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DEMANDA HÍDRICA E ADUBAÇÃO ORGÂNICA NO CULTIVO PROTEGIDO DE PIMENTÃO NA REGIÃO NORTE DA BAHIA

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1 RESUMO

Objetivou-se determinar a evapotranspiração da cultura (ETc), o coeficiente de cultivo e a eficiência do uso da água para produção de pimentão (*Capsicum annuum L.)* cultivado sob dois compostos de solo em ambiente protegido. O experimento foi conduzido em Juazeiro-BA, no período de junho a outubro de 2019. O pimentão foi cultivado em vasos, o delineamento foi blocos casualizados, parcelas subdivididas, utilizou-se quatro lâminas de irrigação (95, 100, 105 e 110% de ETc) e dois níveis de adubação do solo: A1 (25 % de esterco e 75% de solo) e A2 (40 % de esterco e 60% de solo), os quais tiveram como base estudos desenvolvidos por Santana (2019). A ETc foi determinada através de dois conjuntos de lisímetros de lençol freático constante e o coeficiente de cultivo foi determinado a partir da ETc e da evapotranspiração de referência. A demanda hídrica total da cultura para o nível de adubação A1 foi de 527,3 mm e para o A2 foi de 395,7 mm. Os coeficientes de cultivo máximos e mínimos foram respectivamente 0,78 e 0,23 para A2; 1,02 e 0,34 para A1. O nível A1 de adubação apresentou maior produtividade e satisfatória conversão de água em massa fresca do fruto.

Palavras-chave: evapotranspiração, irrigação, coeficiente de cultivo.

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WATER DEMAND AND ORGANIC FERTILIZATION IN PROTECTED PIMENTÃO CULTIVATION IN THE NORTH REGION OF BAHIA

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2 ABSTRACT

The objective was to determine crop evapotranspiration (ETc), crop coefficient and water use efficiency for the production of sweet pepper (Capsicum annuum L.) cultivated under two soil compounds in a protected environment. The experiment was conducted in Juazeiro-BA, from June to October 2019. The pepper was grown in pots, the design was randomized blocks, split plots, four irrigation depths were used (95, 100, 105 and 110% of ETc) and two levels of soil fertilization: A1 (25% manure and 75% soil) and A2 (40% manure and 60% soil), which were based on studies developed by Santana (2019). ETc was determined using two sets of constant water table lysimeters and the crop coefficient was determined from ETc and reference evapotranspiration. The total water demand of the crop for the A1 fertilization level was 527.3 mm and for that A2 was 395.7 mm. The maximum and minimum crop coefficients were respectively 0.78 and 0.23 for A2; 1.02 and 0.34 for A1. The A1 level of fertilization showed higher productivity and satisfactory conversion of water into fresh fruit mass.

Keywords: evapotranspiration, irrigation, crop coefficient.

3 INTRODUCTION

Bell pepper (*Capsicum annuum L.*) is a vegetable crop of great economic importance, ranking among the ten most cultivated and consumed vegetables in Brazil. The considerable increase in production in recent years is due mainly to the greater spread of its cultivation in protected environments (TAZZO et al., 2012).

In addition to being a prominent region in Brazilian agribusiness, particularly for irrigated mango and grape cultivation, the Sub-Middle São Francisco Valley also boasts favorable soil, climate, and logistics characteristics for vegetable production. However, given the sensitivity of vegetables to extreme weather conditions, production in the region is limited, particularly during the spring–summer seasons, which are characterized by high solar radiation, high temperatures, and low relative humidity.

The use of protected environments is a highly relevant technique for horticultural production, as it uses coverings that mitigate the microclimate of the cultivation site, altering the radiation and energy balances of the environment, since it reduces the incidence of solar radiation inside the environment and consequently the thermal effects, benefiting the development of plants and reducing water losses through evaporation and evapotranspiration (ARAQUAM, 2013).

According to Albuquerque et al. (2012), determining the water consumption required by a crop at each stage of its development, as well as atmospheric losses through evapotranspiration, is crucial. This allows for efficient water use, an important factor in water-scarce regions, reducing costs for producers. Furthermore, establishing an irrigation system that provides plants with the water and nutrients they need to reduce losses through percolation and evaporation, as well as the risk of soil salinity. Currently, the drip water supply method has gained popularity and is becoming widespread in agricultural practices, especially in protected areas (LIU et al., 2019).

Like other vegetables, peppers require a large amount of water for their development, and this factor potentially affects their production (MUNIANDY et al., 2016). Therefore, the extreme importance of determining parameters that aim to promote the efficient use of water by the plant is evident, such as fruit quality and a lower occurrence of diseases due to excess water in the soil (TAZZO et al., 2012).

In this context, crop evapotranspiration (ETc) is a very important variable for determining the water supply required for crop development and is expressed in mm d^{-1}. It can be measured directly via lysimetry or estimated via mathematical models associated with reference evapotranspiration (ET_0) on the basis of the product of this and crop coefficients (ALBUQEURQUE et al., 2012). Currently, there is a list developed by Allen et al. (1998) containing several crop coefficients. However, according to Muniandy et al. (2016), several studies differ from those established in the literature; thus, Kc values are variable depending on factors such as development stage, crop type, irrigation technique used, soil characteristics, and regional climate.

Thus, adequate irrigation management is an indispensable technology, especially for regions with high atmospheric demand, aiming, above all, to provide productivity with a lower water supply (SOUZA et al., 2019). Thus, it is possible to use water depths on the basis of cultivation coefficients (Kc) determined on the basis of the crop's water needs and the region's climate (LORENZONI et al., 2019).

Therefore, the objective of this study was to determine the efficiency of water use and the cultivation coefficients for each phenological phase of the Itamara pepper hybrid, which was grown in pots within a protected environment in the northern region of Bahia.

4 MATERIALS AND METHODS

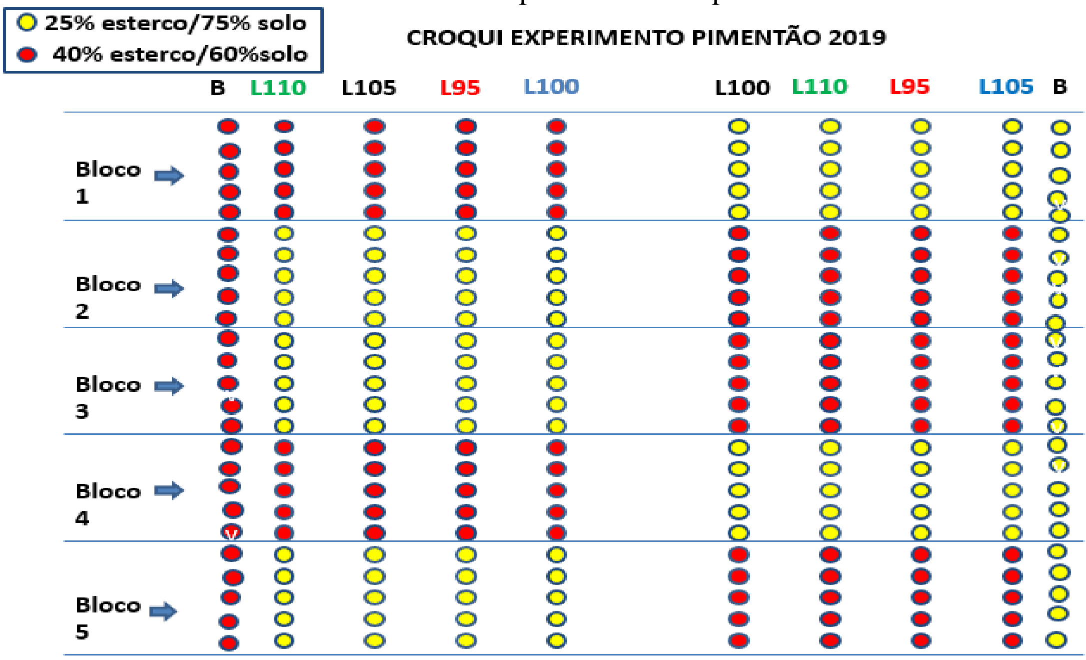
This article was excerpted from the dissertation entitled "Water demand and productive aspects of bell pepper subjected to different levels of organic fertilization and irrigation depths in protected cultivation." The study was conducted in the experimental area of the Federal University of Vale do São Francisco, Juazeiro-BA campus (09° 24' 42” S, 40° 29' 55” W and altitude of 368 m), from June to October 2019.

According to the Köppen-Geiger climate classification (2013), Juazeiro is in a region that presents a BSw'h 'semiarid' climate, characterized by high temperatures and low relative humidity, with a dry season between the months of May and October and a rainy season between the months of November and April.

The structure used was a protected environment with the following dimensions: 18 m wide, 24 m long and 3 m high. It is covered and closed on the sides with a light-diffusing Chromatinet screen (Polysack). Plastic Industries®), gray in color, with 40% shade. The Itamara hybrid pepper was used and was grown in 12-liter pots spaced 1.0 m between rows and 0.5 m between plants.

The statistical design was randomized blocks (DBC), subdivided plots, with plots consisting of four irrigation depths, randomly distributed (95%; 100%; 105%; and 110% of ETc) and subplots, with two fertilization proportions, A1 25% goat manure with 75% soil and A2 40% goat manure with 60% soil, five replicates, on the basis of studies developed by Santana (2019) (Figure 1). The border comprises an area of 25 m².

Figure 1. Sketch of the experimental useful area (100 m²) showing the distribution of pepper cultivation and the location of the pots inside the protected environment.



The physical and chemical characteristics of the soil used were as follows: clayey texture with soil density (Ds) = 1.24 Mg m $^{-3}$; particle density (Dp) = 2.44; total porosity (Pt) = 49; hydrogen potential of water (pH) = 7.2; P = 3.27 mg dm $^{-3}$; K^+ = 0.36 $cmol_c$ dm $^{-3}$; Ca^{2+} = 22.8 $cmol_c$ dm $^{-3}$; Mg^{2+} = 2.2 $cmol_c$ dm $^{-3}$; Al = 0 $cmol_c$ dm $^{-3}$; cation exchange capacity (CEC) = 25.39 $cmol_c$ dm $^{-3}$; Na^+ = 0.05 $cmol_c$ dm $^{-3}$; Cu = 0.4 mg dm $^{-3}$; Zn = 0.1 mg dm $^{-3}$; Fe = 14.6 mg dm $^{-3}$; Mn = 49.5 mg dm $^{-3}$; B = not significant; and organic matter = 7.6 g kg $^{-1}$.

Thirty-four days after sowing, the pepper seedlings reached four to six definitive leaves, were 15 cm tall, and were therefore transplanted into pots in a protected environment. The total crop cycle, from transplanting to the last harvest (DAT), lasted 127 days.

The irrigation system used was drip irrigation, with self-compensating sprinklers, a flow rate of 2 L/h and an efficiency coefficient of 97%. A reservoir (1000 L fiberglass tank) was installed in the experimental area for water storage.

ETc) values were obtained from two sets of constant water table lysimeters (one for each fertilization level), each consisting of five replicates (pots), which were interconnected to form a communicating pot system (Figure 2). ETc readings were taken daily at 9:00 a.m. via graduated rulers (in mm) fixed to the lysimeter supply reservoirs. On the basis of the ETc values obtained daily by the difference in the readings of direct water consumption observed over a 24-h period, for each lysimeter set (fertilization level: A1 and A2), the gross water depth for localized irrigation was determined via Equation 1:

$$L_b = \frac{ETc}{Ei} \quad (1)$$

where:

L_b = Raw blade (L)

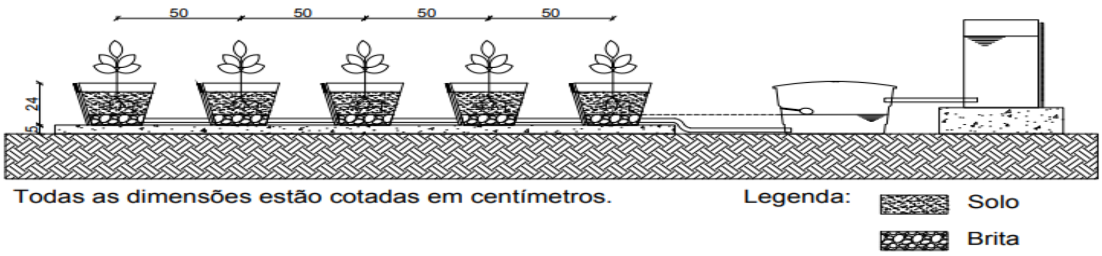
Ei = irrigation efficiency.

Lb was determined for each fertilization level, and the percentages corresponding to 95%, 100%, 105% and 110% of ETc were calculated. The irrigation time (T_i) was subsequently determined daily through the simple relationship established by the system flow rate and gross depth, according to Equation 2.

$$T_i = 60^* L_b/2 \quad (2)$$

To avoid advective effects, lysimeters were installed in the center of the experimental area. The soil inside the lysimeters contained the same proportions of goat manure and soil as did the other pots in the study area. To ensure a constant supply and to maintain the same level, the lysimeters were connected to a flow-through reservoir equipped with a float connected to the supply tank, which allowed immediate replacement of evapotranspired water and kept the soil at field capacity (Figure 2).

Figure 2. Constant water table lysimeters were installed in the central area of the protected environment.



Reference evapotranspiration (ETo) was determined via Equation 3, Penman–Monteith (FAO, 1998), which is based on data obtained from an automatic meteorological station located next to the experimental area and was installed in accordance with the standards established by the World Meteorological Organization (WMO).

Within the protected environment, sensors connected to a Campbell Scientific CR1000 datalogger were installed at two central points. These sensors were programmed to take readings every five seconds and generate averages every 60 minutes of the following meteorological variables: average, maximum and minimum air temperatures; instantaneous, minimum and maximum relative humidity; average, maximum and minimum wind speed; and the components of the radiation balance: global solar radiation, reflected solar radiation, radiation emitted by the atmosphere, radiation emitted by the surface and net radiation.

$$ETo = \frac{0{,}408\, s\,(R_n - G) \ + \ \gamma \frac{900}{T_{med} + 273} U_2\,(e_s - e_a)}{s + \gamma(1 + 0{,}34\, U_2)} \quad (3)$$

where:

ETo - reference evapotranspiration, mm d^{-1};

s - slope of the water vapor pressure curve, kPa $^{o}C^{-1}$;

Rn - daily net radiation, MJ m^{-2} d^{-1};

G - daily soil heat flux, MJ m^{-2} d^{-1};

γ - psychrometric constant, kPa $^{o}C^{-1}$;

Tmed - average daily air temperature, °C;

U2 - average daily wind speed at a height of 2 m, ms^{-1};

es - average daily water vapor saturation pressure, kPa;

ea - average daily water vapor pressure, kPa.

The crop coefficients (Kc) for each phenological stage were determined by the ratio between the crop evapotranspiration

(ETc) and the reference evapotranspiration (ETo), Equation (4).

$$Kc = \frac{ETc}{ETo} \quad (4)$$

The phenological stages of pepper were determined according to the recommendations of Marouelli and Silva (2012), as follows: I - transplanting and seedling taking; II - vegetative development until the beginning of flowering; III - reproductive phase, when the fruits reach 50% of their size; IV - of this last phase, the 1st harvest after the peak of production; V - from the peak of production until the last harvest.

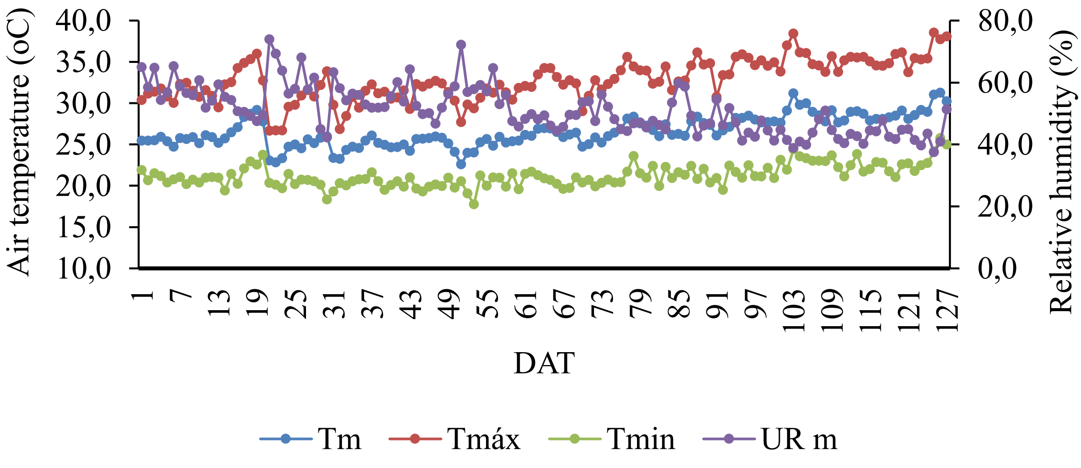
The fruits were harvested at 65, 80, 87, 98, and 108 DAT. For each plot, the plants were separated according to the fertilization level, and in the subplots, the fruits were identified, placed in previously identified plastic bags, and then weighed on a scale with an accuracy of 0.005 g. The average total productivity (t ha $^{-1}$) for each slide (95%; 100%; 105%, and 110% of ETc) was determined by adding the weight of fresh fruits per plant for each fertilization level and averaging the replicates.

Water use efficiency (WUE) was determined according to the methodology described by Souza et al. (2011), that is, by the relationship between the total production per plant (kg) and the respective volume of water applied (m3). The contribution of precipitation during the experiment was insignificant since the rainfall index within the protected environment was only 2.1 mm. The data were subjected to analysis of variance and regression via SISVAR software version 5.1 (FERREIRA, 2011).

5 RESULTS AND DISCUSSION

Graph 1 shows the behavior of the average, maximum, and minimum temperatures and relative humidity in the protected environment during the study period. The average temperature value (Tm) was approximately 25 °C, with a maximum thermal amplitude of 13 °C and a minimum of 7 °C.

Graph 1. Temperature variation: average (Tm), maximum (Tmax), minimum (Tmin) and relative air humidity (URm) in a fully protected greenhouse.



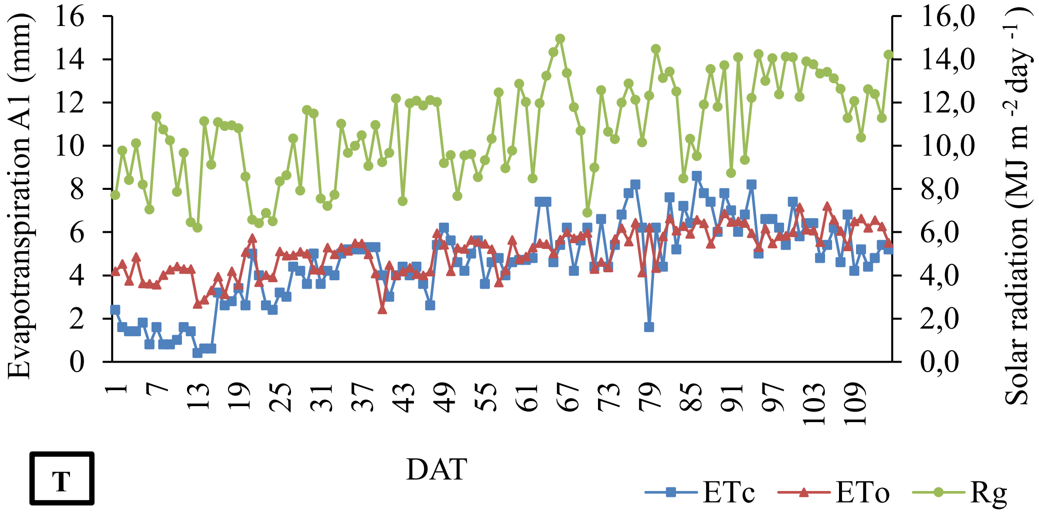
On the basis of these temperature results, the studied environment presented ideal conditions for pepper production, since, according to Marouelli and Silva (2012), temperatures below 25 °C slow plant development, and temperatures above 35 °C cause greater flower drop. It was also observed that on some days, the maximum air temperature exceeded 35 °C, but this situation did not affect crop development, as it occurred at the end of the cycle.

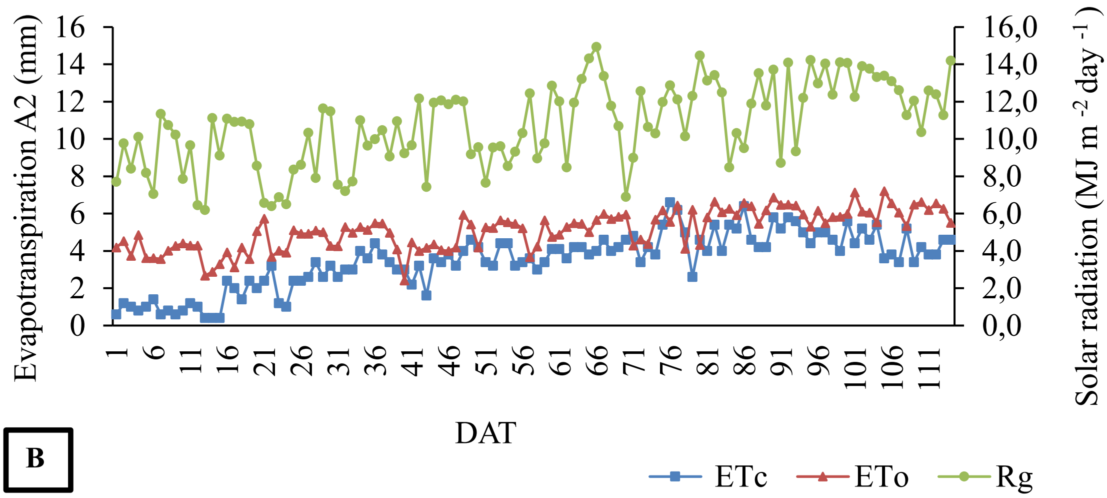
Graph 1 also shows that the relative humidity varied between 40% and 70%, decreasing from 88 DAT until the end of the cycle. Marouelli and Silva (2012) reported that average temperatures of approximately 30 °C combined with a relative humidity close to 90% are ideal for fruit development and quality, especially in terms of color and nutritional value. However, outdoor pepper cultivation in the study region may be restricted by high temperatures and low humidity, especially during the spring and summer seasons.

During the period between 90 and 127 DAT, flower abortion and the formation of fruits of lower commercial value were observed in both treatments. This may have occurred because of the combination of low relative humidity and high temperatures. According to Silva et al. (2002), this situation causes a water deficit in the plant, causing the death of buds, the fall of flowers and the formation of small fruits.

The accumulated and average daily crop evapotranspiration values during the experimental period were 527.3 mm and 4.6 mm, respectively, for A1 and 395.7 mm and 3.5 mm, respectively, for A2 (Graph 2). Therefore, in terms of percentage, A2 had a water consumption corresponding to 75% of the consumption observed for A1, indicating that a greater proportion of manure incorporated into the soil may have resulted in a reduction in evapotranspiration, mainly from soil evaporation.

Graph 2. Global solar radiation, reference evapotranspiration (ETo) and crop evapotranspiration (ETc) for fertilization levels A1 (A) and A2 (B).





The ETc curves in Graph 2 show that throughout the crop cycle, water consumption for both treatments (A1 and A2) was greater during the fruiting phenological stage (i.e., from 30 DAT onward), which represented 80% of the total water demand. Additionally, in Graph 2, it can be seen that from 87 DAT onward, despite the decrease in relative humidity (Graph 1), which in theory represents a greater atmospheric water demand, ETo and ETc were lower. This situation shows that, on average, because there was less solar radiation, the availability of solar energy is the predominant factor in the evapotranspiration process.

On the other hand, on some days during the crop cycle, in addition to the normal reduction caused by the shade screen (cover), due to greater cloud cover, there was also a reduction in the incidence of global solar radiation on the pepper crop. The opposite situation was observed by Lorenzoni et al. (2019), who studied the evapotranspiration of the bell pepper hybrid Magali R. in a greenhouse (where the relative humidity is relatively high) in Maringá, Paraná, from May to September 2015. These authors reported an increase in ETc on days with a relatively high incidence of solar radiation.

Notably, the ETc values for A1 and A2 in the initial phase (up to 16 DAT), due to the limited development of crops, presented very low daily values. However, later, the ETc for A1 began to present values very close to ETo. However, the ETc for A2, during the remainder of the crop cycle, continued to present values much lower than the reference evapotranspiration. These lower ETc values for A2 can be explained mainly by the probable reduction in soil evaporation, mentioned previously, that is, by the greater proportion of organic matter (goat manure) in the soil.

Pivetta et al. (2010), studying the maximum evapotranspiration of the "Vidi " pepper hybrid grown in a plastic greenhouse in Rio Grande do Sul during spring, reported values obtained in drainage lysimeters: an accumulated value of 101.5 mm and a daily average of 0.81 mm. However, in contrast, the evaporation measurements carried out with a Piche evaporimeter inside the greenhouse were extremely different: 353.8 mm accumulated, and the daily average was 2.8 mm. However, ETc can be highly variable in relation to the structure used, growing region, time of year, solar energy availability, photoperiod, and general environmental conditions.

The interaction between the irrigation depth and fertilization factors (percentages of manure and soil) did not significantly affect the productivity (t ha $^{-1}$) or water use efficiency (kg m $^{-3}$) at the 5% probability level. However, when the factors were considered separately, a significant effect was observed only for the fertilization factor (Table 1).

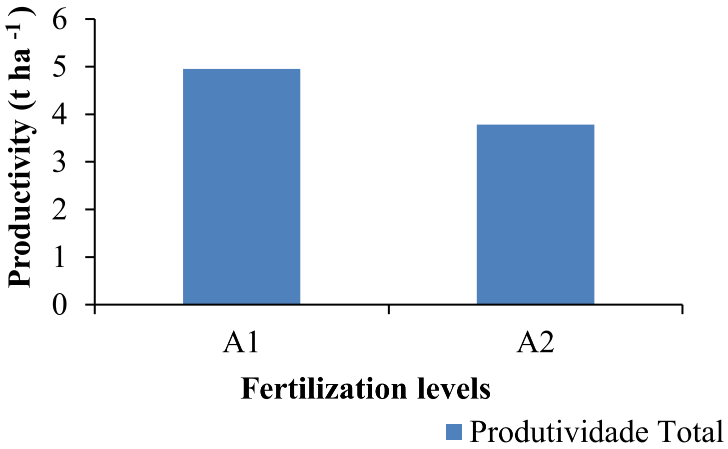
Table 1. Summary of analysis of variance (F values) for productivity (PT) and water use efficiency (WUE) under pepper cultivation in Juazeiro, BA.

FV	GL	PT	USA
Blocks	4	3,001 ^{NS}	2,962 ^{NS}
Blade (L)	3	0.258 ^{NS}	0.123 ^{NS}
Error 1	12	-	-
Fertilization (A)	1	21,391 **	5,609 **
W x H	3	0.515 ^{NS}	0.533 ^{NS}
Error 2	16	-	-
CV 1 (%)		33,31	33.69
CV 2 (%)		18.38	17.78

FV – Source of variation, GL - degrees of freedom, ** – significant at the 5% probability according to the F test, NS – not significant.

The average total productivity of pepper reached values of 4.95 t ha $^{-1}$ and 3.78 t ha $^{-1}$ for fertilizer levels A1 and A2, respectively (Graph 3). These results indicate that a lower proportion of goat manure fertilizer (A1), regardless of the application depth, presented a greater yield than did the treatment with a higher fertilizer proportion (A2). However, since only the chemical analysis of the soil and not the manure-soil mixture was performed for fertilizer levels A1 and A2, the possibility of micronutrient toxicity and a consequent decrease in production for A2 cannot be ruled out.

Graph 3. Average total productivity of peppers according to irrigation depth.



Aragão et al. (2008), studying pepper (hybrid Magali R.) in a covered environment with 30% shading in Juazeiro-BA from May to November 2007, reported a commercial productivity of 5.98 t ha $^{-1}$. This result indicates a productivity 17% greater than that obtained in the present study for treatment A1 (4.95 t ha- ^{1}), which may be due to the cultivar, availability and quality of solar radiation and more suitable microclimatic conditions in the protected environment, among other factors.

Pires et al. (2010), who cultivated bell pepper (hybrid Margarita) between May and October 2008, also obtained a productivity of 9.44 t ha $^{-1}$ in Juazeiro-BA. Although the authors used organic fertilization with goat manure and 50% shade cover, the difference in productivity can be explained by several factors, including smaller spacing, cultivation in soil, cultivar and water supply.

Table 2 shows that a greater volume of water was applied to the treatment with a lower proportion of goat manure fertilizer. The lower proportion of fertilizer may have generated greater soil heating and, consequently, greater evaporation in A1. On the other hand, the higher proportion of organic matter may have promoted greater soil aggregation and, consequently, greater soil water retention in A2.

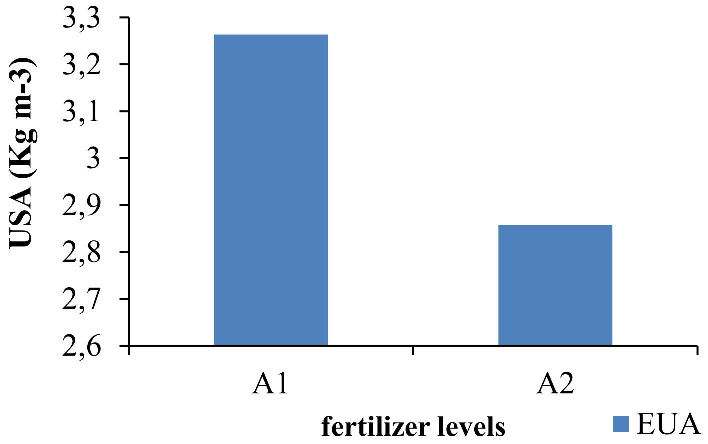
Cardozo et al. (2016), studying the effect of organic fertilization on bell pepper production in a protected environment, also noted that organic fertilization was viable since the average productivity of bell peppers was similar to that obtained with mineral fertilization. Furthermore, they reported that the best results were associated with total soil water replenishment.

Table 2. The total volume of water (^{m3}) applied for each percentage of ETc during the pepper cycle corresponded to the different percentages of ETc.

	95% ETc	100% ETc	105% ETc	110% ETc
A1 (25%)	0.070	0.074	0.078	0.082
A2 (40%)	0.061	0.065	0.068	0.071

In Graph 4, A1 presented the highest water use efficiency index (EUA), and the maximum value was observed at the 95% ETc depth. The minimum value was observed for A2 at 105% ETc (2.59 kg m $^{-3}$).

Graph 4. Water use efficiency (EUA) for pepper production under conditions of different irrigation depths and two fertilization levels.



The results obtained in this study regarding water use efficiency (WUE) were greater than the value of 1.5 kg m^{-3} reported by Gordin (2018) for Rubia R. pepper grown in a protected environment in Recife-PE during the period from October 2017--February 2018, in which mini-lysimeters were used to determine the best irrigation depth. On the basis of the crop evapotranspiration (ETc) and reference (ETo) data (Graph 2), the average values of the cultivation coefficient (Kc) were obtained for each pepper development stage and are presented in Table 3.

Table 3. Average values of cultivation coefficients for each phenological phase of pepper.

Phenological Stages	A1 (25%)	A2 (40%)
II	0.34	0.23
III	0.76	0.53
IV	1.01	0.77
V	1.02	0.78

The crop yield coefficients found for the two fertilization levels in the protected environment, as expected, differed from those recommended by FAO-56 for open-air irrigated environments: 0.6 (initial phase), 1.05 (intermediate phase), and 0.9 (final phase). These differences can be considered normal, considering that in open-air environments, climatic conditions—high incidence of global solar radiation, high temperatures, and high wind speeds—contribute to greater water transfer from vegetated surfaces to the atmosphere through the process of evapotranspiration. Consequently, the crop yield coefficients are greater than those in covered and laterally enclosed environments, which provides crops with a lower incidence of global solar radiation, lower temperatures, and lower wind speeds.

Lorenzoni et al. (2019), studying bell peppers in a greenhouse in the municipality of Maringá, Paraná, between May and September 2015, reported that the Kc values were not only higher than those reported in the present study but also significantly higher than those recommended by FAO-56 for open-air environments: 0.86 and 1.4 for the initial and final stages, respectively. These authors stated that these coefficients vary depending on the soil and climate conditions, as well as the different stages of plant development. However, it is important to emphasize that the effects generated by the microclimate within protected environments, such as a greenhouse, especially the generally high relative humidity, contribute to a reduction in evapotranspiration. However, thermal conditions due to increased temperatures both during the day and at night have opposite effects, contributing to greater evapotranspiration.

6 CONCLUSION

The results obtained in this study indicate that the treatment with a lower percentage of goat manure fertilization (A1), regardless of the applied depth, contributed positively to the increase in productivity and water use efficiency.

Future research should analyze the manure/soil composition to understand the nutritional characteristics of this compound, aiming to provide more informed discussions about the possibility that larger proportions of manure could cause toxicity due to excess micronutrients and consequently contribute to a decrease in productivity.

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