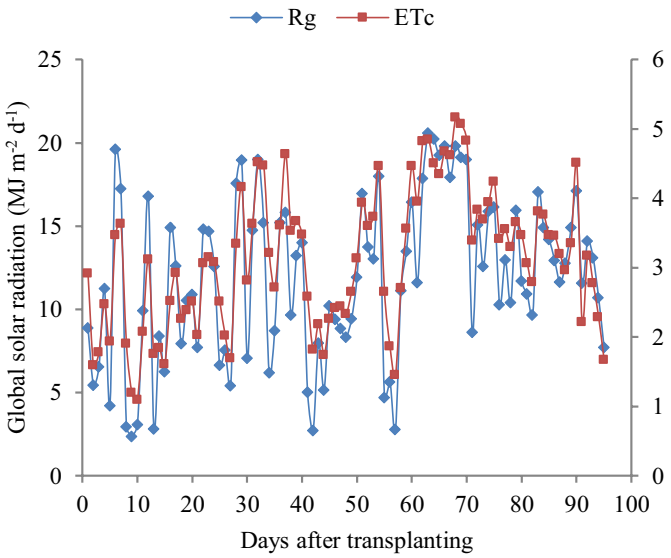

Figure 2. Variation of crop evapotranspiration and global solar radiation along the experimental period

into heat, stimulating the transpiration process, modifying the temperature of plant tissues, with consequences for the metabolic processes (Zhang et al., 2010).

The melon vegetative cycle lasted 95 days, divided into four phenological stages, as presented in Table 2.

The duration of each stage differs from those indicated by the FAO Bulletin nº. 56 under the conditions of the region of California, which can be related to the genetic material used and climatic characteristics of the region. In the present experiment, the predominant climate in the municipality of Maringá is Cfa, mesothermal humid subtropical, with cold and dry winters and hot and rainy summers. In contrast, a large portion of California has a Mediterranean climate, with hot and dry summers and mild and humid winters.

It is noted that there was a rapid crop development in the initial, growth and intermediate stages, which are shorter compared with the data from FAO. For calculations of the water demand of the crop, FAO data would underestimate the reality.

The temperatures recorded in the experimental period (Table 1) remained for most of the cycle within the ideal limits for melon development (25 to 32 ºC), favoring the reduction of the crop cycle.

Durations of phenological stages similar to those presented in Table 2 were observed by Peres et al. (2013) for the melon crop in protected environment in the region of Araras, SP, and the initial stage lasted 15 days, growth stage 30 days, intermediate stage 15 days and final stage 22 days, totaling a vegetative cycle of 82 days.

The values of crop coefficient (Kc) of the netted melon were higher than those recommended by the FAO Bulletin nº. 56 in the initial and intermediate stages, while in the final stage, the Kc values were close, as presented in Table 3.

Table 2. Duration of the melon phenological stages

Phenological stage	Duration (days)	
	Measured	FAO
I – Initial	20	30
II – Growth	30	45
III – Intermediate	25	35
IV – Final	20	10
Total	95	120

Table 3. Melon crop coefficients in protected environment, Maringá, PR, and FAO data

Stage	Crop coefficients	
	Measured	FAO
Initial	0.87	0.50
Intermediate	1.15	0.85
Final	0.64	0.60

The fact that Kc values measured in this experiment are higher than those from FAO (Table 3) is related to the frequent wetting of the soil surface that occurred due to the irrigations, potentiating soil water evaporation rates. According to Allen et al. (1998), for the condition of frequent wetting, Kc values can increase and become close to 1.0 to 1.2.

The high relative air humidity recorded in some periods of the cycle is also a factor that contributes to the elevation of Kc values, because it reflects in the reduction of ET_o.

Allen et al. (1998) also claim that crops managed in espaliers, which reach height of 1.5 to 2.0 m, need Kc values to be increased.

Peres et al. (2013), evaluating the use of weighing lysimeters to determine melon crop coefficients for the cultivation in protected environment in the region of Araras, SP, obtained Kc values of 0.20, 1.10 and 0.50 for the initial, intermediate and final stages, respectively.

Miranda et al. (2004) determined the crop coefficient for the watermelon crop irrigated by a drip system, in the region of Paraipaba-CE, using weighing lysimeter for ETc determination and the FAO Penman-Monteith method for ET_o estimation, and observed initial Kc of 0.30, intermediate of 1.15 and final of 0.58.

The Kc values of the initial stage observed by these authors is lower than that of the present study. This fact can be related to the type of lysimeter used, because water table lysimeters have a constant water replacement in the system and the plants are not well developed in this stage, thus increasing water evaporation from the soil.

Tabulated values of Kc are useful as a general guide and for comparison, but always when possible, one should use local observations and consider the effects of variety, climate and cultivation practices, because the use of tabulated values may lead to underestimation or overestimation of crop water demands.

In the present study, there is an underestimation of the values provided by FAO in the initial and intermediate stages of the melon crop, knowing that water deficit may become the main cause of yield reduction.

Conclusions

1. The total water consumption of the melon crop, Sunrise hybrid, was 295 mm, considering a vegetative cycle of 95 days.

2. The recommended values of melon crop coefficient, under drip irrigation in a protected environment in the municipality of Maringá-PR are 0.87, 1.15 and 0.64 for the initial, intermediate and final stages, respectively.

3. Compared with the recommendations of FAO, there were lower durations of the phenological stages and higher values of crop coefficient, highlighting the importance of conducting regional studies on the determination of crop evapotranspiration and crop coefficient.

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