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Horticultural Science/ Original Article

Water regimes and hydrogel applied on bell pepper grown in a protected environment

Abstract – The objective of this work was to evaluate the effect of the application of different doses of hydrogel and irrigation levels on the morphophysiological and productive behavior of a bell pepper cultivar, in a protected environment. Four doses of hydrogel (0.0, 0.6, 1.2, and, 2.4 g per plant) and four irrigation levels (50, 75, 100, and, 125%) were used, on the basis of the daily evapotranspiration of a bell pepper crop grown in a sandy soil. Height, stem diameter, and leaf area were measured at 70 and 100 days. At the end of the experiment, bell pepper yield and water use efficiency were estimated. Hydrogel associated with irrigation increases leaf area, productivity, and irrigation-water use efficiency. The applied water deficit (132.8 and 199.26 mm), associated with the hydrogel doses, does not affect the plants morphologically.

Index terms: *Capsicum annuum*, deficit irrigation, water management.

Regimes hídricos e hidrogel aplicados em pimentão cultivado em ambiente protegido

Resumo – O objetivo deste trabalho foi avaliar os efeitos da aplicação de diferentes doses de hidrogel e diferentes níveis de irrigação no comportamento morfofisiológico e produtivo de uma cultivar de pimentão, em ambiente protegido. Foram utilizadas quatro doses de hidrogel (0,0, 0,6, 1,2 e 2,4 g por planta) e quatro níveis de irrigação (50, 75, 100 e 125%), com base na evapotranspiração diária do cultivo de pimentão plantado em solo arenoso. A altura, diâmetro do caule e área foliar foram medidos aos 70 e 100 dias. Ao final do experimento, foram estimados o rendimento e a eficiência do uso da água da cultivar de pimentão. O hidrogel associado à irrigação aumenta a área foliar, a produtividade e a eficiência do uso da água de irrigação. O deficit hídrico aplicado (132,8 e 199,26 mm), associado às doses de hidrogel, não afeta morfologicamente as plantas.

Termos para indexação: *Capsicum annuum*, irrigação deficitária, manejo da água.

Introduction

Bell pepper (*Capsicum annuum* L.) is a Solanacea shrubby originated in the Americas with a deep and pivoting root system (Santos et al., 2018a).

In Brazil, the production of *Capsicum annuum* in open fields is 334,615 tonnes of fruit per year in an area of about 15,000 ha, and an average yield of 22 tonnes ha^{-1} (Rocha, 2017). According to HfBrasil (2017), bell pepper is adapted to various soil and climate conditions in

Brazil. The largest Brazilian producers of bell pepper are the states of Minas Gerais, São Paulo, Ceará, Rio de Janeiro, Espírito Santo, and Pernambuco. They account for 87% of the Brazilian production. According to Lopes et al. (2018), the Minas Gerais and São Paulo states cultivate about 5,000 ha, encompassing a production of 120,000 tonnes per year.

In the semiarid region of the Northeast, 31.4% of bell pepper production is in the state of Ceará, where the Ibiapaba plateau stands out with 15,704 tonnes per year (IBGE, 2017). The production region of Ibiapaba shows low groundwater volume, irregular rainfall, and a sandstone formation, which results in low availability of water for irrigation. Water deficit in bell pepper cultivation has limited the achievement of high productivity and fruit quality, either in protected environments, or in open fields (Cantuário et al., 2014). The total water requirement of bell pepper is estimated to be between 450 to 650 mm, and it depends on climate conditions and on the length of the cycle (Sousa et al., 2011; Marouelli & Silva, 2012).

According to Silva et al. (2015), water stress is one of the factors that affects growth, physiological behavior, and productivity of cultivated plants. The lack or excess of water significantly affects the production and productivity of cultivated plants (Silva et al., 2011; Wang et al., 2023). Water stress has known effects on plant growth; however, such effects depend on the species, genotype, plant age, plant development stage, stress duration, and severity (Anjum et al., 2011). Understanding these parameters in cultivated plants is important for the selection of tolerant cultivars (Ferraz et al., 2012). However, complementary strategies are necessary, to reduce the negative effects of water deficit on the growth and productivity of plants grown in water-scarce regions (Alotaibi et al., 2023).

The use of hydro-absorbent polymers in the form of hydrogels can be one of the technologies to increase production. It has been used to improve water and nutrient retention in arable soils (Nassaj-Bokharaei et al., 2021). Hydrogel in irrigated agriculture has the potential to cope with droughts in agroecosystems. Hydrogel is able to retard the severity of water scarcity in plants. According to Ljubojević et al. (2017), hydrogel is widely used in agriculture, forestry, and fruit growing, although the technical and economic effects of its use are not yet fully known. Studies with hydrogel in protected cultivation are also necessary (Piroli et al., 2022), especially in the cultivation of vegetables for commercial purposes. Madramootoo et al. (2023) reported that in tomato plants under water deficit, cellulose hydrogel increased the plant biomass, area index, and yield.

The hypothesis of the present study is that doses of hydrogel mitigate the effects of deficit irrigation on bell pepper production, without affecting the morphophysiological parameters of the plant.

The objective of this work was to evaluate the effect of the application of different doses of hydrogel and irrigation levels on the morphophysiological and productive behavior of a bell pepper cultivar, in a protected environment.

Materials and Methods

The experiment was carried out from April to August 2022, in an experimental area belonging to the Instituto Agropolos do Ceará, in the municipality of São Benedito (4º03'34"S, 40º53'39"W, at 867 m altitude), in the state of Ceará, Brazil. The climate of the region is mild tropical hot semi-arid, classified as BSh (Alvarez et al., 2014); the mean temperature ranges from 22 to 29ºC, and average annual rainfall is 940.2 mm from January to May (Ipece, 2018).

The protected environment was made of an arched metal structure, 30 m long, 15 m wide, and 3 m high, covered with 250 μm transparent polyethylene. The soil in the area was classified as Neossolo Quartzarênico Órtico latossólico, equivalent to Entisols (Quartzipsamments) (Santos et al., 2018b).

Samples of the soil used in the experiment were colected at 0–20 cm soil depth for chemical and physical characterizations using Embrapa's methodology (Teixeira et al., 2017). The chemical results were: 0.57 g kg^{-1} C; 0.99 g kg^{-1} soil organic matter; 3.9 mg dm^{-3} P; 0.25 cmol$_c$ dm^{-3} K; 3.9 cmol$_c$ dm^{-3} Ca; 1.65 cmol$_c$ dm^{-3} Mg; 6.6 pH H_2O; and 0.74 dS m^{-1} EC. The physical results were: 741.3 g kg^{-1} sand; 142.5 g kg^{-1} silt; 116.2 g kg^{-1} clay; loamy sand soil texture; 1.25 g cm^{-3} soil density; 2.55 g cm^{-3} particle density; and 51% total soil porosity). This information was used to define the bell pepper fertilization.

Bell pepper 'Dahra RX' was planted at 0.8 m spacing between rows and 0.5 m between plants.

A localized drip irrigation system was employed, using 16 mm diameter polyethylene lines with emitters spaced at 0.50 m apart, with a controlled flow rate at 2.3 L h^{-1} in each pit, and 0.5 kgf cm^{-2} working pressure of. The irrigation system was equipped with a suspended water tank (1.0 m high) of 1,000 L, with a float-controlled level, a bypass line, manual valves, lateral lines, and a 0.75 hp pump.

The irrigation management was determined on basis of the crop daily evapotranspiration (ETc), obtained according to following equation: ETc = ETo × kc, where: ETc is the evapotranspiration of the crop (mm per day); ETo is the evapotranspiration reference (mm per day); and Kc is the crop coefficient (dimensionless).

Reference evapotranspiration (ETo) was estimated using the method of class A evaporation tank, which was installed in situ, considering the conditions of the protected environment. Data were collected daily, at 09:00 h. ETo was multiplied by the crop coefficient (kc) values proposed by Doorenbos & Kassan (1994), which were 0.4, 0.7, 1.05, and 0.85 for phases I, II, III, and IV, respectively.

Granulated polymer was weighed to obtain 0.6, 1.2, and 2.4 g per plant, and they were placed in a 1000 mL beaker. Between 300 and 500 mL water were added to hydrate the polymer until it stopped expanding and forming the hydrogel. The hydrogel was incorporated into the soil, around the root of each plant, 25 days after transplanting (DAT), coinciding with the different levels of irrigation, according to the treatments of the subplot. The hydrogel was applied directly to the pit five to eight cm below the surface of the soil. There was no loss of hydrogel through leakage. As the bell pepper roots developed, the hydrogel was exposed to the roots.

The experiment was carried out in subdivided plots in a 4 x 4 factorial arrangement. One factor was four irrigation rates: 50%, 75%, 100%, and 125% of ETc (plots). The other factor was four doses of granulated polymer: 0.0, 0.6, 1.2 and 2.4 g (subplots). There were four replicates and 64 experimental units with three useful plants for each treatment, which is a total of 192 plants. Irrigation water came from a tubular well. The hydro-retentive polymer was based on acrylamide and potassium acrylate.

The variables evaluated at 70 and 100 DAT were plant height (PH), stem diameter (SD), and leaf area (LA). At 110 DAT, the variables evaluated were number of fruit per plant (NFP), average fruit weight (AFW), longitudinal fruit length (LFL), transverse fruit length (TFL), total soluble solids (TSS), and productivity (PROD).

Water use efficiency (WUE, in kg m^{-3} of water) was calculated for all treatments. WUE is the ratio between the total production in each plant and the accumulated irrigation blade in the cycle (units of water consumed), according to Santos et al. (2014).

Data were subjected to assumption checking, by the Shapiro-Wilk's test for normality, the Breusch-Pagan's test for homoscedasticity, and Durbin-Watson's test for independence of errors. The assumptions were met. A two-way analysis of variance was carried out, and the F-test (α=0.05) was used. A regression analysis was performed for irrigation rates and hydrogel doses. The freeware version of SISVAR 5.6 software was used (Ferreira, 2019). Treatments were divided into orthogonal contrasts according to Ferreira (2019), in order to compare specific treatments of irrigation (I) and hydrogel (H), such as irrigation within hydrogel [I (H0 versus H0.6; H1.2; H2.4)], and hydrogel within irrigation [H (I50 versus I75; I100; I125)].

Results and Discussion

At 70 and 100 DAT, there was no significant influence ($p>0.05$) of the isolated factors of water regimes, hydrogel, and their interaction on the height and diameter of bell pepper plants, except for leaf area, at 100 DAT (Table 1). In other words, the treatments with water regimes based on ETc, associated with hydrogel for bell peppers, did not affect plant growth in a protected environment. This fact is possibly associated with the normal occurrence of gas exchange in the environment, which indicates the absence of water stress. The average height was 83.6 cm, at 70 DAT, and 90.9 cm at 100 DAT, which may justify a correct use of carbon that can stimulate growth and result in greater biomass production (Furlan et al., 2002).

These results corroborate those observed by Nascimento et al. (2021), who also found no significant effect of irrigation on the height of tomato plants subjected to doses of hydrogel, as well as the findings by Padrón et al. (2015) for pepper irrigated daily. Fernández et al. (2018) reported that the use of hydrogel reduced the water demand of Salvador hybrid bell pepper from 388.6 mm to 197.6 mm, when 2.0 g per plant plant was applied, and to 196 mm, when 2.5

g per plant was used. Therefore, hydrogel can be useful in areas with limited water for irrigation, which is why, in the present study, there was no water stress in plants irrigated with 50% and 75% of ETc. The hydrogel may have canceled out the effects of the irrigation treatments, and there was no statistical significance of these treatments on the height and diameter of 'Dahra RX' bell pepper plants.

The same interpretation as for height applies to stem diameter, as irrigation and hydrogel did not influence stem diameter in isolation, and the interaction between the factors (irrigation versus hydrogel) was also not significant at 5% and 1% probability (Table 1), with 14.91 average value and 16.87 mm, at 70 and 100 DAT, respectively. These results justify those reported in a previous research by Padrón et al. (2015), for daily irrigation based on ETc, and in a study by Souza et al. (2019), for bell peppers under different irrigation levels in protected environment. These authors did not also observe significance for height and stem diameter. The hydrogel may have nullified the effect of the water regimes of 50% and 75% of ETc associated with daily irrigation on this variable.

Irrigation treatments and doses of hydrogel had no significant influence ($p>0.05$) on the leaf area at 70 DAT (Table 1). As a result, there was no reduction of leaf area during the period of the crop's greatest water demand. Consequently, the photosynthetic processes and phytomass production of bell pepper were not compromised. However, there was an influence of water regimes ($p<0.01$) in isolation, at 100 DAT. This fact shows that this variable is more sensitive to the effects of irrigation, in the final phase of the cycle, whose average value increased slightly, in comparison to 70 DAT. Therefore, at this stage of the plant, any variation in the volume of water is capable of influencing leaf size.

Leaf area at 100 DAT increased by 29% linearly, in the same proportion as the amount of water based on ETc (Figure 1 A); in this case, for each unit increase in the applied irrigation, there was an increase of leaf area of 26.96 cm^2. This behavior should be associated with a progressive availability of water in the soil, after daily irrigations within the protected environment, and associated with the lower evapotranspiration rate and the doses of hydrogel.

Over the course of bell pepper productive cycle, four harvests were carried out: the first one at 56 DAT; the second at 72 DAT; the third at 90 DAT; and the last one at 110 DAT. However, at 110 DAT, although the highest number of fruit per plant had been obtained, there was no significance between the factors ($p>0.05$), with the average of 35.4 fruit per plant (Table 2). This fact can be attributed to a genetic characteristic of bell pepper 'Dahra RX', which is why producers of Ibiapaba region prefer it.

Different results were observed by Souza et al. (2019), as the average obtained in their research was 39 fruit per bell pepper plant, under different irrigation levels in a protected environment.

The results of the present study show that the doses of polymer in the form of hydrogel may have canceled

Table 1. Mean square of the analysis of variance for plant height, stem diameter, and leaf area, at 70 and 100 days after transplanting (DAT) of *Capsicum annuum* 'Dhara RX' grown in protected environment, subjected to water regimes and doses of hydrogel.

Sources of variation	DF	Plant height (PH)		Stem diameter (SD)		Leaf area (LA)	
		70	100	70	100	70	100
Irrigation (I)	3	44.69^{ns}	33.01^{ns}	2.18^{ns}	1.21^{ns}	187.13^{ns}	1,194.77**
Replicate	3	110.4	229.26	4.71	2.44	167.62	142.04
Error (1)	9	53.89	57.08	1.24	0.78	53.35	73.56
Hydrogel (H)	3	4.62^{ns}	19.37^{ns}	0.04^{ns}	1.03^{ns}	30.34^{ns}	123.58^{ns}
Interaction I x H	9	29.1^{ns}	39.14^{ns}	1.15^{ns}	1.17^{ns}	35.45^{ns}	29.34^{ns}
Error (2)	36	26.70	32.09	0.93	1.44	92.77	62.21
$CV_{(1)}$ (%)		8.78	8.31	7.47	5.23	13.26	15.11
$CV_{(2)}$ (%)		6.18	6.23	6.48	7.12	17.48	13.39
Mean		83.60 cm	90.92 cm	14.91 mm	16.87 mm	55.10 cm^2	56.78 cm^2

**Significant at 1% probability. ^{ns}Nonsignificant at 5% probability. CV: coefficient of variation.

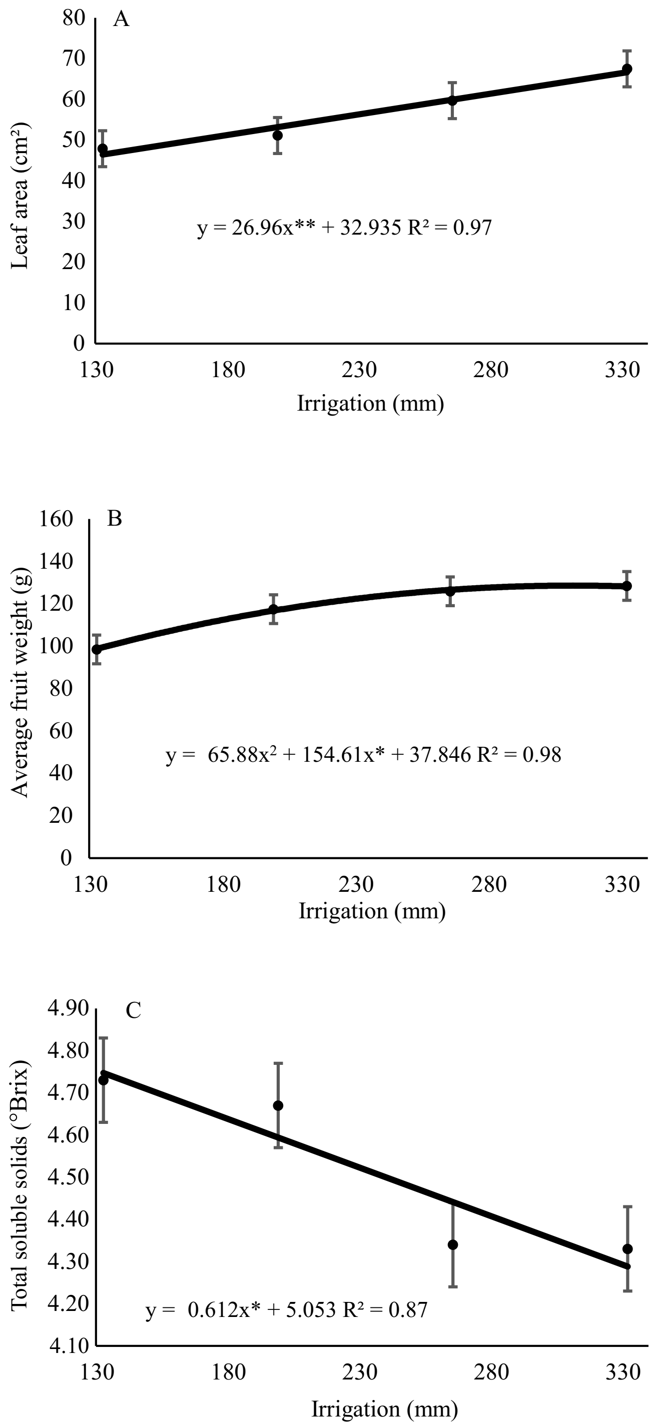

Figure 1. Parameters of *Capsicum annuum* 'Dhara RX' grown in protected environment and subjected to water regimes associated with doses of hydrogel, for: A, leaf area at 100 days after transplanting (DAT); B, average fruit weight at 110 DAT, in function of the irrigation level; C, total soluble solids in fruit at 110 DAT, in function of the irrigation level.

out the effect of deficit irrigation (132.8 mm = 50% and 199.3 mm 75% of ETc, respectively). In other words, favoring the availability of water in the soil influences ($p<0.01$) the productivity of bell pepper (Table 2).

This way, hydrogel is confirmed as a technology that helps supply water to plants by behaving as a water-retaining agent and soil conditioner, justifying its use in agriculture (Ferreira et al., 2014). In a cultivation of maize (*Zea mays*) on sandy soils, results showed that the hydrogel increased the efficiency of water use (Albalasmeh et al., 2022), allowing water to be conserved in the soil for longer, favoring greater production.

The average weight of bell pepper fruit analyzed at 100 DAT was significant ($p<0.05$), due to the effect of irrigation applied throughout the cycle in isolation, with the average weight of 117.55 g (Table 2). Besides, the longitudinal fruit length (LFL) and transverse fruit length (TFL) of these fruit were not influenced ($p>0.05$) by the treatments to which plants were subjected, with average lengths for LFL and TFL equal to 116.11 mm and 60.78 mm, respectively (Table 2). In a study on irrigation levels for bell peppers, in a protected environment, Souza et al. (2019) found lower results for fruit length. In an older study, Furlan et al. (2002) found that the average fruit length ranged from 118 to 135 mm, when irrigated with 100% of ETc. However, despite the lower LFL in the present study than that observed by those authors, fruit can also be marketed (Ceagesp, 2015).

Bell pepper total soluble solids (TSS) were 4.52 °Brix average, which was also influenced ($p<0.05$) only by irrigation (Table 2). For the productivity, there was a significant interaction ($p<0.05$) between the irrigation and hydrogel factors (Table 2). Overall, average total productivity was estimated at 103.9 Mg ha^{-1}.

Irrigation isolated effect on average fruit weight resulted in 128.55 g maximum weight for 311.7 mm irrigation (Figure 1 B). These findings corroborate those by Souza et al. (2019), who observed an increase of average fruit weight as a function of water availability for bell peppers. Notwithstanding, Santos et al. (2018a) reported higher fruit weight as a result of irrigation corresponding to 100.5% of ETc, in bell pepper cultivated subjected to irrigation and potassium fertilization.

Water deficiency reduces the accumulation of water in fruit (Patanè & Saita, 2015), favoring a higher

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concentration of total soluble solids (TSS). The isolated effect of irrigation on TSS caused a linear reduction of 0.61 °Brix for each increase of irrigation level (Figure 1 C), which corresponded to 8.45% reduction. The highest TSS value (4.73 °Brix) was observed in the smallest amount of water (132.8 mm) received by bell pepper plants.

The TSS is important to verify the fruit quality, mainly in production intended for fresh consumption, but also in the process of product industrialization. This is necessary because the high values of this parameter make it possible to reduce the time and energy required to evaporate water and increase fruit productivity, which results in a greater processing efficiency, improving the post-harvest quality of bell pepper (Faria et al., 2013). The effect of lower water volumes applied to bell pepper plants led to an intensification of fruit acidity and to a progressive accumulation of solutes in the fruit. However, in the bell pepper fruiting phase, a lack of water restricts the translocation of nutrients (calcium) and reduces the leaf coverage, making them susceptible to diseases (apical rot) and physiological disorders (Hartz et al., 2008). Water is one of the resources that not only limits the plant growth, but whose deficiency also limits other plant functions, such as cell expansion (Taiz et al., 2017).

There was a simultaneous interaction between irrigation and hydrogel for the total productivity of bell pepper, since productivity augmented as irrigation increased in the presence of hydrogel (Figure 2). The highest productivity was estimated at 119.5 Mg ha^{-1} at the highest accumulated irrigation rate (332.1 mm); in addition, this increase occurred with the hydrogel treatments (Figure 2). The lowest productivity (53.3 Mg ha^{-1}) was found in the treatment at the lowest irrigation level (132.8 mm) and no hydrogel. Therefore, we can infer that the 332.1 mm irrigation regime that increased the productivity of 'Dahra RX' bell pepper is due to a positive association with hydrogel, which received enough water for constant hydration and made it available to the plants.

Lower productivity results were observed for tomatoes grown in a protected environment subjected to water stress; the authors found a productivity increase ranging from 68.7–72.7 Mg ha^{-1}, as the level of irrigation augmented (Ozbahce & Tari, 2010). Therefore, it seems that bell pepper (when subjected to different water regimes in protected environments in association with the use of hydrogel) is more sensitive than tomato, since it had a higher productivity than tomato. Different results were reported by Oliveira et al. (2015) for the productivity evaluation of the Magali R bell pepper cultivar, in a conventional planting in Seropédica, in the state of Rio de Janeiro, Brazil; these authors found 38.3 Mg ha^{-1} productivity, as a result of three harvests with 45-day interval, which are the harvests at much greater intervals than those carried out in the present study.

The analysis of orthogonal contrasts clearly showed the positive effect of hydrogel in contrast to irrigation on bell pepper productivity, since there was no significant

Table 2. Mean square of the analysis of variance for the number of fruit per plant (NFP), average fruit weight (AFW), longitudinal length (LFL), transverse fruit length (TFL), total soluble solids (TSS), and total productivity of *Capsicum annuum* 'Dhara RX', at 110 days of transplanting, in protected environment subjected to water regimes associated with doses of hydrogel.

Sources of variation	DF	Mean Square					
		NFP	AFW	LFL	TFL	TSS	Productivity
Irrigation (I)	3	38.21^{ns}	2,945.54*	21.5^{ns}	28.8^{ns}	0.727*	8,556.3**
Replicate	3	38.35	406.48	638.1	98.4	0.237	134.1
Error (1)	9	21.77	450.53	47.9	9.7	0.160	131.3
Hydrogel (H)	3	9.89^{ns}	371.31^{ns}	50.2^{ns}	7.3^{ns}	0.246^{ns}	734.9**
Interaction I x H	9	15.86^{ns}	322.61^{ns}	73.1^{ns}	18.8^{ns}	0.162^{ns}	352.6*
Error (2)	36	20.75	191.70	52.8	14.0	0.265	164.8
$CV_{(1)}$ (%)		15.01	18.06	5.9	5.2	8.84	11.54
$CV_{(2)}$ (%)		14.65	11.78	6.3	6.2	11.38	12.93
Mean		35.40	117.5 g	116.1 mm	60.7 mm	4.52 °brix	103.9 Mg ha^{-1}

* and **Significant at 5 and 1% probability, respectively. ^{ns}Nonsignificant at 5% probability. CV, coefficient of variation.

difference between irrigation at 50% of ETc and the other water regimes associated with hydrogel doses (Table 3). This behavior shows that the hydrogel has a positive effect on bell pepper productivity (Figure 2). The combinations of irrigation with 50% of ETc, and the other irrigation levels associated with hydrogel do not differ from each other, however, from the second split, the data show that there is a difference between the absence and presence of hydrogel, indicating that the use of hydrogel is convenient for bell pepper productivity in protected environment. Therefore, further studies are necessary, before recommending any dose of hydrogel and interaction with irrigation rates for bell peppers in protected environments.

Water use efficiency (WUE) was influenced ($p<0.01$) by irrigation and hydrogel, as well as by the simultaneous interaction between these factors, with 43.99 kg m^{-3} water overall mean, which is consistent with high total productivity.

Water use efficiency (WUE) reduced as a result of the increase of irrigation water, whose lowest value (31.3 kg m^{-3} water) occurred for the accumulated irrigation of 332.1 mm without hydrogel. WUE showed a slight decrease, as hydrogel doses increased, certainly because there was more water available,

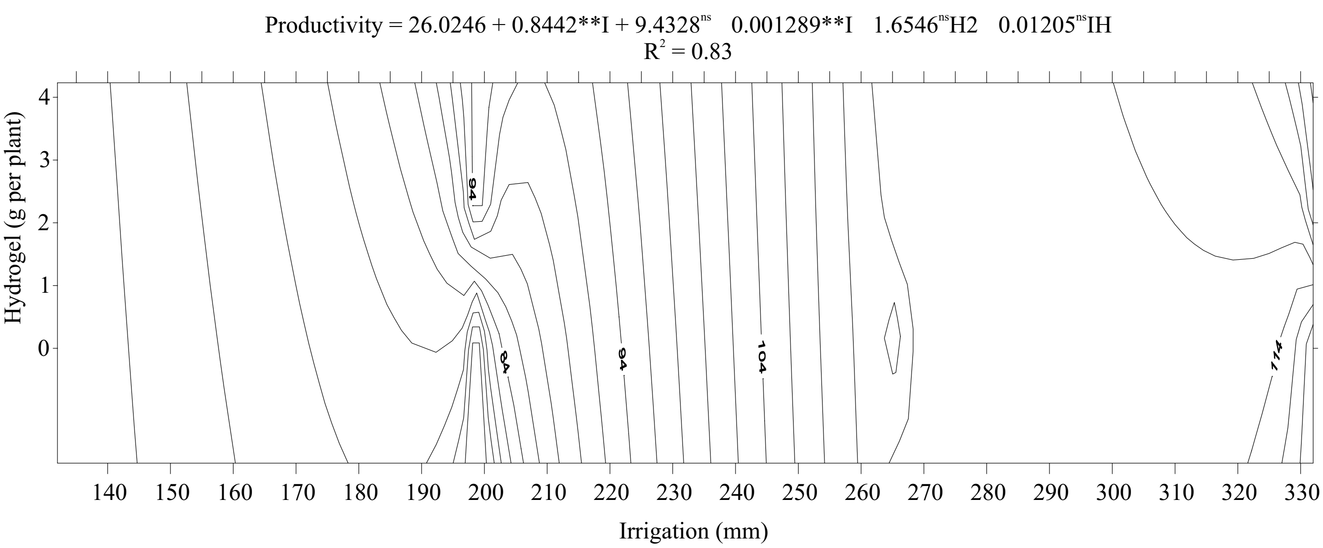

Figure 2. Significant interaction effect for total productivity of *Capsicum annuum* 'Dhara RX', at 110 days of transplanting, in function of irrigation (I) x hydrogel (H) in protected environment

Table 3. Pairwise comparisons by the orthogonal contrast analysis of the irrigation (I) and hydrogel (H) treatments for *Capsicum annuum* 'Dhara RX' productivity.

Contrast(1)	Estimated difference	Standard error	t-test	P-value(2)
$I_{50\%}$ (H_{0g} *vs* $H_{0.6g}$; $H_{1.2g}$; $H_{2.4g}$)	-14.00	4.93	-2.83	0.000
$I_{75\%}$ (H_{0g} *vs* $H_{0.6g}$; $H_{1.2g}$; $H_{2.4g}$)	-7.87	4.93	-1.59	0.000
$I_{100\%}$ (H_{0g} *vs* $H_{0.6g}$; $H_{1.2g}$; $H_{2.4g}$)	-5.99	4.93	-1.21	0.000
$I_{125\%}$ (H_{0g} *vs* $H_{0.6g}$; $H_{1.2g}$; $H_{2.4g}$)	-16.38	4.93	-3.32	0.000
H_{0g} ($I_{50\%}$ *vs* $I_{75\%}$; $I_{100\%}$; $I_{125\%}$)	-40.68	4.93	-8.24	0.007
$H_{0.6g}$ ($I_{50\%}$ *vs* $I_{75\%}$; $I_{100\%}$; $I_{125\%}$)	-39.39	4.93	-7.98	0.118
$H_{1.2g}$ ($I_{50\%}$ *vs* $I_{75\%}$; $I_{100\%}$; $I_{125\%}$)	-22.65	4.93	-4.58	0.231
$H_{2.4g}$ ($I_{50\%}$ *vs* $I_{75\%}$; $I_{100\%}$; $I_{125\%}$)	-48.27	4.93	-9.77	0.002

(1)Irrigation inside the hydrogel [I (H_{0g} *vs* $H_{0.6g}$; $H_{1.2g}$; $H_{2.4g}$)], and hydrogel inside the irrigation [H ($I_{50\%}$ *vs* $I_{75\%}$; $I_{100\%}$; $I_{125\%}$)]. (2)Nominal significance levels of the t-test.

due to the presence of hydrogel (Figure 3). This can be attributed to excess water affecting the nutrients in the first soil layers, which may have been leached out instead of being absorbed by the plants (Santos et al., 2016).

However, the highest WUE value was observed for the 132.8 mm irrigation, which corresponds to 1.2 g of hydrogel; thus, WUE seems to correlate with the use of hydrogel in deficit irrigation. These results are similar to those by Souza et al. (2019) and Padrón et al. (2015), who observed the same behavior in bell pepper. Notwithstanding, they differ from those found by Matos Filho et al. (2020), who reports that the highest WUE was observed for irrigation of 335.4 mm. In addition, WUE and productivity can be improved under water deficit in various crops, including bell pepper, depending on the water management adopted (Yu et al., 2020). In this case, determining the WUE under deficit irrigation seems to be important for regions with limited water resources.

Hence, hydrogel seems to be a viable alternative for areas of recurrent drought, to delay the severity of water deficit, since it increases the efficiency of water use (Felippe et al., 2020), influencing the productivity of bell pepper 'Dahra RX'.

Similar results were also reported by Piroli et al. (2022) for cut lisianthus (*Eustoma grandiflorum*) grown in a protected environment, as the authors reported that there was a significant effect of the irrigation management *vs* hydrogel interaction, for the efficient use of water in the different growing seasons. It is important for plants to have a high WUE and an acceptable productivity with less water use according to Santos et al. (2016). Thus, Souza et al. (2019) reported that the best use of water in the cultivation of bell pepper occurred for irrigation of 160.45 mm, in comparison with the highest treatment of 374.38 mm. Therefore, the findings of the present research justify growing 'Dahra RX' bell pepper with deficit irrigation associated with the use of hydrogel, in protected environments, to improve the water use efficiency, which is an appropriate parameter for optimizing their productivity.

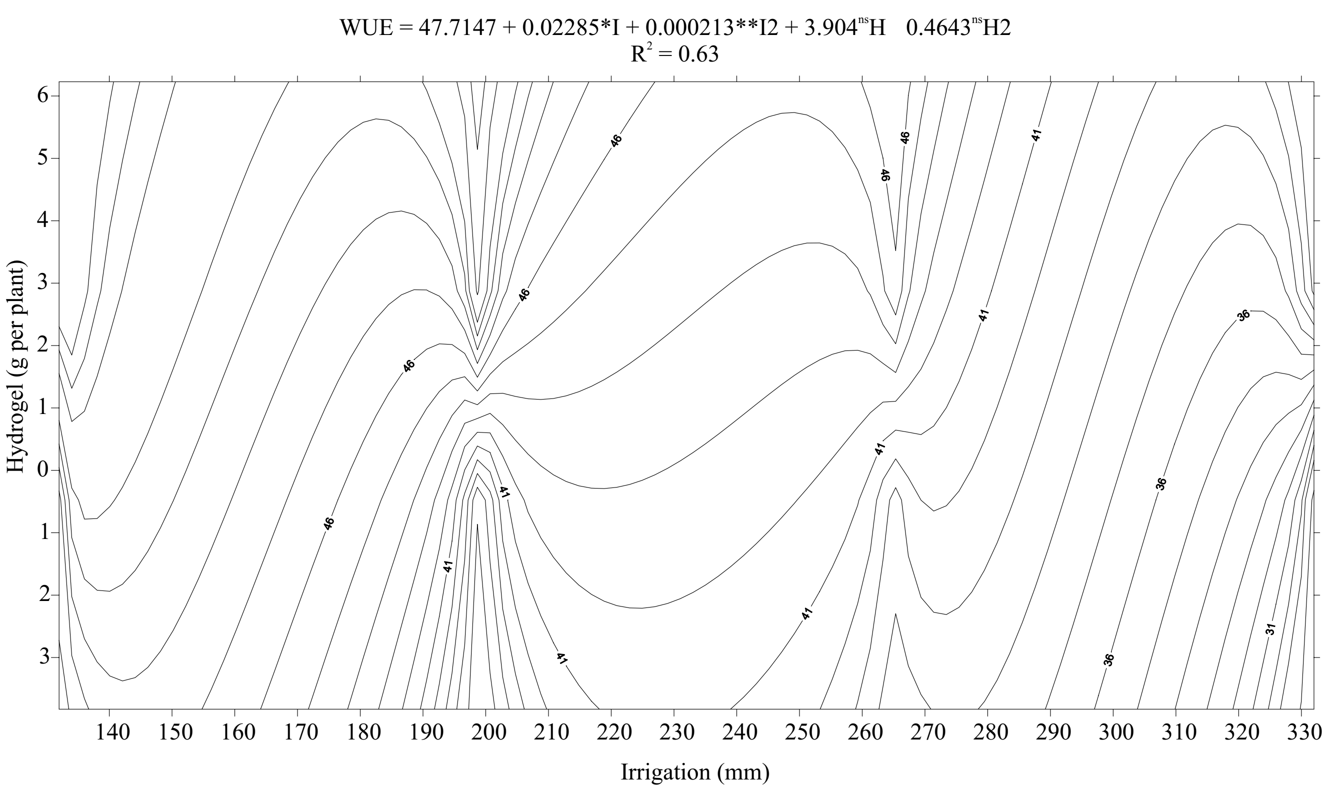

Figure 3. Effect of simultaneous interaction between irrigation (I) x hydrogel (H) on the water use efficiency (WUE) in *Capsicum annuum* 'Dhara RX' plants in protected environment.

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Conclusions

1. Irrigation combined with hydrogel increases the leaf area of bell pepper (*Capsicum annuum*), fruit weight, fruit production per plant, and the quality of soluble solids.

2. Water deficit regimes associated with hydrogel do not affect the bell pepper morphology.

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