Morphological responses of bell pepper under water regimes and hydrogel

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Abstract: Efficient water management in water scarcity is essential when irrigating cultivated plants. This research aimed to evaluate the responses to application of hydrogel doses and different irrigation levels on the morphological characteristics of bell pepper plants grown in the open field. To this end, an experiment was set up with bell pepper in subdivided plots, considering, as plots, four irrigation levels (50%, 75%, 100%, and 125% of ETc) and, as a subplot, four doses of hydrogel (0.0; 0.60; 1.20 and 2.40 g pl^{-1}) with four repetitions, in the open field. The variables analyzed were plant height, fruit number, fruit weight, and bell pepper phytomass. The doses of hydrogel favored plant growth and increased the number of fruits and the phytomass of the bell pepper. The use of hydrogel in bell pepper cultivation improves the morphological aspect of bell pepper plants. Finally, the hydrogel allows bell pepper to be produced for up to 110 days with a total cumulative water table of only 683.1 mm in the open field.

Keywords: Irrigation management. *Capsicum annuum*. Phytomass. Semi-arid. Polymer.

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1 Introduction

Water is one of the fundamental inputs for agricultural production and should be used rationally since a lack or excess of water significantly affects the productivity of cultivated plants (Silva et al., 2011). Considering the problems of water scarcity, especially for crop irrigation in arid and semi-arid regions, Hatfield and Dold (2019) report the need to improve the efficiency of irrigation water use without reducing productivity, but mainly with a view to save water, so crop production can be increased without increasing the area.

Capsicum annuum can be grown on the Ibiapaba plateau throughout the year, preferably with short-cycle cultivars (90 to 120 days) to reduce costs (Menezes et al., 2024). Irrigation is essential for producing this species in semi-arid regions, as it is one of the most sensitive vegetables to water deficit (Doorenbos and Kassam, 1986). Due to its sensitivity to the effects of irrigation (excess or deficit of water),

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the drip irrigation method is the most recommended for cultivation (Lopes et al., 2018), as it provides water directly near the plant's roots and is more efficient in applying water.

Thus, efficient irrigation management can be improved as an alternative that reduces the amount of water and/or the frequency of irrigation, as horticulturists can increase their profits from the crop by using hydrogel (Ekebafe et al., 2011; El-Idrissi et al., 2023). However, in the face of climate change, it is a challenge to increase the productivity of cultivated plants without reducing or at least maintaining their water demands (Souza et al., 2019).

The plants react to the effects of water deficit in different ways, such as stomatal closure, smaller leaf area, earlier senescence, and leaf abscission (Taiz et al., 2017). Therefore, making efficient use of water at each phenological stage as an adaptation mechanism is very important for guaranteeing crop productivity. Controlled water deficit as a reduction in water supply to improve the efficiency of water use without affecting plant development and productivity is currently a much-discussed subject (Yang et al., 2017), however, there is still room for improvement. It should be noted that a slight reduction in yields can be allowed with the use of deficit irrigation (Fathi and Tari, 2016), but the water saved in operations will compensate for the losses in crop yields so you can maximize the profit from the crop (Menezes et al., 2024).

This study aimed to evaluate the responses of hydrogel application underwater regimes on the morphological characteristics of bell pepper plants grown in the open field.

2 Material and methods

The experiment was carried out in the open field in an area of Quartzarenic Neosol (Quartzipsamments) belonging to the Agropolos Institute, in São Benedito, Ceará, Brazil, (4º 02' 56“ S; 40º 51' 54” W and at 903 m). The climate is mild tropical hot semi-arid, classified as Bhs according to Alvares et al. (2014), with an average temperature ranging from 22° C to 29ºC and an average annual rainfall of 940.2 mm from January to May (IPECE, 2017).

The soil in the area was collected at a depth of 0.2 m for chemical and physical characterization before the experiment was set up (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). The methodology for the chemical and physical analyses was suggested by EMBRAPA (2017) to help manage the fertilization and liming for planting the hybrid bell pepper *cv*. Dahra RX. The spacing adopted for growing bell pepper was 0.80 m between rows and 0.50 m between plants.

The irrigation system used in the experiment was drip irrigation, using polyethylene lines with a diameter of 16 mm and a length of 6 m. The emitters were spaced 0.50 m apart at the same spacing as the bell pepper, with an actual flow rate of 2.1 L h^{-1} at each plant and a working pressure of 0.51 kPa. The irrigation system had a 1,000 L water tank with a float-controlled level, a bypass line, manual valves, lateral lines, and a 0.75 hp motor pump.

The calculation of the plant water consumption was based on the crop daily evapotranspiration (ETc), based on the reference evapotranspiration (ETo), obtained using the “A” Class Tank method (Standardized by the USWB/USA and FAO with the following dimensions: internal diameter of 120.6 cm and internal height of 25.4 cm), which was installed at the experiment site and the data collected 9 a.m. daily and then entered into spreadsheets to estimate the ETc. ETo was obtained according to Equation 1 and then multiplied by the bell pepper crop coefficient values (K_C) proposed by Doorenbos and Kassan (1994), which were 0.4, 0.7, 1.05, and 0.85 for phases I (initial), II (development), III (mid), and IV (final), respectively, as per Equation 2.

$$ETo = Ev \times Kt \tag{1}$$

Where ETo is the reference crop evapotranspiration (mm day^{-1}), Ev is the height of evaporated water in the tank (mm day^{-1}), Kt is the tank coefficient (dimensionless).

$$ETc = ETo \times Kc \quad (2)$$

Where ETc is the crop evapotranspiration (mm day^{-1}), ETo is the reference crop evapotranspiration (mm day^{-1}), Kc is the cultivation coefficient (dimensionless).

A polymer based on acrylamide and potassium acrylate was used as a hydrogel. It was applied after hydration for around 10 minutes until it fully expanded. At 25 days after transplanting (DAT) the bell pepper was incorporated into the soil around the root of each plant in the experimental unit.

The experiment was conducted in subdivided plots with four irrigation regimes: 50%, 75%, 100%, and 125% of ETc (plots) and four doses of polymer in the form of hydrogel: 0.0, 0.60, 1.20, and 2.40 g plant^{-1} (subplots), with four replications and three useful plants per experimental unit (6 m), totaling 192 plants.

The irrigation treatments (water regimes) were applied daily from 25 days after transplanting the bell pepper seedlings (DAT) in the field based on the ETc and the doses of the polymer in the form of hydrogel were applied and incorporated into the soil around the root of the plant, taking care to leave 5 to 8 cm below the surface of the soil in the hole, so that there was no loss of the hydrogel due to leakage when it expanded.

To check the effects of water regimes and hydrogel on the bell pepper plant, plant height (PH), stem diameter (SD), and leaf area (LA) were assessed at 70 and 100 DAT; at 110 DAT, the number of fruits per plant (NFP), average fruit weight (PMF), longitudinal fruit length (LL) and fresh mass of the aerial part (MFPA) were assessed.

Plant height (PH) was measured using a graduated ruler, while stem diameter (SD) was measured using a digital caliper. Plant height was determined from the base of the stem to the apex of the shoot, and stem diameter was measured at 2 cm from the ground. These assessments were carried out at 70 and 100 days after transplanting (DAT); Leaf area (LA) was estimated non-destructively using a portable leaf area meter (LI-3100 model from LI-COR) at 70 and 100 DAT; Number of fruits per plant (NFP) was counted manually on each plant at 110 DAT, considering all the fully developed fruits; Average fruit weight (PMF) was obtained from the average individual weight of the fruit harvested per plant, using a precision scale; Longitudinal fruit length (LL) was measured with a digital caliper, taking into account the distance between the base and the apex of the fruit, at 110 DAT, finally, the fresh mass of the aerial part (MFPA) was determined after harvesting the fruit, at 110 days after transplanting (DAT). The plants were cut at ground level, separating the aerial part (leaves, stem, and branches). The material was weighed immediately on a digital scale with a precision of 0.01 g to obtain the fresh mass of the aerial part of each plant.

The data were subjected to the Shapiro-Wilk test to verify normality, the F test in the analysis of variance (ANOVA), all at 5% probability, and also regression analysis for irrigation regimes and hydrogel doses, using SISVAR 5.6 software (Ferreira, 2019).

3 Results and discussion

The variables analyzed in the experiment had significant effect ($p < 0.01$) from the water regimes adopted in the treatments: (PH) (Figure 1a and 1b) at 70 and 100 DAT, while the hydrogel treatment exerted a significant effect ($p < 0.05$) on the PH of bell pepper only at 100 DAT (Figure 1c), it is worth noting that there was no significant interaction between the water regime and the hydrogel for that variable at 70 and 100 DAT.

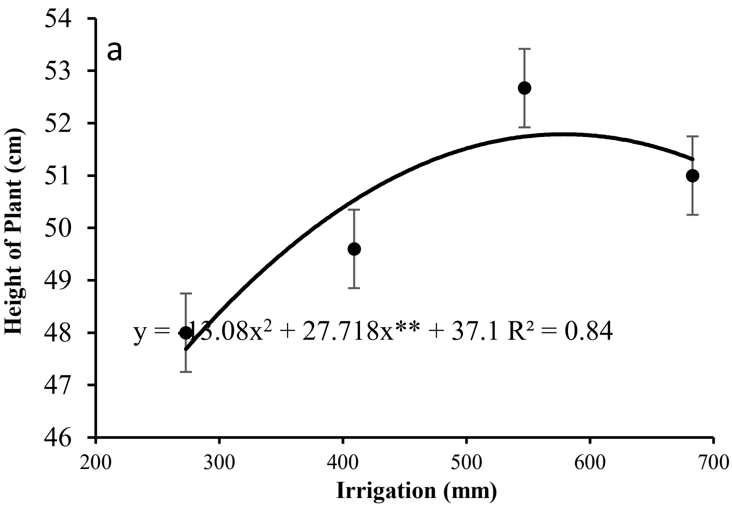
At 70 DAT (Figure 1a), the highest PH was 51.7 cm for an irrigation regime corresponding to 579.5 mm (105% of ETc), while at 100 DAT the plants showed a linear increase as the irrigation regimes increased, with an increase of around 20.86%, reaching the highest PH (69.7 cm) for a water regime of 683.1 mm (Figure 1b).

These results are higher than those found by Matos Filho et al. (2020) when studying the development of bell pepper as a function of irrigation levels and doses of hydrogel, who found a maximum height of 34.4 cm at 90 DAT when they applied 494.2 mm (83.3% of the ET_{actual}). In the present study, when the plants were measured at 100 DAT, the lowest height (57.5 cm) was observed for the 273.2 mm water regime (50% of *ETc*), but according to Besharati et al. (2021), this reduction in growth is due to the adaptation mechanism to the conditions of the water regime to which they were subjected. In addition, at this time, the plants with thicker/wider leaves were also visually observed to be "diseased" for that treatment, i.e. attacked by a bacterial disease, but without affecting the phytomass production of the aerial part. It should be noted that at 100 DAT the hydrogel promoted an increase of 2.78 cm for each increase in the dose of hydrogel, resulting in an increase of 10.4% compared to the plants that did not use hydrogel (Figure 1c).

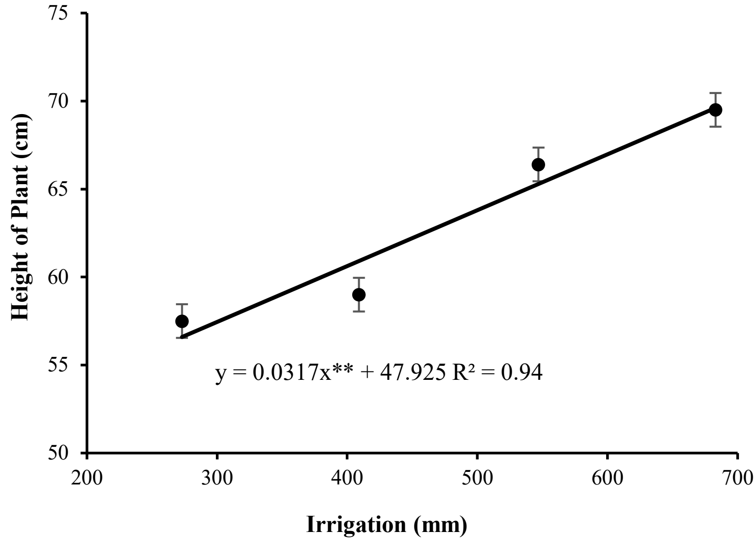
Thus, in the different stages of plant growth, it is important to know the effect of water (rain/irrigation) on the growth of cultivated plants and their yields (Doorenbos and Kassam, 1994) since in the semi-arid region, irregular rainfall is common, which limits and compromises the development of peppers and other cultivated plants. From the behavior of the plants, the hydrogel seems to be relevant to plant growth since the peppers responded to the effects of using hydrogel associated with irrigation regimes, influencing the height and stem diameter of the bell pepper.

There was no influence of the water regimes ($p \geq 0.05$) on the stem diameter (SD) of the bell pepper at 70 and 100 DAT, whose averages were 14.72 and 14.91 mm, respectively, but there was a significant effect of the application of hydrogel alone on the diameter at 70 DAT (Figure 2), which resulted in an increase of 6.83% compared to the control dose. Souza et al. (2019) also observed no statistical difference for the Stem Diameter variable of bell pepper when subjected to irrigation frequency and levels.

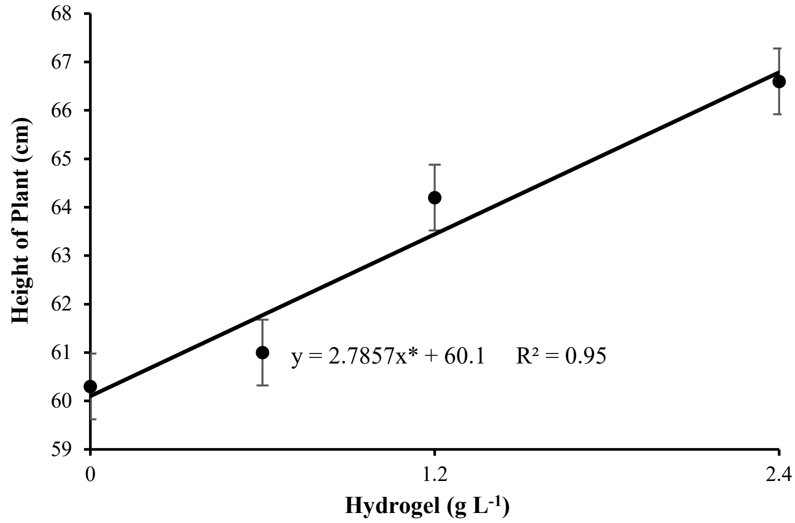
It is worth noting that the leaf area (LA) variable of the bell pepper followed the same trend as the PH, i.e. it was influenced by irrigation at 70 and 100 DAT ($p < 0.01$), and there was also a significant influence of the hydrogel alone ($p \geq 0.05$). At 70 DAT, the increase in the analyzed variable was 32.9% compared to the lowest water regime (273.2 mm), and the highest LA value was 14.2 cm^2 for the highest water regime applied, which was 683.1 mm (Figure 3a). At 100 DAT (Figure 3b), there was also a 32.9% increase compared to the lowest water regime (273.2 mm). However, about the application of the hydrogel, it was at 100 DAT that the dose of 1.57 g L^{-1} promoted the maximum leaf area of 41.2 cm^2 (Figure 3c). In these phases, the plant needs a greater amount of available water to properly promote leaf expansion, consequently regulating photosynthetic processes and resulting in greater production of photo assimilates, with the highest value being 41.2 cm^2 in the hydrogel treatment, i.e. the polymer performed its function of making water available when the plant needed it.



(a) Height of bell pepper plants subjected to water regimes at 70 DAT



(b) Height of bell pepper plants subjected to water regimes at 100 DAT



(c) Doses of hydrogel at 100 DAT in the open field

Figure 1 Average values

Note: *, ** significant at 5% and 1% probability levels using the t-test, respectively.

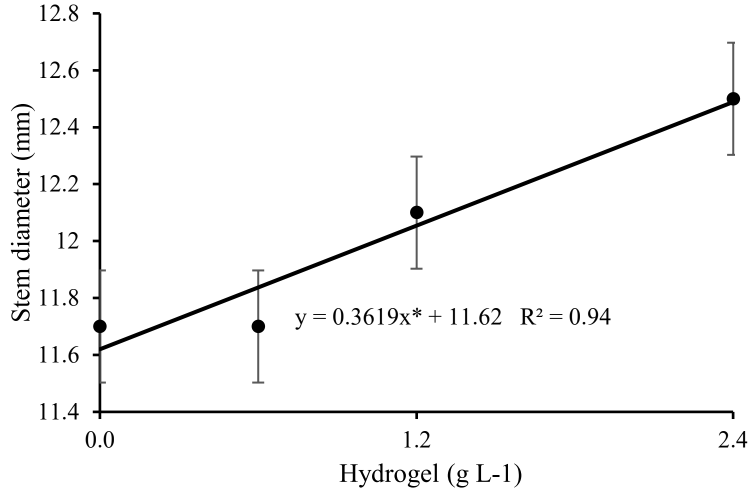


Figure 2 Stem diameter of bell pepper plants subjected to doses of hydrogel at 70 DAT in the open field.

Note: * Significant at the 5% probability level using the t-test.

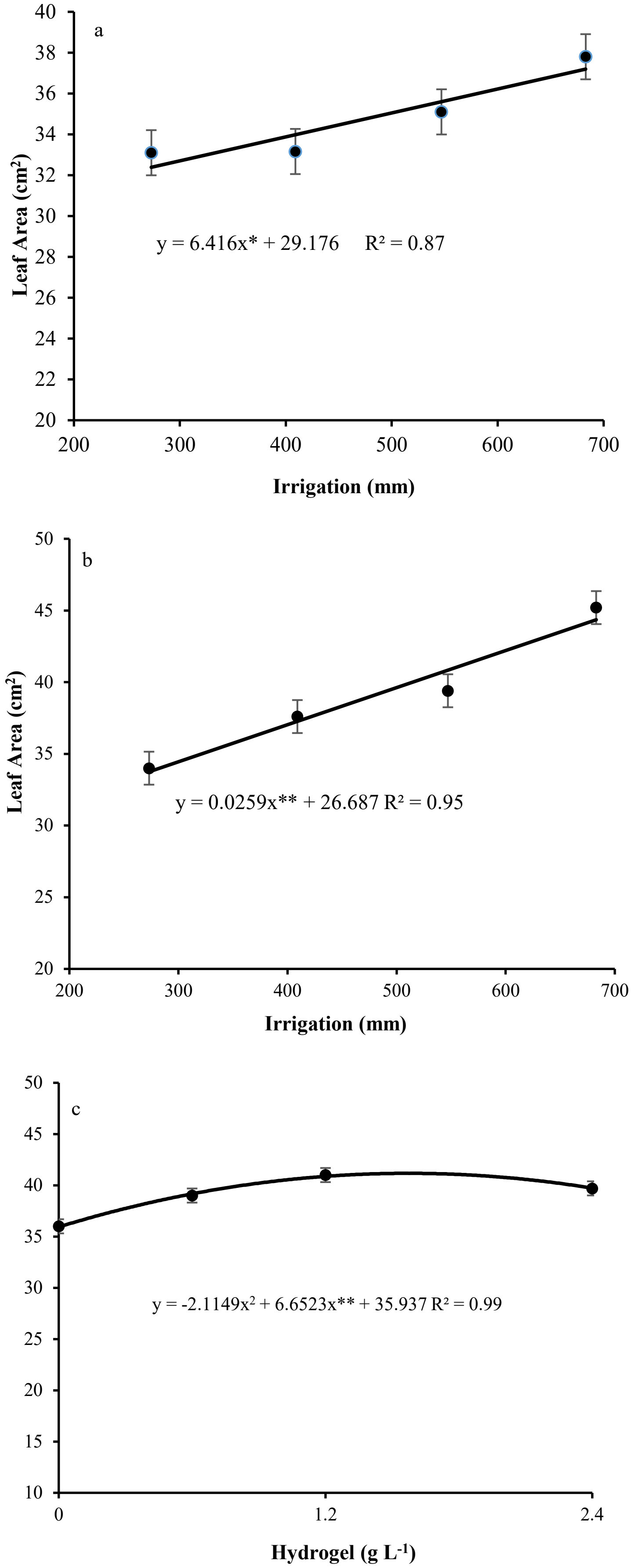


Figure 3 Leaf area of bell pepper plants subjected to water regimes at 70 and 100 DAT (Figures a and b) and doses of hydrogel at 100 DAT (Figure c) in the open field

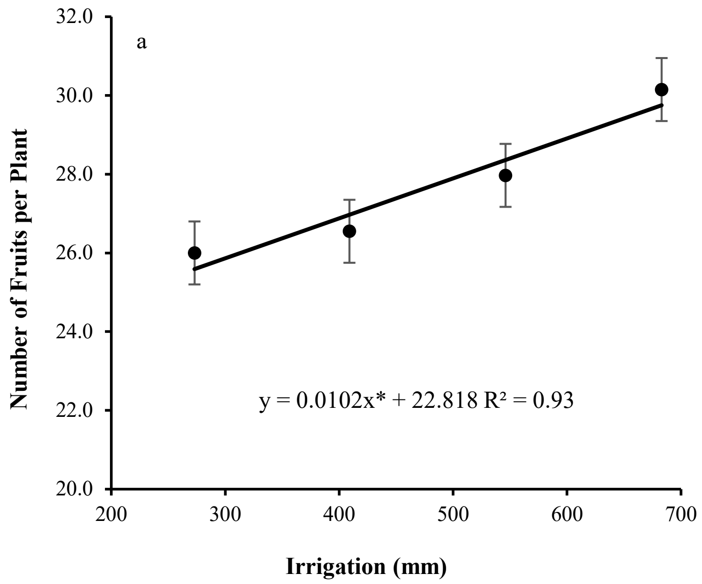
Note: *, ** significant at 5% and 1% probability levels using the t-test, respectively.

Considering that at 100 DAT the plants that received the hydrogel had greater PH growth (Figure 2c), indicating that the hydrogel acted favorably on the height and leaf area of the bell pepper plants. Padrón et al. (2015) stated that the hydrogel can influence morphological characteristics such as PH, LA, and NFP due to the increase in water availability by the polymer. According to Beniwal et al. (2010), hydrogel-treated soil can mitigate the effects of some stress on plants, while Navroski et al. (2016) add that hydrogel added to the soil allows for greater real water capacity in the system.

As for the effects of hydrogel on leaf area, whose behavior is similar to that found by Besharati et al. (2021), in Roselle plants (*Hibiscus sabdariffa* L.) under drought conditions and using hydrogel, the authors report that there was a significant increase in LA with the application of hydrogel. This may be related to the fact that the hydrogel helps keep water in the soil for longer, thereby increasing water storage in the root zone and, consequently, making the plant more tolerant to drought (Menezes et al., 2024). Similar results were also observed by Carvalho et al. (2013), in passion fruit seedlings, where the authors found that there was an increase in the leaf area of seedlings grown with the hydrogel for all irrigation intervals, compared to seedlings without the addition of the hydrogel. It appears that using 1.57 g of hydrogel could have a significant effect on the expansion of the bell pepper leaf, thus benefiting photosynthetic processes and increasing phytomass production.

The water regimes alone had an influence ($p < 0.05$) on NFP at 110 DAT (Figure 4a). The hydrogel alone also influenced ($p \leq 0.01$) the NFP (Figure 4b). The increase in irrigation levels led to a linear increase of 14.1% in NFP, compared to the water regime of 50% of ETc (273.2 mm), reaching a total of 31.1 fruits per plant in the regime of 125% of *ETc* (683.1 mm). As for the doses of hydrogel on NFP, there was an increase of 2.0 fruits for each dose, with 2.4 g of hydrogel resulting in 30.1 fruits per plant. Thus, it is possible to understand that increasing irrigation regimes and increasing doses of hydrogel favor the increase in NFP of Dahra RX bell pepper.

These results differ from those found by Matos Filho et al. (2020), since, in irrigation levels associated with doses of hydrogel in bell pepper, the maximum was 5.7 fruits per plant for the water regime corresponding to 80% of the ET_{actual} (474.6 mm) at 100 DAT and without significance for the hydrogel, according to these authors. In a study on the application of biofertilizers at different times to bell pepper, Leal et al. (2020) found an average of 14.3 fruits per plant when fertilized with bovine biofertilizer. This superiority of NFP in the present study is due to the improved use of hydrogel, reflecting the increase in productivity.



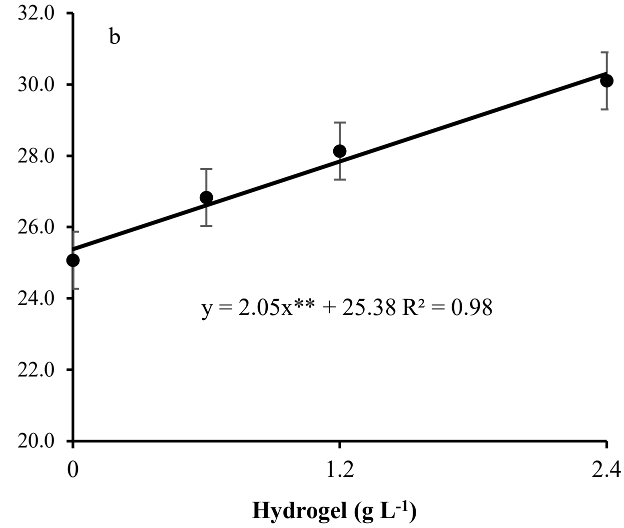
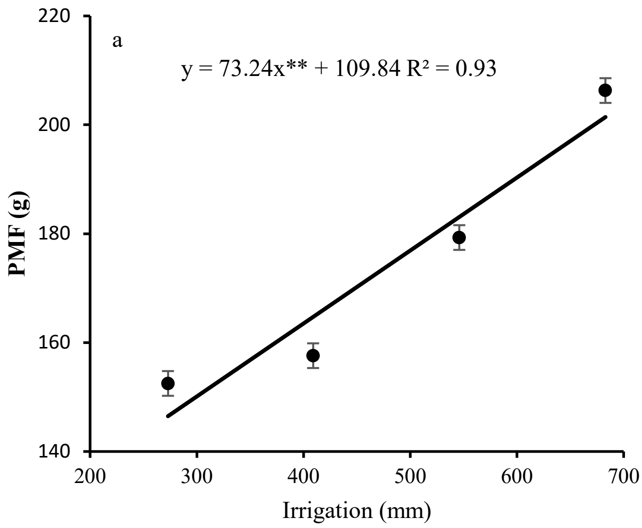


Figure 4 Number of fruits per plant (NFP) of bell pepper counted at 110 DAT in the open field and subjected to different water regimes (Figure a) and doses of hydrogel (Figure b)

Note: **, * significant at the 1% and 5% probability levels using the t-test, respectively.



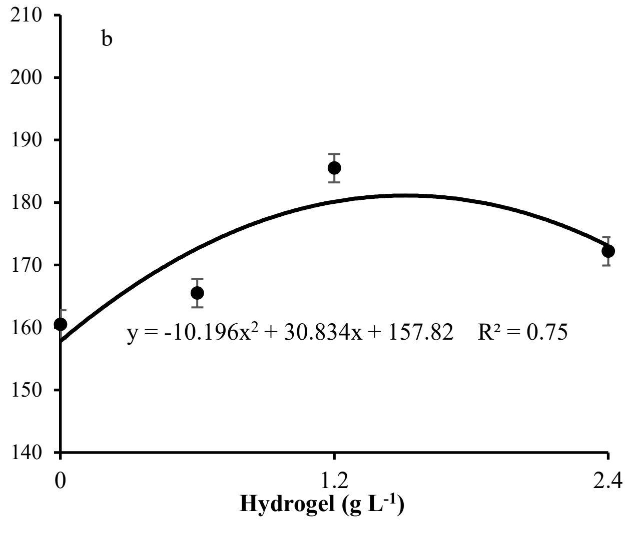


Figure 5 Average values: a - Average fruit weight (PMF) of bell peppers at 110 DAT subjected to different water regimes; b - Average fruit weight (AFW) of bell peppers at 110 DAT subjected to different doses of hydrogel. **, * significant at t-test level, respectively.

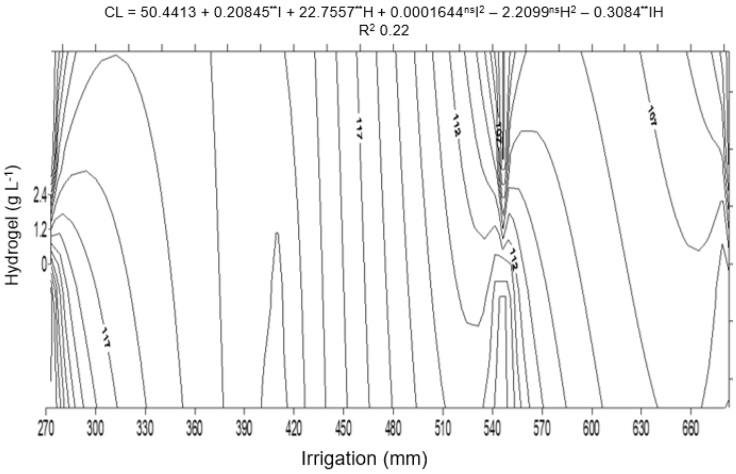


Figure 6 Effect of the interaction between irrigation regimes and hydrogel doses on longitudinal length (LL) at 110 DAT in bell pepper plants in the open field

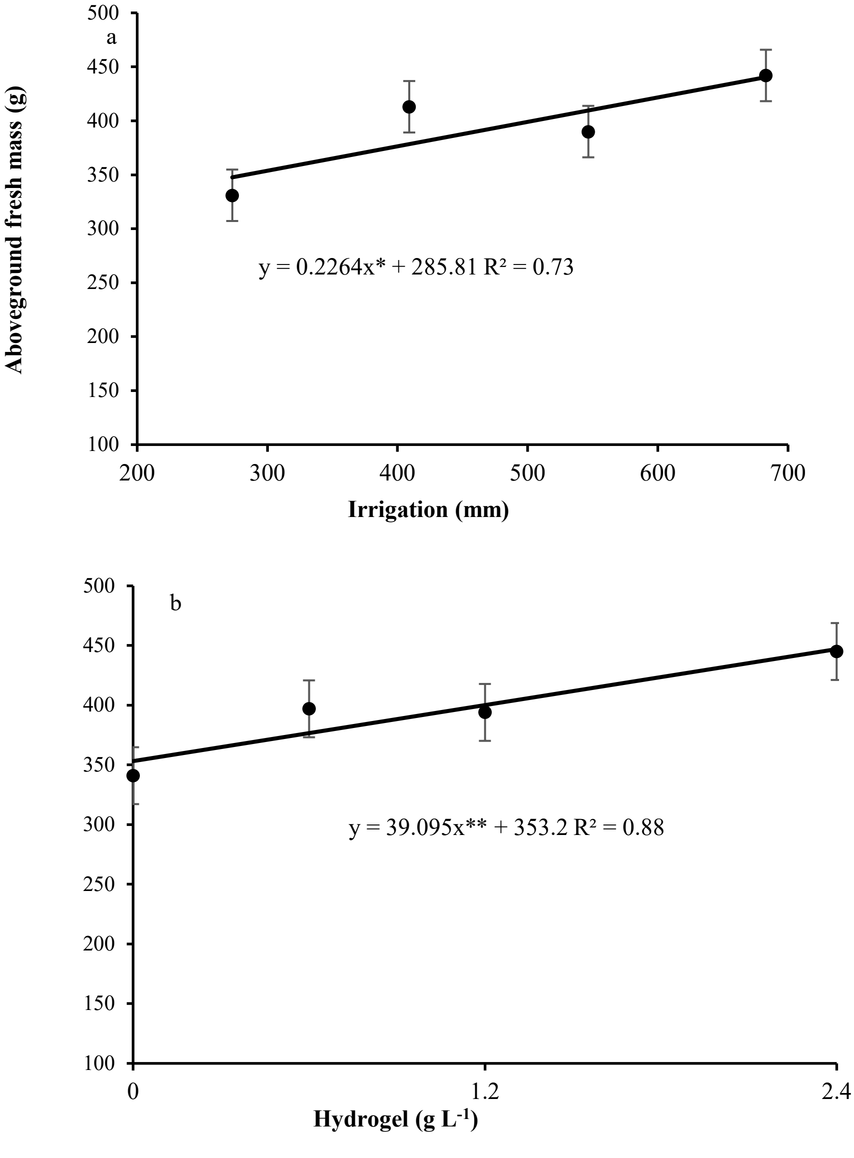


Figure 7 Average values: a - Fresh mass of the aerial part (MFPA) of bell pepper plants at 110 DAT subjected to different water regimes; b - Fresh mass of the aerial part (MFPA) of bell pepper plants at 110 DAT subjected to different doses of hydrogel.

Note: *, ** significant at the 5% and 1% probability levels using the t-test, respectively.

The isolated effect of the irrigation regimes on the average fruit weight of the bell pepper (PMF) led to an increase of 73.2 g in this variable for each increase in the irrigation regime, with a linear increase. The highest PMF (206.3 g) was observed in the water regime corresponding to 683.1 mm, with a 35.3% increase in PMF (Figure 5a). The doses of hydrogel also had a significant influence ($p \leq 0.01$) on the PMF (Figure 5b), with the maximum PMF being 181.2 g for a dose of 1.51 g of hydrogel per plant. It should be noted that increasing the availability of water in the soil favors an increase in the mass of bell pepper fruit, a fact that can lead to an improvement in the quality and final productivity of bell pepper.

The fruit of the Dahra RX studied here, according to its commercial group, can reach up to 285 g of fresh mass with the appropriate cultural treatments, so it can be seen that the results of this study were close to the ideal weight stated by the supplier, but the average weight of the fruit from both the irrigation regimes and the hydrogel is accepted on the market for sale, according to CEAGESP (2015).

These findings may be associated with the genetic characteristics of this cultivar, the irrigation management adopted, and fertilization, in addition, the PMF is higher than those found by Pimenta et al. (2016) in a study comparing conventional and organic systems in which the average weights were 101.44 g and 101.92 g, respectively. In addition, Leal et al. (2020), evaluating fruit morphology as a function of the use of biofertilizer, reported a lower average weight (100 g) than this study. However, like most vegetables, the cultivation of bell pepper depends on the regular distribution of water during its cycle (Marouelli and Silva, 2012), as well as adequate cultural treatments such as weeding and fertilization, as was done in this study.

There was also a significant interaction ($p < 0.05$) between the irrigation regimes and hydrogel doses for LL. Based on this interaction (Figure 6), there was a trend towards higher LL values for the higher irrigation regimes, with the highest LL observed with the application of a 437.1 mm water regime and a dose varying between 1.0 – 2.1 g plant^{-1} of hydrogel, resulting in a maximum LL of 119.8 mm, while the lowest LL was 95.1 mm at the lowest irrigation regime (273.2 mm) in the absence of hydrogel. The behavior of LL is similar to the results obtained by Aragão et al. (2012), who also observed a significant effect for the interaction between the same irrigation regimes tested here and nitrogen doses, and found that there was a trend towards higher LL for lower water regimes associated with higher nitrogen doses. These findings corroborate those of Silva et al. (2017), who reported that the highest morphometric values of bell pepper fruit were observed with the highest irrigation regime in a drip system. It should be noted that the LL of the bell pepper obtained in this study, which is classified by the Brazilian Ministry of Agriculture, are commercial fruits, as their length is ≥ 60 mm and diameter ≥ 40 mm.

There was an isolated effect of irrigation regimes and hydrogel, which had a significant influence ($p < 0.05$ and $p < 0.01$) on the production of fresh mass of the aerial part (MFPA). The increase in fresh shoot mass was proportional to the increase in irrigation regimes, with a rise of approximately 33.5% compared to the lowest accumulated irrigation regime (273.2 mm), reaching a maximum value of 442.1 g in the 683.1 mm water regime (Figure 7a). The same behavior was observed for the doses of hydrogel in the MFPA, with an increase of 39 g for each increase in the dose of polymer in the form of hydrogel, reaching 445 g of MFPA of the bell pepper at 110 DAT, corresponding to an increase of 30.5% of the control dose (Figure 7b).

The data show that no severe or moderate water stress could negatively affect the growth of the Dahra RX bell pepper plants, indicating that the hydrogel regulated the availability of water to the plants. Generally, when plants are exposed to deficient water stress, especially during the growth phase, there is a reduction in the photosynthetic process and various other metabolic processes, such as the water content in the cells. This was not the case in this study since stomatal conductance (gs) and productivity were not affected. This behavior reinforces the positive influence of the hydrogel on phytomass production associated with different water regimes.4 Conclusions

The results showed that the use of hydrogel in the cultivation of bell pepper in under-irrigation regimes allows vegetative growth to occur normally. In addition, it provided a greater number of fruits in the hydrogel, including better productivity of the bell pepper crop in the open field, indicating an alternative to its use associated with deficit irrigation in the case of regions with water restrictions for irrigation.

To define the level of irrigation and dose of hydrogel to provide economically sustainable higher yields, it is recommended to use higher fractions of water replacement and higher doses of hydrogel for Dahra RX bell pepper.

References

Alvares, C. A., J. L. Stape, P. C. Sentelhas, J. L. M. Gonçalves, and G. Sparovek. 2014. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22(6): 711-728.

Aragão, V. F., P. D. Fernandes, R. R. Gomes Filho, C. M. Carvalho, H. O. Feitosa, and E. O. Feitosa. 2012. Produção e eficiência no uso de água do pimentão submetido a diferentes lâminas de irrigação e níveis de nitrogênio. *Revista Brasileira de Agricultura Irrigada*, 6(3): 207-216.

Beniwal, R. S., R. Langenfeld-Heyser, and A. Polle. 2010. Ectomycorrhiza and hydrogel protect hybrid poplar from water deficit and unravel plastic responses of xylem anatomy. *Environmental and Experimental Botany*, 69(2): 189-197.

Besharati, J., M. Shirmardi, H. Meftahizadeh, M. Dehestani Ardakani, and M. Ghorbanpour. 2021. Changes in growth and quality performance of Roselle (*Hibiscus sabdariffa* L.) in response to soil amendments with hydrogel and compost under drought stress. *South African Journal of Botany*, 145: 334-347.

Carvalho, R. P., M. C. M. Cruz, and L. M. Martins. 2013. Frequência de irrigação utilizando polímero hidroabsorvente na produção de mudas de maracujazeiro-amarelo. *Revista Brasileira de Fruticultura*, 35(2): 518-526.

CEAGESP. 2015. Norma de Classificação do Pimentão Para o Programa Brasileiro para a Melhoria dos Padrões Comerciais e Embalagens De Hortigranjeiros. Available at: https://ceagesp.gov.br/wp-content/uploads/2015/07/pimentao.pdf. Accessed 9 July 2024.

Doorenbos, J., and A. H. Kassam. 1986. Yield Response to Water, Irrigation and Drainage, Paper 33. Rome, Italy: FAO.

Doorenbos, J., and A. H. Kassam. 1994. *Efeito da água no rendimento das culturas*. Campina Grande: FAO.

Ekebafe, L. O., D. E. Ogbeifun, and F. E. Okieimen. 2011. Polymer applications in agriculture. *Biokemistri*, 23(2): 81-89.

El-Idrissi, A., O. Dardari, F. N. N. N. Metomo, Y. Essamlali, A. Akil, O. Amadine, S. Aboulhrouz, and M. Zahouily. 2023. Effect of sodium alginate-based superabsorbent hydrogel on tomato growth under different water deficit conditions. *International Journal of Biological Macromolecules*, 253(5): 127229.

EMBRAPA. 2017. Empresa Brasileira de Pesquisa Agropecuária. *Manual de métodos de análises de solo*. 3ed. Rio de Janeiro.

Fathi, A., and D. B. Tari. 2016. Effect of Drought Stress and its Mechanism in Plants. *International Journal of Life Sciences*, 10(1): 1-6.

Ferreira, D. F. 2019. SISVAR: a computer analysis system to fixed effects split plot type designs. *Revista Brasileira de Biometria*, 37(4): 529-535.

Hatfield, J. L., and C. Dold. 2019. Water-Use Efficiency: advances and challenges in a changing climate. *Frontiers in Plant Science*, 10(8): 103.

IPECE. 2017. Instituto de Pesquisa e Estratégia Econômica do Ceará. *Perfil municipal 2017 de São Benedito*, Ano I, Fortaleza, 17p.

Leal, Y. H., J. G. Moura, T. I. Silva, T. J. Dias, M. P. S. Leal, and J. E. S. Ribeiro. 2020. Yield and morphological attributes of bell pepper fruits under biological fertilizers and application times. *Revista Ceres*, 67(5): 374-382.

Lopes, S. M., E. Alcantra, R. M. Rezende, and A. S. Freitas. 2018. Avaliação de frutos de pimentão submetidos ao ensacamento no cultivo orgânico. *Revista da Universidade Vale do Rio Verde*, 16(1): 1-11.

Marouelli, W. A., and W. L. C. Silva. 2012. *Irrigação na cultura do pimentão*. Circular Técnica 101. Brasil: Embrapa Hortaliças.

Matos Filho, H. A., C. A. Silva, and A. V. S. Bastos. 2020. Níveis de irrigação associados a doses de hidrogel na cultura do pimentão. *Revista Brasileira de Agricultura Irrigada*, 14(2): e3906.

Menezes, A. S., L. G. Pinheiro Neto, E. A. Bastos, D. E. O. Ramos, T. V. A. Viana, C. H. C. Sousa, R. V. Façanha, and F. G. N. Lopes. 2024. Water regimes and hydrogel applied on bell pepper grown in a protected environment. *Pesquisa Agropecuária Brasileira*, 59: e03566.

Navroski, M. C., M. M. Araújo, O. M. Pereira, and C. S. Fior. 2016. Influência do polímero hidroretentor nas características do substrato comercial para produção de mudas florestais. *Interciencia*, 41(5): 357-361.

Padrón, R. A. R., L. R. Ramírez, R. R. Cerquera, H. M. C. M. Nogueira, and J. L. U. Mujica. 2015. Desenvolvimento vegetativo de pimentão cultivado com lâminas e frequências de irrigação. *Tecnologia & Ciência Agropecuária*, 9(2): 49-55.

Pimenta, S., D. Menezes, D. G. Neder, R. A. Melo, A. L. R. Araujo, and E. A. Maranhão. 2016. Adaptability and stability of pepper hybrids under conventional and organic production systems. *Horticultura Brasileira*, 34: 168-174.

Silva, A. R. A., F. M. L. Bezerra, C. C. M. Sousa, J. V. Pereira Filho, and C. A. S. Freitas. 2011. Desempenho de cultivares de girassol sob diferentes lâminas de irrigação no Vale do Curu, CE. *Revista Ciência Agronômica*, 42(1): 57-64.

Souza, Á. H. C., R. Rezende, M. Z. Lorenzoni, F. A. S. Santos, and J. M. Oliveira. 2019. Response of bell pepper to water replacement levels and irrigation times. *Pesquisa Agropecuária Tropical*, 49: e53662.

Taiz, L., E. Zeiger, I. M. Møller, and A. Murphy. 2017. *Fisiologia e desenvolvimento vegetal*. 6th ed. Porto Alegre: Artmed.

Yang, H., T. Du, R. Qiu, J. Chen, F. Wang, Y. Li, C. Wang, L. Gao, and S. Kang. 2017. Improved water use efficiency and fruit quality of greenhouse crops under regulated deficit irrigation in northwest China. *Agricultural Water Management*, 179: 193-204.