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Estimation of the crop coefficient (kc) for bell pepper under greenhouse conditions

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ABSTRACT: This study aimed to determine the crop coefficient (kc) and respective water consumption of the Magali R. bell pepper hybrid cultivated in a protected environment from May to September 2015. Reference evapotranspiration was estimated using the Modified Penman-Monteith method and data were collected from an automatic weather station installed inside the greenhouse at the Universidade Estadual de Maringá, in the municipality of Maringá, PR, Brazil (23° 25’ 57” S, 51° 57’ 8” W, and altitude of 542 m). Evapotranspiration was measured using constant water table lysimeters. The total water consumption of the bell pepper crop was 282 mm and the average consumption was 2.35 mm d^{-1}. The maximum evapotranspiration was 5.37 mm d^{-1}. Crop coefficient values for the bell pepper were 0.86, 1.55, and 1.4 for the initial, intermediate, and final stages, respectively, which were higher than those recommended by the Food and Agriculture Organization.

Key words: *Capsicum annuum* L., evapotranspiration, irrigation management

Estimativa do coeficiente de cultura (kc) do pimentão em condições de casa de vegetação

RESUMO: Objetivou-se com este estudo determinar o coeficiente de cultura (kc) e respectivo consumo de água da cultura do pimentão, híbrido Magali R., cultivado em ambiente protegido no período de maio a setembro de 2015. A evapotranspiração de referência foi estimada pelo método de Penman-Monteith Modificado com dados coletados em estação meteorológica automática instalada no interior da casa de vegetação localizada na Universidade Estadual de Maringá, no município de Maringá, PR, (23º 25’ 57” S e 51º 57’ 8” O, e altitude de 542 m). A evapotranspiração da cultura foi mensurada por meio de lisímetros de lençol freático constante. O consumo total de água da cultura do pimentão foi de 282 mm, com consumo médio de 2,35 mm d^{-1}, atingindo a evapotranspiração máxima da cultura de 5,37 mm d^{-1}. Os valores do coeficiente de cultivo encontrados para o pimentão foram de 0,86; 1,55 e 1,4 para o estádio inicial, intermediário e final, respectivamente, sendo mais elevados do que os recomendados pela FAO.

Palavras-chave: *Capsicum annuum* L., evapotranspiração, manejo de irrigação

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INTRODUCTION

The bell pepper (*Capsicum annuum* L.) is a member of the Solanaceae family common to the Americas. In Brazil, it is one of the 10 most important vegetables for 'in natura' consumption and food processing, and is used to manufacture condiments, preserves and sauces (Carvalho et al., 2011; Lorenzoni et al., 2016).

Technologies aiming to boost productivity are applied to bell pepper cultivation (Sediyama et al., 2014), such as cultivation in a protected environment and irrigation. However, with water scarcity, proper irrigation management becomes indispensable since the agricultural sector demands high amounts of water due to the requirements of each crop (Albuquerque et al., 2012).

Determining water consumption and estimating crop coefficients (kc) are fundamental for efficient irrigation management, because water depth is estimated by the kc based on the crops' actual water requirements (Gomes et al., 2010). Most applied kc values reported in the literature were proposed by Allen et al. (1998). However, kc values may vary due to climatic differences between regions, and the plants' water consumption may therefore be estimated incorrectly.

The kc values reported by Albuquerque et al. (2012) for bell pepper crop in Recife, PE, Brazil, and by Lozano et al. (2017) for the melon crop in Maringá, PR, Brazil, differed from those suggested in the literature (Allen et al., 1998). This further indicates that kc must be adjusted for each region.

Thus, the purpose of this study was to obtain the kc and water consumption of bell peppers under the edaphoclimatic conditions of Maringá, PR state, Brazil, using constant water table lysimeters in a protected environment.

MATERIAL AND METHODS

The experiment was conducted at the Centro Técnico de Irrigação da Universidade Estadual de Maringá in the municipality of Maringá, PR, Brazil (23° 25' 57" S, 51° 57' 8" W, and altitude of 542 m), from May to September 2015 in a greenhouse with 30 m long, 7 m wide and 3.5 m high, and an arched ceiling lined with polyethylene film (150 μm) and a white anti-insect screen along the sides.

According to the Köppen climate classification, the region's climate is classified as Cfa and humid mesothermal (Alvares et al., 2013), and the soil of the study area is classified as Ultisol.

The physical and chemical characteristics of the soil were determined based on the methodologies described by EMBRAPA (2009): bulk density = 1.01 Mg m^{-3}; sand = 122.6 g kg^{-1}; silt = 120.6 g kg^{-1}; clay = 756.8 g kg^{-1}; pH $CaCl_2$ = 6; pH H_2O = 6.8; OM = 9.5 g dm^{-3}; P = 71.22 mg dm^{-3}; K = 0.35 $cmol_c$ dm^{-3}; Ca = 4.38 $cmol_c$ dm^{-3}; Mg = 1.77 $cmol_c$ dm^{-3}; Al = 0 $cmol_c$ dm^{-3}; CTC = 9.8 $cmol_c$ dm^{-3}; V (%) = 66.34; Cu = 10.34 mg dm^{-3}; Zn = 15.82 mg dm^{-3}; Fe = 64.18 mg dm^{-3}; Mn = 78.11 mg dm^{-3}; Na = 59 mg dm^{-3}; and B = 0.18 mg dm^{-3}.

The lysimeters and surrounding area were filled with soil that had been previously turned over and fertilized based on its chemical composition and recommendations for the crop. The Magali R. bell pepper hybrid was cultivated by seeding in polyethylene trays with 50 compartments filled with commercial substrate.

Seedlings were transplanted on May 13, 2015 (34 days after seeding), when they had four to six permanent leaves in the lysimeters and in the plots (3 m in length, 0.5 m in width and 0.15 m in height) with spacings of 1 m between rows and 0.5 m between plants. The final harvest was on October 10, 2015, and the total cycle was 120 days.

A drip micro-irrigation system was employed with a statistical uniformity coefficient (SCu) of 91%, considered excellent by Frizzone et al. (2012). Each plot contained a lateral polyethylene line (16 mm in diameter) with 12 pressure compensating emitters (discharge of 8 L h^{-1}) with 0.25 m spacings between them.

The amount of water consumed by the crop was assessed by its evapotranspiration (ETc). Two constant water table lysimeters were constructed in the center of the greenhouse with PVC boxes with capacity of 500 L, a diameter of 1.17 m, and a depth of 0.65 m. Two bell pepper plants were transplanted spaced 0.5 m apart in each lysimeter, similar to the conditions of the plots (Figure 1).

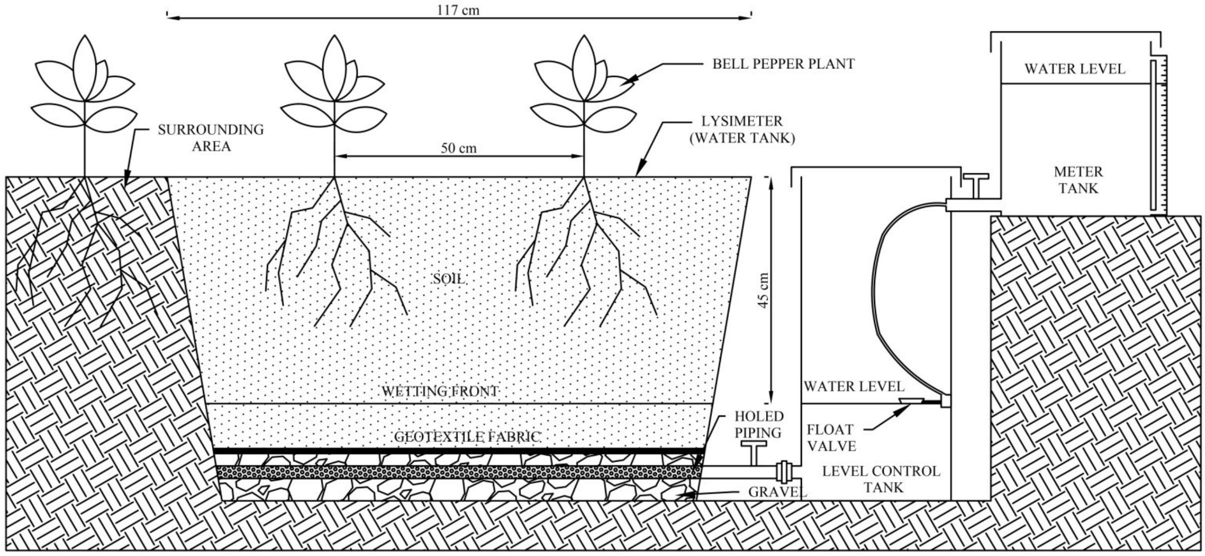

Figure 1. Illustration of the constant water table lysimeter built inside the greenhouse

The water consumed by the plants was automatically replaced by a system connected to the lysimeter. This included a receptacle composed of a PVC pipe (200 mm in diameter), a highly sensitive float valve, and a water supply tank with a volumetric graduation scale that was connected to the receptacle by a flexible tube.

Water was replaced in the tank daily at 07:30 A.M., based on the supply tank's volumetric graduation scale. A digital scale (0.1 g) was used to weigh the amount of water needed to reach the tank's control level. The evapotranspiration depth (mm) was obtained based on the relationship between the extracted volume (L) and the surface area of the lysimeter (m^2).

The reference evapotranspiration (ET_0) was estimated according to the modified Penman-Monteith equation (PMAP) (McNaughton & Jarvis, 1983), as recommended for a protected environment. Except for r_a (resistance to sensible heat flow), all other parameters followed the Penman-Monteith-FAO methodology (Eq. 1) (Allen et al., 1998). The climate approach of this methodology was selected given its application to studies conducted in protected environments for determining ET_0 given by Eq. 1 (Peres et al., 2013; Lozano et al., 2017).

$$ET_o = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{Tmed+273}U_2\left(e_s-e_a\right)}{\Delta+\gamma\left(1+0.34U_2\right)} \quad (1)$$

where:

ET_0 - reference evapotranspiration, mm d^{-1};
Δ - slope of the water 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 $^oC^{-1}$;
Tmed - daily mean air temperature, °C;
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.

Data on meteorological variables were obtained via a weather station positioned inside the protected environment and kept temporarily in a datalogger connected to the station.

The crop coefficients were determined by calculating the ratio of the crop's evapotranspiration values (ETc) over the reference evapotranspiration values (ET_0), Eq 2:

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

The bell pepper's crop cycle was divided into four development stages to calculate the mean kc, which varies with the phenological phases of the crop (Allen et al., 1998). Four distinct phases were considered: I) initial phase (from seeding to emergence); II) growth phase (vegetative development until the beginning of flowering); III) intermediate phase (reproductive phase, from the flowering stage to the beginning of maturation); and IV) final phase (from maturation to final harvest) (Marouelli & Silva, 2012).

RESULTS AND DISCUSSION

During the crop cycle, the average, maximum and minimum air temperatures registered inside the protected environment were 20.7, 30.6, and 14.3 °C, respectively. As stated by Filgueira (2003), temperatures that favor optimal production should vary, on average, between 19 and 21 °C, and temperatures below 15 or over 35 °C affect the crop phases.

In this research, it was recorded periods with temperatures above 35 °C and below 15 °C. Nevertheless, these temperatures did not damage the crop, as they were not constant and occurred at short intervals during the day or at night.

In addition to air temperature, relative humidity and solar radiation are the main meteorological elements that affect the evapotranspiration rate, since they directly influence the vital functions of the plant (Lemos Filho et al., 2010; Oliveira et al., 2012). The Table 1 shows the mean meteorological conditions inside the greenhouse for the months of experiment conduction.

Ismael Filho et al. (2015) reported that air temperature influences evapotranspiration, since heat emitted by the cultivated surface and solar radiation absorbed by the atmosphere increase the air temperature. Moreover, heated air close to the plant transfers energy to the crop, thereby increasing evapotranspiration rates. The energy consumed during evapotranspiration originates from radiant and thermal energy from solar radiation (Cunha et al., 2002).

The ideal relative humidity range for the bell pepper crop is 50–70%. Relative humidity near saturation (100%) disrupts pollen due to excessive water absorption, whereas values below 50% reduce flower pollination due to pollen dehydration (Tivelli, 1998). Values above the ideal range were observed in May, June and July. However, they were close to the desired values and did not damage the crop.

The relationship between air temperature and relative humidity is inversely proportional; thus, as the temperature increases, relative humidity decreases (Figure 2A). Increased solar energy increases the air temperature, which reduces relative humidity resulting in a higher evapotranspiration rate (Cunha & Escobedo, 2003).

As the temperature rises, the retention capacity of the air for water vapor increases, which serves as a reservoir that either contracts as the temperature decreases or expands as it increases (Silva et al., 2002). This results in increased evapotranspiration as the water molecules leave the surface and enter into the air.

During a cycle composed of 120 days after transplant (DAT), the total water consumption of the Magali R. bell

Table 1. Monthly mean values of temperature, relative humidity and solar radiation observed in greenhouse during the research period

Month	Temperature (°C)			Relative air humidity (%)	Solar radiation (MJ m^{-2} d^{-1})
	Maximum	Mean	Minimum		
May	28.8	20.4	15.5	75.7	6.9
June	30.1	19.9	13.0	71.4	8.0
July	27.9	18.7	13.0	76.2	6.7
August	34.1	22.4	14.2	58.4	10.5
September	32.4	22.2	16.2	69.9	8.3

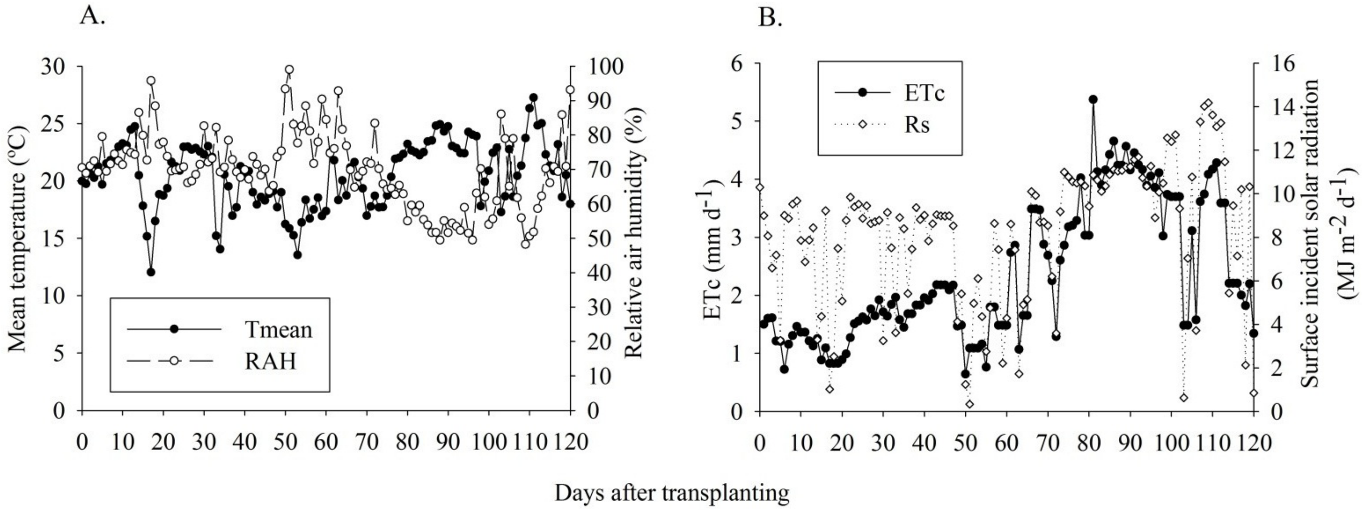

Figure 2. Climatic conditions observed during the experimental period: Mean temperature – Tmean and relative air humidity – RAH (A) and Bell Pepper crop evapotranspiration – ETc and surface incident solar radiation – Rs (B)

pepper hybrid crop was 282 mm with a mean of 2.35 mm d^{-1} (Figure 2B). Variations in water consumption throughout the cycle were attributed to the regional weather conditions and the development stages of the plant.

The maximum evapotranspiration value (ETc) of the crop was 5.37 mm d^{-1} (Figure 2B), was observed at 81 DAT during the intermediate stage of development when there was an increase in leaf area and fruit development. The minimum ETc value (0.64 mm) was observed during growth at 50 DAT, a period characterized by low temperatures due to the winter season (July).

Souza et al. (2011) recorded a total water consumption of 363 mm and a mean ETc of 2 mm d^{-1} in conventional tillage and a total of 335 mm and a mean ETc of 1.85 mm d^{-1} in zero tillage for the bell pepper over 181 DAT in Seropédica, RJ, Brazil. The average values obtained for conventional tillage were close to those observed in the present study; however, water consumption was higher since the crop cycle was longer.

Silva et al. (2017) observed a total consumption of 530 mm for the bell pepper and an average of 6.6 mm d^{-1} in Arapiraca, AL, Brazil, during a 150-day cycle. Albuquerque et al. (2012) reported a mean ETc of 1.97 mm d^{-1} and a total water consumption of 206.85 mm over 105 DAT for the bell pepper crop cultivated in fields in Recife, PE, Brazil.

These studies highlight the relevance of estimating water consumption for a given region since distinct mean ETc and total consumption values were found for the same crop at each location. This variation may be related to the duration of the crop cycle, the climatic conditions of the region, genetic material, or cropping system (field or protected environment).

Solar radiation varied considerably during the experimental period, which is supposedly due to the large oscillation between cloudy days and days with clear skies (Figure 2B). Solar radiation is one of the most influential factors in ETc since its elevation increases ETc values. The lowest value observed was 0.33 MJ m^{-2} d^{-1} and the highest was 14.17 MJ m^{-2} d^{-1} at 51 and 109 DAT, respectively.

The same phenological stages were observed for the bell pepper crop as those suggested by Allen et al. (1998): 25 days in stage I (initial), 35 days in stage II (growth), 40 days in stage III (intermediate), 20 days in stage IV (final), and a total duration of 120 days.

The crop coefficient (kc) values attained for bell pepper from the ratio between ETc and ET$_0$ were higher than those recommended by Allen et al. (1998) throughout all phenological stages of the crop (Figure 3).

The kc values indicated by FAO (Allen et al. 1998) are 0.6 (initial phase), 1.05 (intermediate phase) and 0.9 (final phase). Under greenhouse conditions, the values observed were 0.86, 1.55 and 1.4 for the initial, intermediate and final phases, respectively. Lozano et al. (2017) obtained kc values that were higher than those recommended by FAO (Allen et al., 1998) for melon crops in a protected environment.

Those authors also reported that spikes in relative humidity in the air during certain periods of the cycle contribute to the rise in kc values. This was reflected by the reduced ET$_0$ inside the protected environment. In this study, relative humidity in the air was elevated during the growth and intermediate phases (Figure 2A), which contributed to the decreased ET$_0$ in this period.

Oliveira et al. (2014) reported that kc values can exceed one during the reproductive phase for many crops, and that

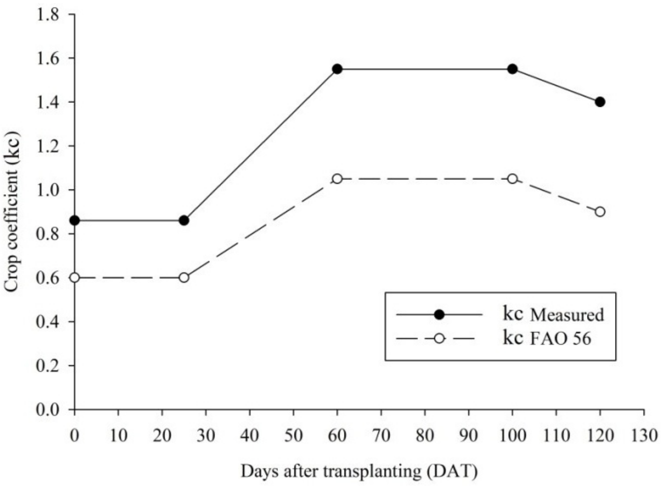

Figure 3. Bell pepper crop coefficients (kc) in greenhouse, Maringá, PR, Brazil, and according to FAO (Allen et al., 1998) recommended data

they vary with the phenological stage. Souza et al. (2011) also found different kc values from those observed in the present study, with values of 0.32, 1.18 and 0.77 for conventional tillage and 0.34, 1.05 and 0.86 for zero tillage.

Although kc values approximating those recommended by FAO (Allen et al., 1998) were reported for some phases of bell pepper development, those authors noted the necessity of adjusting kc for each specific region according to its edaphoclimatic conditions.

In addition to crop-related aspects under specific climatic conditions, determining the reference evapotranspiration may interfere with kc values. Silva et al. (2017) found mean kc values corresponding to 1.05 (phase II) and 1.41 (phase III) by applying the Hargreaves-Samani method to estimate ET_0. Nonetheless, they stated that this method overestimates the kc values compared with the Penman-Monteith-FAO method, which were 0.81 (phase II) and 1.05 (phase III).

Upon estimating the reference evapotranspiration in a protected environment, Oliveira et al. (2017) found that the Penman-Monteith-FAO method overestimated ET_0 inside the environment due to mitigated solar radiation under cover and changes in temperature, relative humidity in the air and wind velocity.

During an experiment in a protected environment over two seasons (autumn and winter) in Almería, Spain, Orgaz et al. (2005) reported average maximum kc values of 1.4 in the intermediate phase for the bell pepper crop.

The elevated kc values obtained in the present study may be related to estimation of evapotranspiration using constant water table lysimeters. In this equipment, water reaches the root by capillary action due to evapotranspiration. However, moisture in the soil of the lysimeter does not represent the conditions of the plot in its surroundings and may overestimate evapotranspiration by up to 10 or 20% (Materán et al., 2009).

In addition, frequent watering of the soil may have contributed to the increase in kc values. Thus, in these types of lysimeters, the soil is always at field capacity and does not permit drying, thus raising the evapotranspiration rates.

According to Allen et al. (1998), kc values may increase with frequent watering. They argue that crops reaching a height of 1.5 to 2.0 m, such as bell peppers, may also demonstrate high kc values.

In this context, research on the development stages of crops and on determining crop coefficients by considering regional climatological conditions is necessary, as kc values vary according to the crop, irrigation system, type of soil and cover, methodology for estimating ET_0, and crop management (Oliveira et al., 2014).

CONCLUSIONS

1. During a 120-day cycle of the Magali R. bell pepper hybrid, the total water consumption was 282 mm and average consumption was 2.35 mm d^{-1}, ranging from 0.64 to 5.37 mm d^{-1}.

2. Under greenhouse conditions in Maringá, PR, Brazil, the average crop coefficient (kc) was 0.86 for the initial phase, 1.55 for the intermediate phase and 1.4 for the final phase.

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