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Management of water deficit in the irrigated production of the green pepper[1]

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ABSTRACT - Information on irrigation management is essential for achieving satisfactory results when cultivating the green pepper. The aim of this study, therefore, was to evaluate the effects of water deficit, which varies according to phenological stage, on the production, growth and physiology of a crop of green peppers. The experimental design was completely randomised, with seven treatments, four repetitions, and plots comprising two plants. The treatments consisted of replacing the water demand during phenological phases I, II, III and IV (in terms of percentage ETc): T1 – 100%/I, 100%/II, 100%/III and 100%/IV; T2 – 100%/I, 75%/II, 100%/III and 75%/IV; T3 – 100%/I, 75%/II, 75%/III and 75%/IV; T4 – 100%/I, 75%/II, 75%/III and 50%/IV; T5 – 100%/I, 50%/II, 75%/III and 50%/IV; T6 – 100%/I, 50%/II, 50%/III and 50%/IV; T7 – 100%/I, 50%/II, 50%/III and 25%/IV. The plants were grown in the field under drip irrigation. The following variables were analysed: plant height; stem diameter, leaf area, shoot dry weight, number of fruits per plant, soluble solids, fruit length, fruit diameter, fruit weight, productivity, relative chlorophyll index, gas exchange, and water use efficiency. Compared to T1, management based on T2, T3 and T4 did not reduce expression of the vast majority of the vegetative variables or of gas exchange. The water deficit from T2 can be employed without any significant reduction in productivity and affords water savings of 12.5% in relation to T1. T1 and T2 give the highest values for water use efficiency. Management based on T1 and T2 is therefore recommended for cultivating the green pepper under field conditions.

Key words: *Capsicum annuum* L. Gas exchange. Irrigation.

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INTRODUCTION

The growth in world population, together with the growing demand for food, is leading to a scenario of water scarcity in meeting the various demands of man, including irrigation. Efforts to increase water use efficiency in agricultural crops are of great importance in preserving water resources, aggravated by the reality of climate change, whose effects can substantially affect agricultural productivity (JACINTO JÚNIOR *et al*., 2019).

Irrigation management strategies aiming at greater water savings have been the object of study in several works. Shammout *et al*. (2018) evaluated the effect of water deficit on yield and water use efficiency in the green pepper and found that a water deficit reduces water consumption with no significant loss in production. Similarly, Silva *et al*. (2018) evaluated the effect of five irrigation depths (50%, 75%, 100%, 125% and 150% of the crop evapotranspiration - ETc) on crop growth in the green pepper and found that the best results were obtained when applying irrigation depths greater than 100% of the ETc.

The green pepper (*Capsicum annuum* L.) is highly valued and cultivated worldwide and is an important source of income for family farming (ABDELKHALIK *et al*., 2020; SOARES *et al*., 2020). The versatility of culinary applications and its nutritional properties allow it to be marketed fresh or integrated into agribusiness, comprising one of the main vegetables consumed in Brazil.

Among the commercial varieties, the Cascadura Ikeda cultivar stands out, characterised by its rusticity, high commercial value and high acceptance on the domestic market. Morphologically, the plant is erect, with high vigour and production, conical fruits with a bright dark green colour (red when ripe), and a cycle that varies from 110 to 120 days (CARDOZO *et al*., 2016).

Some factors are considered limiting to achieving high crop productivity, such as pests and diseases, inefficient fertilisation and an inadequate water supply. The green pepper is particularly sensitive to an irregular water supply, so that an excess of water can favour the proliferation of pests and diseases, and a water deficiency can result in flower abortion and flower drop and is one of the main obstacles to obtaining high productive yields. (CARVALHO *et al*., 2016; NUNES JÚNIOR *et al*., 2017).

A restricted water supply throughout the cycle can reduce the yield of the green pepper. In other crops, however, this reduction may be lessened if the water deficit occurs during phenological stages that are less sensitive to low water availability, as is the case of the pepper (YANG *et al*., 2017). For the green pepper, establishing the effect of a water deficit on different growth stages of the crop requires experimentation, since, although sensitive to water deficit, this information can increase the water use efficiency of the crop.

Considering the lack of information concerning the variation in water demand throughout the crop cycle of the green pepper, the aim of this study was to evaluate the effects of different intensities of water deficit, which vary between the phenological stages of the crop, on production, growth, physiology and water use efficiency in the Cascadura Ikeda cultivar of *Capsicum annuum* L.

MATERIAL AND METHODS

The experiment was carried out between 6 September and 17 December 2019 in an area under full sun at the Federal University of Ceará (Professor Prisco Bezerra Pici Campus), in Fortaleza, Ceará, Brazil (3°44’45” S, 38°34’55” W, at an altitude of 19.5 m).

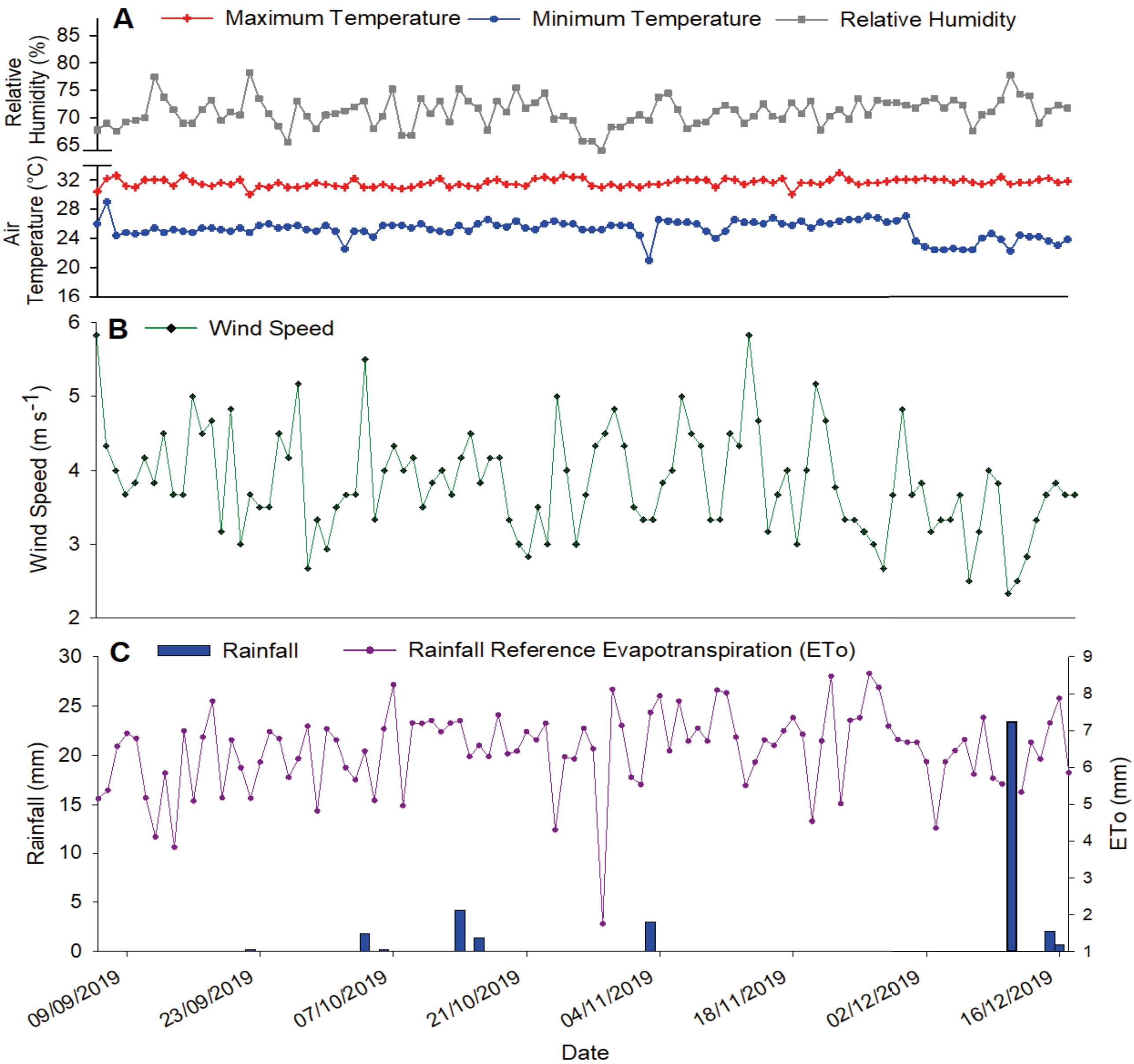
The climate in the region is characterised as rainy tropical savannah, very hot, with a drier period during the winter and maximum rainfall during the summer and autumn. Data on rainfall, relative humidity, wind speed, air temperature and reference evapotranspiration estimated by a Class A pan, were collected during the experiment from a weather station installed in the study area and are shown in Figure 1.

Figure 1 shows that there were no atypical changes in the climate variables of the region during the experiment. The maximum, minimum and mean values for the maximum air temperature, minimum air temperature, relative humidity and wind speed were 33.0, 30.0 and 31.3 °C; 29.0, 21.0 and 25.2 °C; 78.3%, 64.0% and 71.0%; and 5.8, 2.3 and 3.8 m s^{-1}, respectively. Total rainfall was 37.0 mm and consisted of isolated events throughout the experimental period. The total reference evapotranspiration for the period was 699.2 mm, with maximum, minimum and mean values of 8.6, 1.8 and 6.5 mm day^{-1}.

The selected green pepper cultivar was the Cascadura Ikeda. Sowing was carried out on 6 September 2019, in polystyrene trays containing 128 cells filled with substrate based on organic compost and vermiculite (1:1). The trays were kept in a protected environment for 25 days after sowing (DAS), when the seedlings were transplanted to the field.

After clearing the vegetation, the experimental area was prepared by ploughing and harrowing. A spacing of 1.0 m between rows and 0.5 m between plants was adopted, giving a total experimental area of 450 m². Stakes were placed in the ground at the side of each plant to train the plants and provide support throughout the cycle.

Figure 1 - Daily data for air temperature and relative humidity (A), wind speed (B), rainfall and reference evapotranspiration estimated by a Class A pan (C), during the experiment with the 'Cascadura Ikeda' green pepper, in Fortaleza, Ceará, Brazil



The soil in the experimental area was classified as a Red-Yellow Argisol of a sandy clay-loam texture (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2013), with 62%, 10% and 28% sand, silt and clay, respectively, in addition to a mean density of 1.52 g cm^{-3}. The main chemical characteristics were organic C of 6.41 g kg^{-1}, total N of 0.66 g kg^{-1}, C:N ratio of 9.71, assimilable P of 33 mg kg^{-1}, K^+ of 0.31 $cmol_c$ kg^{-1}, Ca^{2+} of 1.13 $cmol_c$ kg^{-1}, Mg^{2+} of 0.65 $cmol_c$ kg^{-1}, Al^{3+} of 0.18 $cmol_c$ kg^{-1}, H^++Al^{3+} of 2.07 $cmol_c$ kg^{-1}, pH in water of 6.2, and EC of 0.41 dS m^{-1}.

One litre of organic compost based on cattle manure was applied per plant when transplanting the seedlings. For the mineral fertilizer, the sources of macronutrients used were simple superphosphate (18% P_2O_5, applied entirely as base), potassium chloride (58% K_2O) and urea (45% N), the last two applied by fertigation in nine applications throughout the cycle. The source of micronutrients was FTE-BR 12 fertilizer, applied as base. Fertilization was carried out as per Aquino *et al*. (1993). The amounts of fertilizer applied per plant throughout the cycle were 210 g of simple superphosphate, 55 g of urea, 12 g of potassium chloride and 2.5 g of FTE-BR 12.

The experimental design was completely randomised, with seven treatments, four repetitions, and two plants per plot. Treatments consisted of variable water deficits based on the development stage of the crop (Table 1).

Irrigation management was based on daily replacement of the crop evapotranspiration, calculated as per Equation 1.

$$ETc = ECA * Kp * Kc \quad (1)$$

where:

ETc = crop evapotranspiration (mm day^{-1});

ECA = Class A pan evaporation (mm day^{-1});

Kp = pan coefficient (dimensionless), estimated at 0.60, 0.70 and mainly 0.75 during the experiment, based on the local climate conditions;

Kc = crop coefficient (dimensionless).

The values for Kc, based on the phenological stages of the crop, were 0.40 stage I (from emergence to 10% development–30 DAS); 0.70 stage II (10% development up to 75% development, and appearance of the first flowers–55 DAS); 1.05 (full flowering to full fruit maturity–82 DAS), and 0.85 (from maturity to the final harvest–103 DAS), as per Doorenbos and Pruitt (1977) (Figure 2).

A drip irrigation system was used, with emitters spaced 30 cm apart, with a flow rate of 1.42 l h^{-1} at a working pressure of 100 kPa. The irrigation time was calculated as per Equation 2.

$$Ti = \frac{ETc * E_L * E_P * F_C}{E_i * q_e} * 60 \quad (2)$$

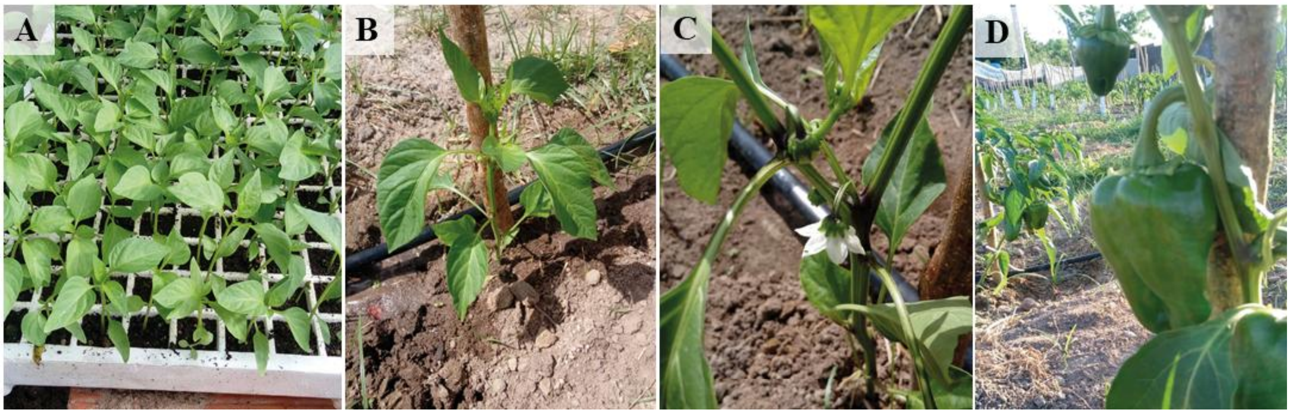
where:

Ti = irrigation time (min.); ETc = crop evapotranspiration (mm day^{-1}); EL = spacing between irrigation lines (m); EP = spacing between plants (m); Fc = ground cover factor (dimensionless), equal to 0.62, based on location, spacing, wetted area and shaded area, given by Fc = (P/100) + (0.15 * (1-(P/100)), where P refers to the wet or shaded area, with the highest estimated value prevailing (KELLER, 1978); Ei = irrigation efficiency (dimensionless), 0.91, estimated from the CUD using the Keller and Karmeli method (1975), and q_e = emitter flow rate (L h^{-1}).

Table 1 - Treatments evaluated during the experiment

Treatment	Percentage ETc			
	Stage I	Stage II	Stage III	Stage IV
T1	100	100	100	100
T2	100	75	100	75
T3	100	75	75	75
T4	100	75	75	50
T5	100	50	75	50
T6	100	50	50	50
T7	100	50	50	25

Figure 2 - Trays with seedlings (A), plant 17 cm tall at 33 DAS (B), start of flowering at 55 DAS (C) and fruiting at 85 DAS (D), in the 'Cascadura Ikeda' green pepper grown in the field (6 September to 17 December 2019), in Fortaleza, Ceará, Brazil



The irrigation time was divided into two periods, half being applied in the morning and half in the late afternoon. The different treatments began after 5 DAT, at the start of stage II. The water used for irrigation had the following characteristics: EC = 0.95 dS m^{-1}, pH = 8.0, SAR = 3.05, Ca^{2+} = 1.3 $mmol_c$ L^{-1}, Mg^{2+} = 3.1 $mmol_c$ L^{-1}, Na^+ = 4.5 $mmol_c$ L^{-1}, and K^+ = 0.4 $mmol_c$ L^{-1}, Rating = C_3S_1.

At 56 days after transplanting (DAT), plant height (PH, cm) and stem diameter (SD, mm) were evaluated. The first of four collections, carried out at intervals of seven days, was made at 57 DAT. The number of fruits per plant (NFP) was counted for each harvest.

The following post-harvest variables were evaluated: soluble solids (SS, °Brix); fruit length (FL, mm), fruit diameter (FD, mm) and mean fruit weight (FW, g $fruit^{-1}$).

The leaf area (LA, cm^2 $plant^{-1}$) was evaluated following the four harvests (78 DAT). To determine the shoot dry weight (SDW, g $plant^{-1}$), the plant material was packed in paper bags and then left to oven dry at 60 °C to constant weight. From the data relating to the four harvests, the productivity of the crop in each treatment was estimated (PROD, t ha^{-1}).

The relative chlorophyll content (SPAD Index), expressed in SPAD units, was measured using a portable meter (SPAD 502, Minolta Co. Ltd, Osaka, Japan) at 28 DAT (flowering) and 56 DAT (maturity). The net rate of photosynthesis (A, µmol m^{-2} s^{-1}), transpiration (E, mol m^{-2} s^{-1}) and stomatal conductance (gs, mol m^{-2} s^{-1}), and the internal CO_2 concentration (Ci, ppm) were determined using an infrared gas analyser (IRGA, Li-COR® 6400 XT). Measurements were taken from 08:00 to 11:00 on the same leaves used to evaluate the relative chlorophyll content.

The data on gas exchange was used to estimate the instantaneous carboxylation efficiency, calculated from the ratio between photosynthesis and the internal CO_2 concentration (A/Ci, µmol H_2O µmol CO_2^{-1}).

Water use efficiency (WUE, kg ha^{-1} mm^{-1}) was calculated for each treatment from the ratio between productivity (kg ha^{-1}) and the total applied irrigation depth (mm) (SANTOS *et al*., 2020; SILVA; CAMPOS; AZEVEDO, 2009).

The data were submitted to analysis of variance by F-test, and when significant, the mean values were compared by Tukey's test (P < 0.05).

RESULTS AND DISCUSSION

Vegetative growth in the 'Cascadura Ikeda' green pepper

The variables of vegetative growth in the 'Cascadura Ikeda' green pepper were significantly affected (P < 0.01) by the applied water deficits (Table 2).

Table 2 - Summary of analysis of variance and test of mean values for the variables of vegetative growth in green pepper grown in the field, in Fortaleza, Ceará, Brazil

Source of Variation	Analysis of Variance – F-Test			
	PH	SD	LA	SDW
Treatment	5.67**	12.10**	4.91**	3.83**
CV (%)	16.29	7.57	27.48	25.18
	Tukey's Test (P < 0.05)			
LSD	18.03	1.23	504.94	37.94
T1	59.9 a	8.40 a	1051.74 ab	79.92 ab
T2	55.3 a	7.61 ab	1079.46 a	86.91 a
T3	48.3 ab	7.54 ab	931.20 abc	77.13 ab
T4	54.6 a	7.13 b	872.66 abc	58.48 ab
T5	43.2 ab	6.94 b	617.63 abc	62.38 ab
T6	42.9 ab	6.39 bc	551.45 bc	49.75 ab
T7	32.7 b	5.51 c	489.95 c	44.12 b

Mean values followed by the same letters in a column do not differ by Tukey's test (P < 0.05); ** - significant (P < 0.01); CV - coefficient of variation; LSD– least significant difference by Tukey's test (P < 0.05); PH - plant height, cm; SD - stem diameter, mm; LA - leaf area, cm^2 $plant^{-1}$; SDW – shoot dry weight, g $plant^{-1}$

With the exception of treatment T7, plant height presented statistically equal values in all treatments. The highest mean value for plant height was found in T1, 59.9 cm, a mean value 83% higher than 32.7 cm, the mean value for treatment T7.

The highest values for stem diameter occurred with the water deficits of T1, T2 and T3. The highest value for this variable in the above treatments was 8.40 mm in T1, 5% higher than the mean value for T7, the lowest mean value found in the study (5.51 mm).

Leaf area showed higher mean values for the water deficits of T1, T2, T3, T4 and T5, where the maximum mean value between these treatments was seen in T2 (1079.46 cm^2 $plant^{-1}$), a value 120.3% greater than 489.95 cm^2 $plant^{-1}$, the estimated mean value for treatment T7.

Shoot fresh weight showed similar behaviour to the other variables of vegetative growth, with higher mean values for the less-severe treatments. Comparing the mean value of treatments T1, T2, T3, T4, T5 and T6 with that found for treatment T7 (44.12 g $plant^{-1}$), the mean value of T2 is seen to be 97% higher than that for the water deficit applied in T7.

In general, increasing the severity of the water deficit reduced the vegetative growth of the crop due to the lower water availability. The treatments that most affected the crop were T4, T5, T6 and T7; among these, treatments T6 and T7 resulted in less vegetative growth due to the greater water deficit to which the plants were exposed, where, with the exception of Stage I, the crop was submitted to a water deficit equal to or less than 50% replacement of the ETc.

A water deficit, depending on the level and duration, can affect the vegetative response of several species of agricultural interest. In the green pepper, stem diameter, for example, tends to increase with an increase in irrigation levels (SOUZA *et al*., 2019).

Maximum plant height was obtained with T1, i.e. under a full supply of water for the crop (100% of the ETc at all stages). The results for this variable are slightly different from those of Matos Filho, Silva and Bastos (2020), who obtained maximum plant height (51.9 cm) when using an irrigation depth equal to the replacement of 75% of the evaporation of a Class A pan. The authors also pointed out that higher levels of irrigation can lead to the leaching of such nutrients as nitrogen, which possibly influenced plant height, promoting higher mean values for this variable when replacing less than 100% of the evaporation of a Class A pan. Similarly, Padron *et al*. (2015) obtained a higher mean plant height (91.5 cm) when subjecting the crop to a water regime equal to 60% of the ETc with daily irrigation.

In general, the stimulus to vegetative growth in the green pepper, seen in response to higher levels of irrigation, can be explained by greater cell growth, driven by turgor and greater photosynthetic activity (DÍAZ-PÉREZ; HOOK, 2017).

It should be noted that the mean values for the variables of vegetative growth were statistically equal for a large part of the treatments under evaluation, suggesting the possibility of saving water without significantly compromising crop development. Observing the mean values obtained for the four variables, there is no statistical difference between the mean values in treatments T1, T2 or T3; therefore, managing irrigation based on T3 can afford a 18.75% saving in water, without compromising the vegetative development of the crop.

Reproductive growth, productivity and water use efficiency in the 'Cascadura Ikeda' green pepper

As shown in Table 3, all the reproductive variables were significantly ($P < 0.01$) affected by the applied water deficits.

With the exception of T7, no statistical difference was seen between treatments for the number of fruits per plant, with values greater than 10 units per plant in T1, T2, T3 and T4, and a marked reduction in T7, with 3.75 fruits per plant, 70% less than the mean value for T1.

The downward trend, in absolute terms, of the number of fruits per plant due to the increase in the water deficit, is in line with Carvalho *et al*. (2016) and Santos *et al*. (2020), who found a reduction in the number of green pepper fruits per plant with an increase in the soil water tension, suggesting that the mean value of this variable is significantly affected by the irrigation management strategy used. An increase in the water deficit causes greater water tension in the soil, reducing water availability, which leads to water stress in the crop and directly affects fruit production (SANTOS *et al*., 2020).

The highest mean values for soluble solids were found in treatments T4, T5 and T6, with the highest mean value between these treatments estimated at 4.18 °Brix in T5, a value 41.7% higher than that seen in treatment T2 (2.95 °Brix), the lowest mean value found. An increase in the levels of soluble solids in response to a greater water deficit was also found in the red pepper by Kuşçu *et al*. (2016), and in the green pepper by Díaz-Pérez and Hook (2017).

Water stress reduces water accumulation in the fruits (PATANE; SAITA, 2015), concentrating the soluble solids. Faria *et al*. (2013) state that the level of soluble solids is of great importance to the quality of the fruit, both in production destined for fresh consumption, and for industrial processing, since high values of this parameter allow a reduction in the time and energy required for water evaporation in addition to greater fruit yield, resulting in more-efficient processing.

Table 3 - Summary of the analysis of variance and test of mean values for the variables of reproductive growth in green pepper (Capsicum annuum L. 'Cascadura Ikeda') grown in the field, in Fortaleza, Ceará, Brazil

Source of Variation	Analysis of Variance – F-Test				
	NFP	SS	FL	FD	FW
Treatment	6.64**	14.82**	60.13**	19.88**	13.83**
CV (%)	24.48	7.41	4.88	7.46	8.36
Tukey's Test (P < 0.05)					
LSD	5.84	0.62	7.94	7.12	9.21
T1	12.38 a	3.14 a	81.43 d	50.18 a	51.03 a
T2	13.63 a	2.95 a	74.10 cd	44.47 ab	40.75 b
T3	11.88 a	3.38 a	55.35 a	47.58 a	32.83 bc
T4	11.75 a	4.15 b	94.08 e	38.92 bc	28.21 cd
T5	9.13 ab	4.18 b	62.68 ab	32.65 c	19.78 d
T6	10.13 a	4.11 b	61.48 ab	32.90 c	19.85 d
T7	3.75 b	3.45 a	66.50 bc	43.97 ab	32.26 bc

Mean values followed by the same letters in a column do not differ by Tukey's test (P < 0.05); ** - significant (P < 0.01); CV - coefficient of variation; LSD– least significant difference by Tukey's test (P < 0.05); NFP - number of fruits per plant; SS - soluble solids, °Brix; FL - fruit length, mm; FD - fruit diameter, mm; FW - mean fruit weight, g fruit^{-1}

Treatment T4 afforded the highest mean value for fruit length, 70% greater than that of treatment T3 (55.35 mm). This result partially disagrees with that of Santos *et al*. (2018), who found the greatest fruit length (11.36 cm) when applying an irrigation depth of 100% of the crop evapotranspiration, whereas the maximum mean value in the present study was obtained using 25% less water. Souza *et al*. (2019) found no significant effect on fruit length in the green pepper in response to different irrigation depths (60%, 80%, 100%, 120% and 140% of the ETc), which suggests the satisfactory performance of the variable even under conditions of greater water restriction, similar to that seen in the present study. Fruit length is not an absolute parameter indicating the productive performance of the crop, since its relationship to other attributes results in low productivity in certain treatments, as shown below.

The highest mean values for fruit diameter were seen in treatments T1, T2, T3 and T7. The highest estimated mean value for these treatments was 50.18 mm for T1, 53.7% higher than that seen in treatment T5 (32.65 mm). Note that treatment T4 afforded the highest mean value for fruit length; on the other hand, this same treatment gave one of the lowest mean values for fruit diameter, demonstrating the elongated shape of the fruit and that it is not directly related to weight. A significant response of this variable to variations in the supply of water to the crop was also seen by Lima *et al*. (2016), who found lower mean values under conditions of greater water restriction.

The highest mean value for fruit weight (51.03 g) was obtained in treatment T1, the treatment where the plants were not subjected to water stress. The mean fruit weight seen in this treatment was 158% greater than that in treatment T5 (19.78 g), the treatment that afforded the lowest mean value for this variable. It is important to note the mean value obtained in treatment T7, that was statistically equal to those found in T2 and T3, but which, in treatment T7, did not result in high productivity due to the low number of fruits per plant. Souza *et al*. (2019) found an increase in the mean value for fruit weight in response to increased water availability. Santos *et al*. (2018), studying irrigation depths and potassium fertilisation in the green pepper, found a maximum mean value for fruit weight using an estimated irrigation depth of 100.48% of the ETc, corroborating the results of the present study.

Crop productivity (t ha^{-1}) was significantly affected by the different water deficits applied to the green pepper (Fc = 41.32; P < 0.01 and P < 0.05) as shown in Figure 3.

The greatest yields in the green pepper were obtained with treatments T1 (12.62 t ha^{-1}) and T2 (11.10 t ha^{-1}), whose respective mean values were 5.5 and 4.8 times greater than that seen in T7 (2.28 t ha^{-1}), the treatment affording the lowest mean value for this variable. T1 and T2 had mean values that were statistically equal; however, it should be noted that T2 used 12.5% less water than T1, which in agriculture is important in terms of water savings.

The green pepper is a crop that is sensitive to water deficit, and reductions in productivity levels are to be expected when the crop is subjected to conditions of stress. Souza *et al*. (2019), analysing levels of water replacement in the green pepper, found a significant reduction in crop yield with the application of greater water restrictions.

Water use efficiency (kg ha^{-1} mm) responded significantly to the water deficits applied to the green pepper (Fc = 28.83; P < 0.01 and P < 0.05), as shown in Figure 4.

As can be seen in Figure 4, the highest value for water use efficiency, in absolute terms, was seen in T2, albeit with a mean value statistically equal to T1 by Tukey's test at a level of 5%. There is an increase of 166.4% in water use efficiency in T2 compared to T7, the treatment where greater water restrictions were applied to the plants.

The trend towards a reduction in water use efficiency in the green pepper under conditions of greater water restriction corroborates Santos *et al*. (2020), who found a linear reduction in water use efficiency for increasing water tension in the soil, where the lowest mean value for this parameter was seen under the most critical water condition (a tension of 65 kPa).

Figure 3 – Tukey's test (p < 0.05) for productivity (t ha^{-1}) in the 'Cascadura Ikeda' green pepper for different variable water deficits during the various stages of crop development (treatments identified as per Table 1)

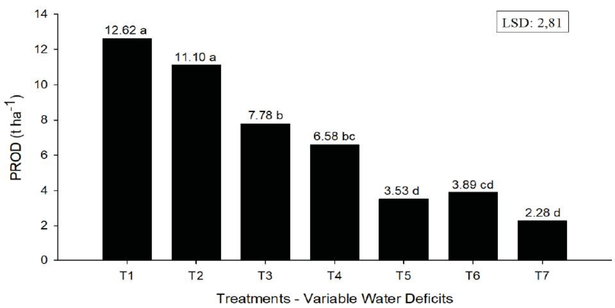
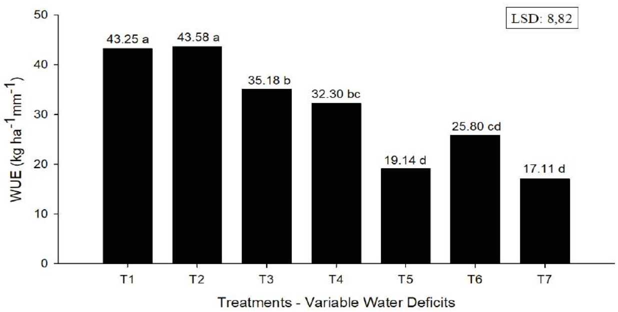


Figure 4 - Water use efficiency (kg ha^{-1} mm^{-1}) in the 'Cascadura Ikeda' green pepper for different variable water deficits during the various stages of crop development (treatments identified as per Table 1)



Although the irrigation depth is smaller in treatments of greater water restriction, such as T3, T4, T5, T6 and T7, the reduction in production levels significantly reduces the values for water use efficiency in these treatments, given that water is one of the factors that most affect agricultural production (TAIZ; ZEIGER, 2013). Among other effects, water restriction causes cellular dehydration, with a consequent reduction in turgor pressure, and results in a reduced rate of growth, stomatal closure, and photosynthetic inhibition, culminating in significant reductions in productivity.

Physiological characteristics of the 'Cascadura Ikeda' green pepper

All the physiological variables under evaluation were significantly influenced by the different water deficits, at both 28 and 56 DAT (Table 4).

The SPAD index, which is related to the relative chlorophyll content and the N status of the plant, showed decreasing behaviour as the severity of the applied water deficits increased in the two evaluations that were carried out (Figure 5).

At 28 DAT, the highest mean values for the SPAD index were seen in treatments T1, T2, T3 and T4, and ranged from 57.62 to 64.25. The lowest mean values were seen in treatments T5, T6 and T7, the treatments with more-severe water deficits.

At 56 DAT, the SPAD index showed similar behaviour to that seen at 28 DAT. The highest mean values were seen in T1 and T2 (66.58 and 63.0, respectively), with the lowest seen in T7 (42.9).

The SPAD index had previously been used as a parameter for evaluating the N status of the green pepper (COSTA *et al*., 2018). Although no relationship has been established for the behaviour of the SPAD index in the green pepper in response to variations in the water supplied to the crop, in other plants of agricultural interest, reductions have been seen in this variable as a function of the water deficit, as in Silva *et al*., (2013), who found lower values for the SPAD index when the crop was subjected to conditions of stress, notably in genotypes that are more sensitive to water deficit.

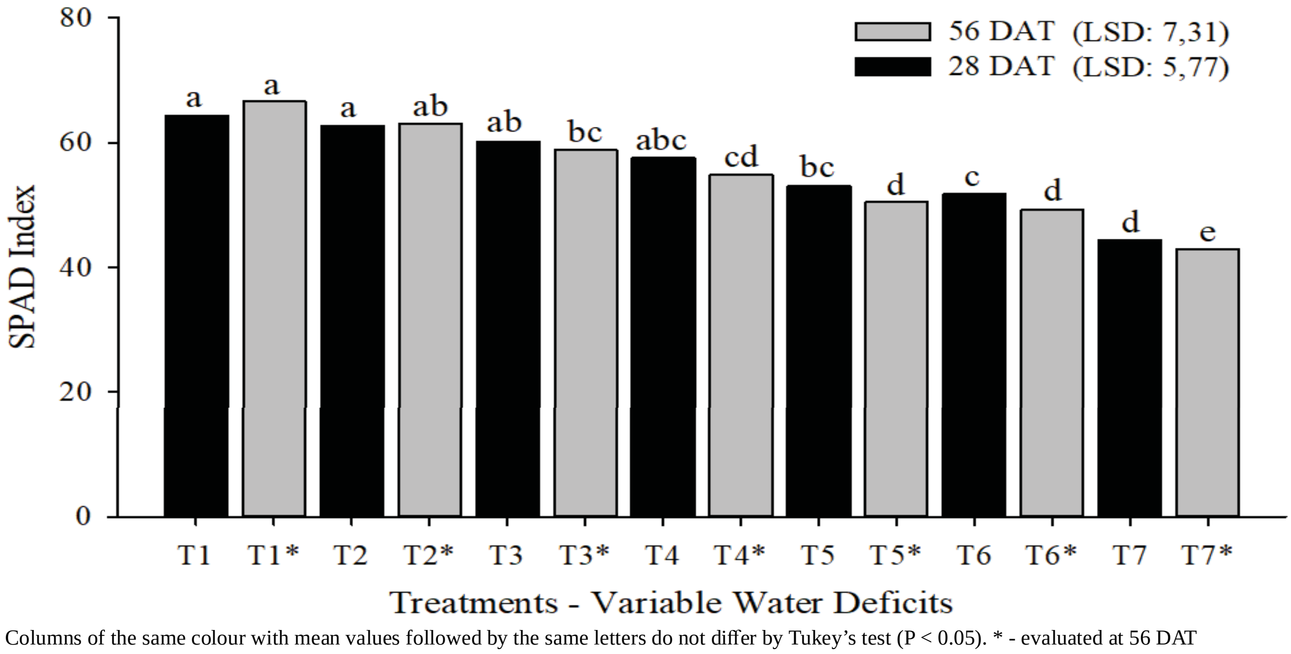
A trend towards a reduction in the SPAD index was seen in the green pepper for an increase in the applied water deficit, similar to the behaviour seen by Silva *et al*. (2013). One of the main mechanisms of nitrogen absorption by the plant is mass flow, where the lower availability of water in the soil in treatments of greater severity may have compromised N absorption by the plant, which is confirmed by the lower mean values for plant transpiration in treatments of greater water deficit (Figure 6B).

Table 4 - Summary of the analysis of variance for the physiological variables of green pepper grown in the field, in Fortaleza, Ceará, Brazil

Analysis of Variance – F-Test			
Variable		Source of Variation	
		Treatment	CV (%)
SPAD	28 DAT	19.41**	5.65
Index	56 DAT	43.72**	4.55
A	28 DAT	63.37**	6.17
	56 DAT	14.38**	14.13
E	28 DAT	17.15**	6.72
	56 DAT	10.02**	10.01
Gs	28 DAT	13.21**	17.75
	56 DAT	6.30*	21.84
Ci	28 DAT	4.48*	5.45
	56 DAT	8.27**	6.03
A/Ci	28 DAT	18.71**	9.34
	56 DAT	13.50**	11.18

** - significant ($P < 0.01$); * - significant ($P < 0.05$); CV - coefficient of variation; A - net rate of photosynthesis, µmol m^{-2} s^{-1}; E – transpiration, mol m^{-2} s^{-1}; gs - stomatal conductance, mol m^{-2} s^{-1}; Ci - internal CO_2 concentration, ppm; A/Ci - instantaneous carboxylation efficiency, (µmol m^{-2} s^{-1}) (µmol m^{-2} s^{-1})$^{-1}$

Figure 5 - Tukey's test for the SPAD index in the 'Cascadura Ikeda' green pepper for different variable water deficits during the various stages of crop development (treatments identified as per Table 1)



Columns of the same colour with mean values followed by the same letters do not differ by Tukey's test ($P < 0.05$). * - evaluated at 56 DAT

At 28 DAT, the net rate of photosynthesis showed the maximum mean value in T1 (23.49 µmol m^{-2} s^{-1}), which was 229% higher than that of treatment T7. At 56 DAT, the behaviour trend of the variable continued, however, despite being higher in absolute terms, T1 presented a mean value statistically equal to T2, T3, T4 and T5 (Figure 6A).

Changes in physiological characteristics, notably in photosynthetic rates, have a direct effect on development and production in the green pepper (LORENZONI *et al*., 2018), as can be seen by the behaviour of the net rate of photosynthesis and productivity, where there is a similarity between the treatments that afforded the highest mean values.

Soares *et al*. (2012) found a similar effect from water deficit on the photosynthetic rate of the tomato, applied during the flowering phase of the crop. Bosco *et al*. (2009) point out that a reduction in the normal flow of CO_2 towards the carboxylation sites constitutes the principal restriction to photosynthetic activity. In this regard, it should be noted that water availability in the crop environment directly influences the process of stomatal opening and closing, thereby affecting the net rate of photosynthesis, which explains the reduction in this variable under conditions of greater water deficit, as seen in Figure 6A.

Transpiration and stomatal conductance were also significantly influenced by the applied water deficits. At 28 and 56 DAT, the maximum mean value for transpiration was seen in T2 (6.21 and 6.29 mol m^{-2} s^{-1}, respectively), albeit statistically equal to the mean values seen in T1 and T3 in both evaluations (Figure 6B). For stomatal conductance, the highest mean values were seen in T1, T2 and T3, with values of 0.53 and 0.55 mol m^{-2} s^{-1}, respectively, for the evaluations carried out at 28 and 56 DAT (Figure 6C).

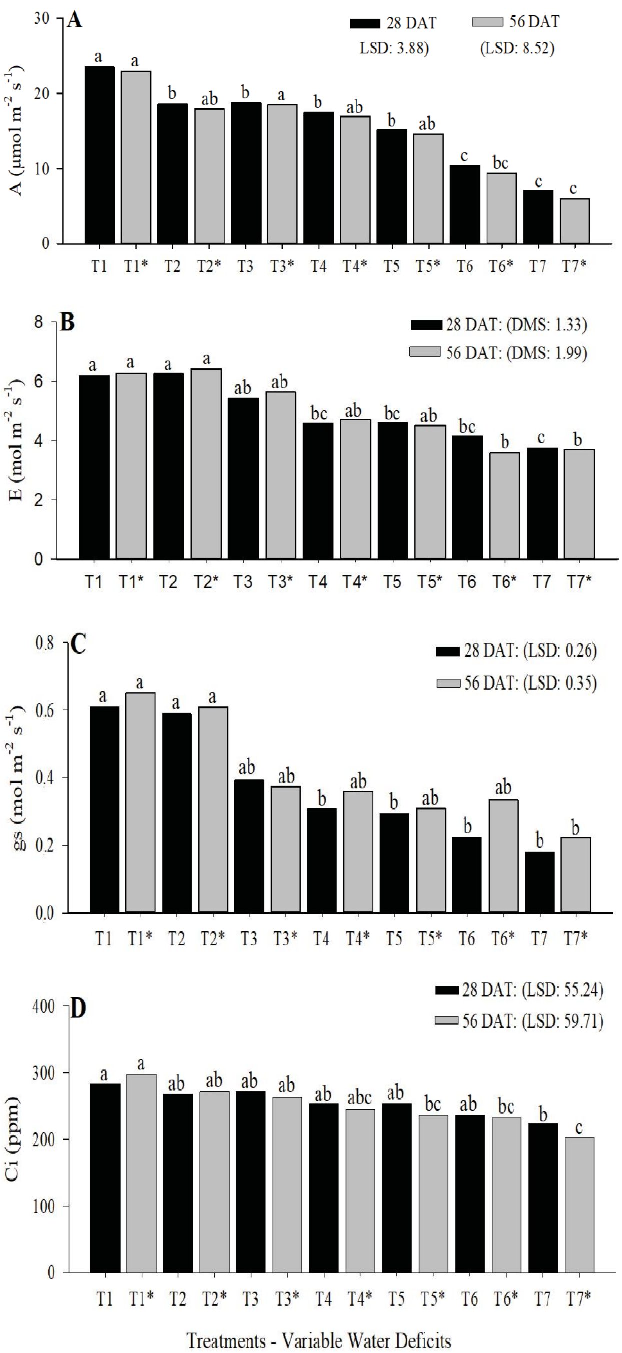
It is known that CO_2 influx necessarily occurs through the stomata during photosynthetic activity, with water efflux via transpiration also occurring during the same process, making stomatal opening and closing the principal mechanism for controlling gaseous exchange in higher plants (SILVA *et al*., 2015). As such, low water availability in the soil can cause stomatal closure and impair transpiration and stomatal conductance, as can be seen in Figures 6B and 6C, where treatments with more severe water deficits afforded lower values for these variables.

The greatest mean value for internal CO_2 concentration in the evaluation carried out at 28 DAS was seen in T1 (283.50 ppm), albeit statistically equal to the other treatments except for T7 (223.50 ppm). At 56 DAT, the variable showed similar behaviour to that of the first evaluation, highlighting a greater difference in mean values in response to the applied water deficits. The highest mean values in this evaluation were seen in T1, T2, T3 and T4, with the maximum seen in T1 (298 ppm), a mean value 46.4% higher than that of treatment T7 (Figure 6D).

A similar result was seen in the aubergine *(Solanum melongena*) by Silva *et al*. (2015), who found higher mean values for internal CO_2 concentration under conditions of greater water availability. Higher Ci values are commonly accompanied by increases in gs, as confirmed by the results seen in the green pepper and shown in Figure 6D.

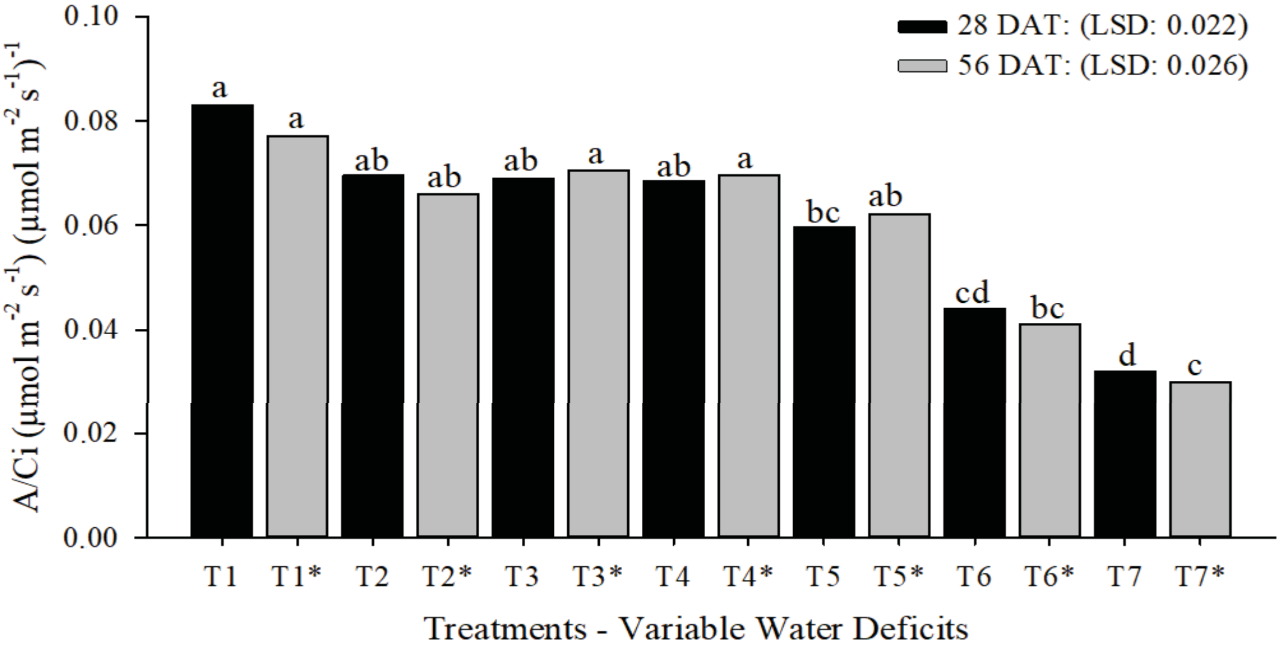
Instantaneous carboxylation efficiency in the green pepper showed a significant response to the application of variable water deficits (Figure 7). At 28 DAT, the highest mean values were seen in T1, T2, T3 and T4, where the highest value, 0.083 (μmol m^{-2} s^{-1}) (μmol m^{-2} s^{-1})$^{-1}$, found in T1, was higher by 159% than the mean value of treatment T7 of 0.032 (μmol m^{-2} s^{-1}) (μmol m^{-2} s^{-1})$^{-1}$.

Figure 6 - Tukey's test for the net rate of photosynthesis (A), transpiration (B), stomatal conductance (C) and internal CO_2 concentration (C) in the green pepper under water deficit (treatments identified as per Table 1)



Columns of the same colour with mean values followed by the same letters do not differ by Tukey's test (P < 0.05). * - evaluated at 56 DAT

Figure 7 - Tukey's test for instantaneous carboxylation efficiency in the 'Cascadura Ikeda' green pepper, in response to the application of different variable water deficits during the various stages of crop development (treatments identified as per Table 1)



Columns of the same colour with mean values followed by the same letters do not differ by Tukey's test ($P < 0.05$). * - evaluated at 56 DAT

At 56 DAT, the carboxylation efficiency maintained the pattern of variation seen at 28 DAT in response to the applied water deficits. The maximum mean value in absolute terms (0.077 (µmol m^{-2} s^{-1}) (µmol m^{-2} s^{-1})$^{-1}$) was seen in T1, albeit statistically equal to T2, T3, T4 and T5. The lowest mean values, seen in T6 and T7, were equal to 0.041 and 0.030 (µmol m^{-2} s^{-1}) (µmol m^{-2} s^{-1})$^{-1}$, respectively.

The instantaneous carboxylation efficiency has a direct correlation with the photosynthetic rate, and with the rate of CO_2 assimilation and its intracellular concentration. Therefore, if intercellular CO_2 concentrations are low, the influx of this component into mesophyll cells is restricted; in this scenario, the plant will start using CO_2 from respiration to maintain a minimum level of photosynthesis, albeit limited (TAIZ; ZEIGER, 2013).

CONCLUSIONS

1. Irrigation management including a water deficit can be applied to the green pepper with a water saving of 12.5% without compromising productivity or water use efficiency, provided that it is carried out with a 25% reduction in irrigation depth during stages II and IV, as in T2, suggesting the possibility of further preservation of the available water resources;
2. A 25% reduction in irrigation depth during stages II and III, and a reduction of up to 50% during stage IV, as in T2, T3 and T4, have no effect on the vast majority of vegetative and physiological parameters of the green pepper. Greater reductions, such as 50% during stages II and III, and 75% during stage IV, as in T5, T6 and T7, significantly reduce the above variables and the aesthetic quality of the plants, due to the greater water deficit. The use of such management when producing peppers in the field is not recommended;
3. The irrigation management recommended for cultivating green pepper in the field include replacing 100% of the evaporation, and a 25% reduction in replacing the evaporation that occurs during stages II and IV.

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