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Response of bell pepper crop subjected to irrigation depths calculated by different methodologies

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Key words:
Capsicum annuum L.
evapotranspiration
dual Kc
single Kc

ABSTRACT
Water must be supplied to a crop in the proper amount and in a timely manner. Vegetables require a good water availability in soil during their entire cycle. Thus, it is very important the implementation of an irrigation management and accurate estimation of water requirement. The objective of this work was to evaluate the effect of five irrigation depths estimated by the dual-Kc and single-Kc methodologies on the characteristics of growth, production and water use efficiency in the pepper crop. A randomized block design was adopted in a split plot arrangement. The effect of five irrigation depths (50, 75, 100, 125 and 150% of crop evapotranspiration - ETc) was evaluated in the plots, and the methodologies were evaluated in the subplots. It was evaluated the root dry matter, total fruit production, leaf temperature, number of aborted flowers and water use efficiency. The interaction between both effects was not significant for any of the variables. The effect of methodology was observed only on the number of aborted flowers. The effect of the irrigation depths was significant on all variables. The irrigation depths that lead to the best agronomic characteristics were superior to 100% of ETc. The ratio between the irrigation depths estimated by single-Kc and dual-Kc methodologies was 1.14. Single-Kc methodology and irrigation depth of 143% ETc were more suitable for the horticulturist. The most efficient irrigation depth in the use of water was 105% ETc.

Palavras-chave:
Capsicum annuum L.
evapotranspiração
Kc duplo
Kc único

Resposta da cultura do pimentão a lâminas de irrigação calculadas por diferentes metodologias

RESUMO
A água deve ser fornecida na quantidade certa e no momento oportuno às culturas. As hortaliças requerem uma boa disponibilidade de água no solo durante todo o ciclo, portanto, se tornam primordial a implementação do manejo da irrigação e a estimativa precisa do requerimento de água pela cultura. Dessa forma, o objetivo deste trabalho foi avaliar o efeito de cinco lâminas de irrigação estimadas pelas metodologias de Kc duplo e Kc único sobre as características de crescimento, produção e eficiência no uso da água na cultura do pimentão. Adotou-se o delineamento em blocos casualizados, no esquema de parcelas subdivididas. Na parcela foi avaliado o efeito de cinco lâminas de irrigação (50, 75, 100, 125 e 150% da evapotranspiração da cultura - ETc) e na subparcela, as metodologias. Foram avaliadas massa seca de raízes, produção total de frutos, temperatura foliar, número de flores abortadas e eficiência no uso da água. A interação entre os dois efeitos não foi significativa para nenhuma das variáveis. O efeito da metodologia somente foi observado para a variável número de flores abortadas. O efeito das lâminas de irrigação foi significativo para todas as variáveis. As lâminas que proporcionam as melhores características agronômicas foram superiores a 100% da ETc. A razão entre as lâminas estimadas pelas metodologias de Kc duplo e Kc único foi de 1,14. A metodologia de Kc único e a lâmina de 143% da ETc foi mais indicada para o horticultor. A lâmina de irrigação mais eficiente no uso da água foi de 105% da ETc.

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Introduction

The bell pepper crop (*Capsicum annuum* L.), as most vegetables, requires good water availability in the soil. This crop requires approximately 450 to 650 mm per cycle, which can even be 30% lower in protected environment (Marouelli & Silva, 2012). Water requirement depends on climate conditions, cycle duration, irrigation system and, particularly, production system.

Irrigation frequency and depth, when adopted without any technical criterion, may promote conditions that increase flower abortion and severity of diseases. These factors are considered to be the ones affecting yield in commercial bell pepper plantations (Patanè & Cosentino, 2010). Hence, implementing irrigation management becomes essential.

Irrigation management involves adjustments of irrigation depth and frequency for the water to be supplied in the right amount and appropriate time. For that, it becomes indispensable to determine the daily water requirement of the crop. One way of determining such requirement is through the utilization of meteorological variables (Allen et al., 2006; Freitas et al., 2017).

Due to the occurrence of soil fungi and nematodes, cultivation in protected environment becomes difficult. One alternative for that is the cultivation in pots or bags filled with substrate (Charlo et al., 2009). Since it is a recent system of production, there are no studies using established methodologies to determine water requirement in the bell pepper crop.

Given the above, this study aimed to evaluate the effect of five irrigation depths estimated by the dual-Kc and single-Kc methodologies on the characteristics of growth, production and water use efficiency in the bell pepper crop.

Material and Methods

The experiment was carried out at the Research Vegetable Garden of the Plant Science Department of the Federal University of Viçosa, Minas Gerais, Brazil (20° 45’ 14” S; 42° 52’ 53” W; and 649 m), from January 15 to June 8, 2015. Cultivation was conducted in a protected environment with dimensions of 10 x 30 m, with anti-aphid screen on the sides and transparent plastic cover (40 μm).

A randomized block design was adopted in split-plot scheme, with three replicates. The effect of five irrigation depths (50, 75, 100, 125 and 150% of crop evapotranspiration - ETc) was evaluated in the plots, whereas the effect of ETc -estimation methodologies (single-Kc and dual-Kc) was evaluated in the subplots. Treatments were implemented 14 days after bell pepper transplantation.

The cultivar ‘Atlantis F1’ was planted on December 10, 2014 on expanded polystyrene trays with 128 cells and the substrate consisted of coconut fiber enriched with P_2O_5. Seedlings were transplanted 36 days after sowing to 10 dm^3 pots, spaced by 0.80 x 0.50 m. The experimental unit was composed of one row with eight plants.

The substrate of the pots was composed of a mixture of sand and soil, at proportion of 1:1 and its chemical and physical-hydraulic properties are presented in Table 1.

Table 1. Results of chemical and physical-hydraulic analyses of the soil: Sand substrate (1:1)

Soil chemical properties	
pH H_2O	5.20
P (mg dm^{-3})	1.15
K (mg dm^{-3})	21.00
Ca^{2+} ($cmol_c$ dm^{-3})	0.13
Mg^{2+} ($cmol_c$ dm^{-3})	0.12
Al^{3+} ($cmol_c$ dm^{-3})	0.00
H+Al ($cmol_c$ dm^{-3})	1.90
T ($cmol_c$ dm^{-3})	2.20
P-rem (mg L^{-1})	6.70
Zn (mg dm^{-3})	0.49
Fe (mg dm^{-3})	28.50
Mn (mg dm^{-3})	3.30
Cu (mg dm^{-3})	1.57
B (mg dm^{-3})	0.09
Soil physical-hydraulic properties	
FC (m^3 m^{-3})[1]	0.15
PWP (m^3 m^{-3})[2]	0.13
Clay (g 100 g^{-1})	30.00
Silt (g 100 g^{-1})	6.00
Sand (g 100 g^{-1})	64.00

Available P, K, Fe, Zn, Mn and Cu extracted with Mehlich I; Exchangeable Ca, Mg and Al extracted with 1 mol L^{-1} KCl; Potential acidity at pH 7.0 extracted with 1 mol L^{-1} calcium acetate; B extracted with hot water; [1] Field capacity; [2] Permanent wilting point

A pressure-compensating drip tape was used, with one emitter per plant, operating with flow rate of 3.45 L h^{-1}, service pressure of 150 kPa and Christiansen’s uniformity coefficient (CUC) of the irrigation system of 96.7%.

Liming and fertilization were performed according to the result of substrate analysis and fertilization recommendation for Minas Gerais. Liming consisted in the application of 16.4 g pot^{-1} of dolomitic limestone (RNV of 96%) and fertilization consisted in the application of 10.5 g of N and K_2O; 25.3 g of P_2O_5; 1.7 g of magnesium; 40 mg of boron; 20 mg of copper; 15.4 g of sulfur; 26.0 g of calcium and 0.2 g of zinc.

Plants were trained using horizontal plastic strings spaced by 20 cm. Weeds were manually controlled. Pests and diseases were controlled through the visual observation of the insect or pathogen.

ETc was estimated using single-Kc (Mantovani & Costa, 1998) and dual-Kc (Allen et al., 2006; Allen & Pereira, 2009; Freitas et al., 2017) methodologies, according to Eqs. 1 and 2, respectively.

$$ETc = ET_0 \times Kc \times K_S \times K_L \tag{1}$$

$$ETc = ET_0 \times \left[\left(KcbK_s \right) + Kc \right] \tag{2}$$

where:

ETc - crop evapotranspiration, mm d^{-1};
ET_0 - reference evapotranspiration, mm d^{-1};
Kc - crop coefficient;
K_S - water stress coefficient;
K_L - location coefficient;
Kcb - basal crop coefficient; and,
K_e - soil evaporation coefficient.

Kc and Kcb values for the phenological stages I, II, III and IV were 0.40 and 0.15, 0.75 and 0.65, 1.10 and 1.15, 0.85 and

0.70 (Allen et al., 2006) with duration of 42, 243, 878 and 1021 cumulative degree-days (CDD), respectively.

The base temperature of the crop was considered as 16 °C (Carvalho et al., 2011a). The phenological cycle was divided into four growth stages. Stage I started after seedling transplantation and ended when the area shaded by plants was approximately 10%. Then, Stage II started, extending up to full flowering. Stage III ended at harvest, when the last stage started, which lasted until the end of harvest (Allen et al., 2006).

K_S (Bernardo et al., 2006) and K_L (Keller & Bliesner, 1990) were calculated by Eqs. 3 and 4.

$$K_S = \frac{\ln(AID+1)}{\ln(TWSC+1)} \quad (3)$$

$$K_L = 0.1\sqrt{P} \quad (4)$$

where:

K_S - stress coefficient;
AID - actual irrigation depth, mm;
TWSC - total water storage capacity, mm;
K_L - irrigation location coefficient ; and,
P - higher value, %, of wetted or shaded area.

Irrigation depths estimated by dual-Kc and single-Kc methodologies were equal to 93 and 81, 140 and 122, 186 and 163, 233 and 203, 279 and 244 mm, corresponding to 50, 75, 100, 125 and 150% ETc, respectively. Due to the small exposed area of soil, evaporation was reduced, resulting in low irrigation depths, and the mean irrigation depth estimated by the dual-Kc methodology was 14.4% higher.

Maximum, mean and minimum air temperatures, mean relative humidity, reference evapotranspiration and solar radiation, obtained by the Metros Weather Station and used for irrigation management, are presented in Figure 1.

The following variations were analyzed: root dry matter (RDM), weighed after removing all substrate particles in water and dried in ovens at 105 °C for 48 h; leaf temperature (LT), determined using an infrared thermometer at noon, with no clouds, in the flowering stage; number of aborted flowers per plant (NAF); total fruit production (TFP), water use efficiency (WUE), relationship between total fruit production and water volume applied per plant.

The data were subjected to analysis of variance by F test. For the factor methodology, means were compared by Tukey test at 0.05 probability level, whereas irrigation depths were evaluated using regression analysis, selecting the best models based on the significance of their terms, using t-test at 0.05 probability level, coefficient of determination and on the agronomic meaning of the behavior. All statistical analyses were performed using the statistical program R.

Results and Discussion

According to the analysis of variance, the effect of interaction between irrigation depths and methodology was not significant on any of the variables (Table 2). For the factor irrigation depths, there were significant differences for all analyzed variables, whereas for the factor methodology, significance was observed on for number of aborted flowers, and the highest value occurred using the dual-Kc methodology (Table 2). This is probably due to the small difference between the irrigation depths calculated by both methodologies, 14% on average.

Root dry matter (RDM) significantly fitted to the quadratic model. The irrigation depth of 129% ETc led to the highest RDM (Figure 2A), corroborating the results of Albuquerque et al. (2012), obtained in a similar study with the bell pepper crop. In both studies, the excess of water, due to the highest

Table 2. Analysis of variance summary and test of means for root dry matter (RDM), leaf temperature (LT), number of aborted flowers (NAF), total fruit production (TFP) and water use efficiency (WUE)

Source of variation	p value				
	RDM (g)	LT (°C)	NAF (flowers)	TFP (kg)	WUE (kg m^{-3})
L	0.002	0.004	0.007	< 0.001	0.027
M	0.717	0.265	0.010	0.676	0.204
L x M	0.562	0.721	0.477	0.606	0.698
Methodology	Test of Means				
Dual-Kc	16.45 a	30.17 a	23.29 a	0.52 a	15.56 a
Single-Kc	16.84 a	30.68 a	18.47 b	0.53 a	17.45 a

Irrigation depths (L), methodologies (M) and means followed by the same letter in the column do not differ statistically by Tukey test ($p < 0.05$)

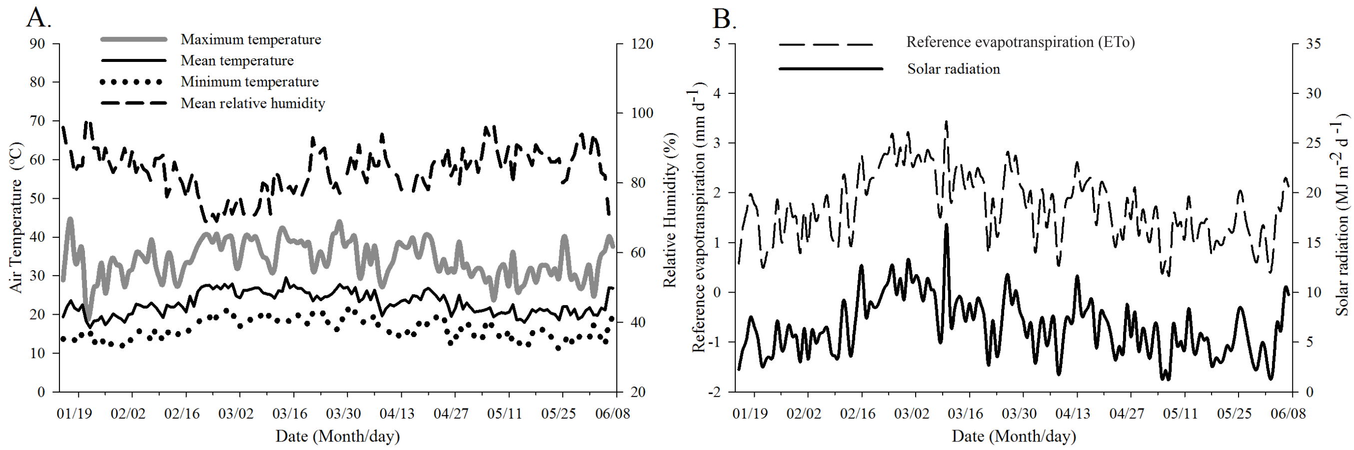
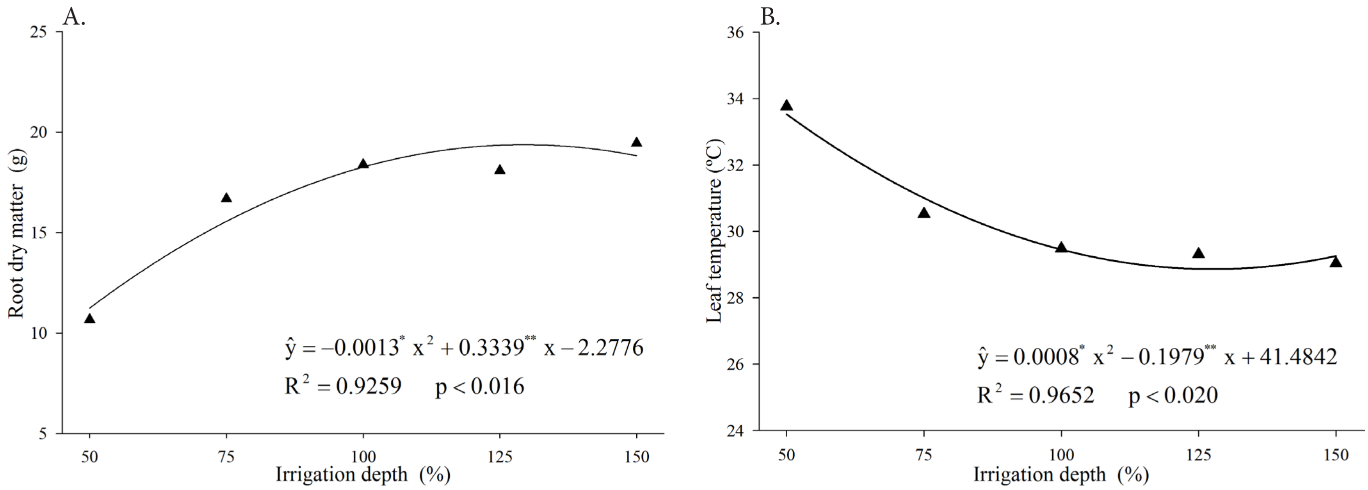


Figure 1. Air temperature and relative humidity (A) and reference evapotranspiration and solar radiation (B) for the bell pepper cultivation period in protected environment



* and ** Significant at 0.05 and 0.01, respectively, by F test

Figure 2. Root dry matter (A) and leaf temperature - LT (B) as a function of irrigation depths

irrigation depths, possibly caused hypoxia in the root system, culminating in reduction of growth and death of roots.

In the tomato crop, reduction in RDM was observed with irrigation depths above 100% ETc when applied in the flowering and fruiting stage (Brito et al., 2015). On the other hand, irrigation depths above 100% ETc in the vegetative stage led to increments in RDM (Brito et al., 2015). Probably, the excess of water in the soil is harmful in the more advanced growth stages of this crop.

Padrón et al. (2015), evaluating bell pepper roots under water deficit, observed reduction in the quantity of roots with smaller diameter, increase of roots with greater diameter and presence of roots at greater depths. These same morphological alterations were observed in *Myrtus communis* (Bañón et al., 2006).

Increments in irrigation depths resulted in reduction of leaf temperature (LT) up to 123% ETc (Figure 2B). Such reduction might have occurred because of the higher water availability for plant transpiration, which consequently reduces leaf temperature (Taiz et al., 2015).

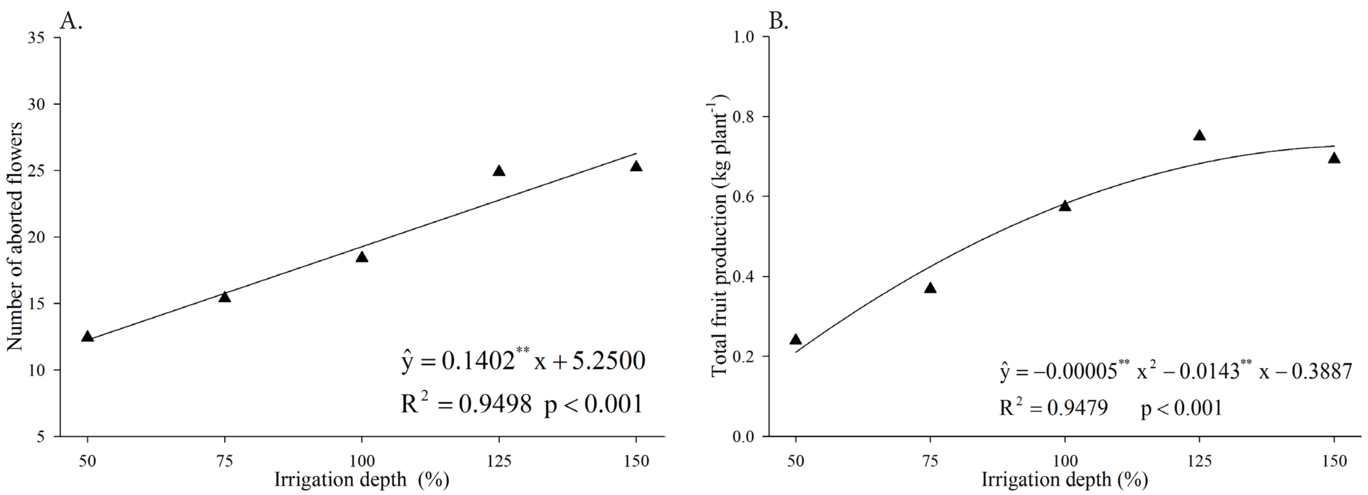
At the highest irrigation depth, there was a small increment in LT (Figure 2B). The excess of water may have compromised root respiration, affecting metabolism and transpiration, consequently making leaf cooling difficult (Freitas et al., 2017).

The number of aborted flowers (NAF) increased linearly with the increment in irrigation depths (Figure 3A). In the bell pepper crop, the number of flowers has high and positive correlation with the number of branches (Gadissa & Chemeda, 2009). Hence, flower abortion increased with the increment in the number of branches, which was evidenced at the highest irrigation depths.

Under water deficit conditions in the field, the reduction of yield caused by the abortion of flowers and fruits occurs at specific times during the crop reproductive stage. The low water availability to the crop leads to stress at the end of the cycle, since the physiological demand was not met.

The quadratic models showed the best fit to the data of total fruit production (TFP). The irrigation depth 143% ETc led to the highest TFP in the present study (Figure 3B), as well as in the study of Aragão et al. (2012). This evidences that the crop water demand in this production system is underestimated.

Although there was higher flower abortion at the highest irrigation depths, the total flower production was sufficiently high to cause high fruit production. It is also worth mentioning that it is characteristic of this crop to produce a high number of flowers and, at the same time, show a high percentage of abortion.



* and ** Significant at 0.05 and 0.01, respectively, by F test

Figure 3. Number of aborted flowers per plant (A) and total fruit production - TFP (B) as a function of irrigation depths

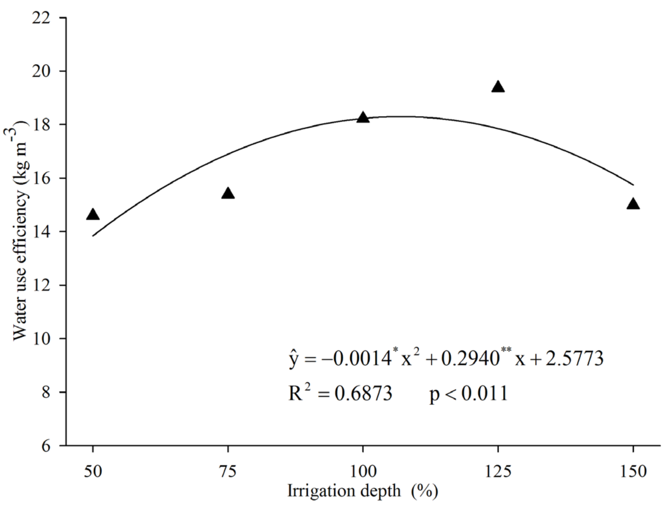
Under field conditions, an increasing linear function explained the same variable as a function of the irrigation depths for bell pepper (Lima et al., 2012) and pepper (Gadissa & Chemeda, 2009, Azevedo et al., 2005). However, the small amplitude of the irrigation depths used by Lima et al. (2012) may have not been sufficient to reach the maximum value of fruit production.

The lowest irrigation depths caused drastic reduction in fruit production. The effect of the lowest irrigation depths was an underdevelopment of the branches, which are responsible for the production of flowers and fruits. Severe water stress causes negative effects on growth, anatomy, morphology, physiology and biochemistry, besides reduction in absorption and translocation of nutrients in the plants (Guang-Cheng et al., 2010; Karimi & Hasanpour, 2014).

Water use efficiency (WUE) was maximal, 18.01 kg m^{-3}, with the irrigation depth corresponding to 105% ETc (Figure 4). In bell pepper cultivation in the field, Carvalho et al. (2011b) observed that the optimal irrigation depth was 78% ETc, leading to WUE of 8.12 kg m^{-3}.

Other authors found WUE values between 4.5 and 12 kg m^{-3} for bell pepper cultivated in conventional system and no-tillage (Coelho et al., 2013; Souza et al., 2011). The great difference between the values are mainly due to the different production systems, which are more or less productive and efficient in the use of water.

Higher WUE was found in the present study, in comparison to others (Coelho et al., 2013; Souza et al., 2011). This demonstrates the efficiency of the system of production in pots with respect to water; thus, it is recommended in situations in which water is the limiting factor of production.



* and ** Significant at 0.05 and 0.01, respectively, by F test

Figure 4. Water use efficiency as a function of irrigation depths

Conclusions

1. The effect of the methodologies was not observed on fruit production per plant, the most important characteristic for the horticulturist.

2. The dual-Kc methodology estimated a 14% higher irrigation depth compared with the single-Kc methodology.

3. The irrigation depth of 143% ETc led to higher fruit production.

4. Single-Kc methodology and irrigation depth of 143% ETc are the most recommended irrigation management strategies to increase the production per plant.

5. The most efficient irrigation depth in water use was 105% ETc.

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