ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.11, p.807-814, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n11p807-814

Hydrogel as mitigator of salt stress during the establishment of *Tagetes patula* L. seedlings[1]

Hidrogel como mitigador do estresse salino durante o estabelecimento de mudas de *Tagetes patula* L.

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HIGHLIGHTS:
- *Hydrogel favors the mitigation of salt stress in* Tagetes patula *L.*
- *Hydrogel reduces thermal stress in the leaves.*
- *Hydrogel increases the production of biomass in seedlings of* Tagetes patula *L.*

ABSTRACT: Hydrogels favor moisture retention in the substrate and can attenuate the effects of salt stress on the production of potted plants. In this context, this research sought to evaluate the use of hydrogel to mitigate the damage caused by the salinity of irrigation water on the emergence, growth, and thermal index of *Tagetes patula* L. seedlings. The research was carried out in a greenhouse, in September 2020, in the municipality of Fortaleza, Ceará State, Brazil. The design used was randomized blocks in a split plot. The plots corresponded to seven levels of electrical conductivity of the irrigation water - ECw (0.5, 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 dS m^{-1}) and the subplots corresponded to four hydrogel concentrations (0, 1.0, 2.0, and 3.0 g L^{-1}), with five replicates and each subplot consisted of 27 seeds. The application of 3.0 g hydrogel L^{-1} of substrate favored the production of leaves and reduced the thermal index in plants associated with the increase in the salinity of the substrate up to 6.0 dS m^{-1}. The use of 3.0 g L^{-1} hydrogel increases seedling height, leaf dry mass, and total dry mass compared to treatments without water-retaining polymer, even at moderate (2.0 to 3.0 dS m^{-1}) and high (4.0 to 6.0 dS m^{-1}) salinity levels, thus indicating a possible effect of mitigation of damage caused by the salinity of the irrigation water. However, the intensity of this mitigating effect decreases at higher levels of salt stress.

Key words: ornamental, brackish water, emergence, polymer

RESUMO: Os hidrogéis favorecem a retenção de umidade no substrato e podem atenuar os efeitos do estresse salino na produção de plantas em vaso. Nesse contexto, buscou-se avaliar o uso do hidrogel para mitigar os danos causados pela salinidade da água de irrigação na emergência, crescimento e índice térmico de mudas de *Tagetes patula* L. A pesquisa foi realizada em casa-de-vegetação, em setembro de 2020, no município de Fortaleza, estado do Ceará, Brasil. O delineamento utilizado foi em blocos casualizados em parcelas subdivididas. As parcelas corresponderam a sete níveis de condutividades elétricas da água de irrigação - CEa (0,5, 1,0, 2,0, 3,0, 4,0, 5,0 e 6,0 dS m^{-1}) e as subparcelas corresponderam a quatro concentrações de hidrogel (0, 1,0, 2,0 e 3,0 g L^{-1}), com cinco repetições e cada subparcela foi composta por 27 sementes. A aplicação de 3,0 g de hidrogel L^{-1} de substrato favoreceu a produção de folhas e reduziu o estresse térmico nas plantas associado ao aumento da salinidade do substrato até 6,0 dS m^{-1}. A utilização de 3,0 g L^{-1} de hidrogel incrementou a altura das plântulas, massa seca da folha e massa seca total em comparação aos tratamentos sem o polímero retentor de água, mesmo em níveis moderados (2,0 a 3,0 dS m^{-1}) e altos de salinidade (4,0 a 6,0 dS m^{-1}), indicando assim possível efeito mitigador dos danos causados pela salinidade da água de irrigação. Entretanto, a intensidade desse efeito mitigador deminui nos maiores níveis de estresse salino.

Palavras-chave: ornamental, água salobra, emergência, polímero

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• Ref. 260996 – Received 12 Feb, 2022
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• Accepted 24 Jun, 2022 • Published 07 July, 2022
Editors: Geovani Soares de Lima & Hans Raj Gheyi

INTRODUCTION

The Brazilian northeast has more than 50% of its territory with a semi-arid climate, characterized by irregularity of rainfall and long periods of drought (Silva et al., 2022). In this region it is common to find sources of brackish water, which can be used for irrigation of gardens and landscaping, hence serving as a water alternative during periods of low availability of freshwater (Bezerra et al., 2020).

However, choosing salt-tolerant plants and using management techniques are extremely important (Oliveira et al., 2018). Saline water can affect plant development and quality due to nutritional imbalance and phytotoxicity (Taiz et al., 2017; Braz et al., 2019). Concerning ornamental plants, this fact can hinder commercialization, because the ornamental plant market prioritizes the choice of resistant and good quality seedlings (Bezerra et al., 2020; Lacerda et al., 2020).

Seedlings of ornamental plants should be produced under adequate temperature and substrate (Figueiredo et al., 2019), and two or more materials should be used for the production of a good substrate (Lima et al., 2020). In addition, it is recommended to use soil conditioners, which after being incorporated into the substrate have the capacity to improve physical, physico-chemical, and biological properties (Teixeira et al., 2019).

Hydrogel is a soil conditioner that can optimize the use of fertilizers by retaining and making available a greater concentration of macronutrients in the substrate, promoting greater plant development (Navroski et al., 2015). In addition, the maintenance of moisture in the root zone of plants, under the influence of hydrogel (Neves et al., 2021), may favor the dilution of salts and absorption of water (Lessa et al., 2019), making the water-retaining polymer a possible mitigator of salt stress. In this context, the objective was to evaluate the use of hydrogel to mitigate the damage caused by the salinity of irrigation water on the emergence, growth, and thermal index of *Tagetes patula* L. seedlings.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse covered with low-density polyethylene film, 80% transparency to solar radiation, located in the experimental area of the Agrometeorological Station of the Universidade Federal do Ceará, in the municipality of Fortaleza (3º 44' 44" S; 38º 34' 50" W, 19 m altitude), Ceará State, Brazil. Air temperature and relative humidity data were obtained with a HOBO® temp/RH/light/external data logger, programmed to record every 30 min. The mean air temperature was 25.2 °C, ranging from 33.0 to 20.1 °C, while the mean relative humidity was 63.5% ranging from 86.7 and 42.0%, according to Figure 1. The photoperiod was approximately 12 hours.

The experimental design adopted was randomized blocks in split plots with five replicates. The plots were composed of seven levels of electrical conductivity of irrigation water - ECw (0.5, 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 dS m^{-1}) and the subplots corresponded to four hydrogel concentrations (0, 1.0, 2.0, and 3.0 g L^{-1}), with five replicates. Each plot consisted of a tray divided into four equal parts and each subplot consisted of 27 cells, totaling 140 experimental units and 3,780 observational units.

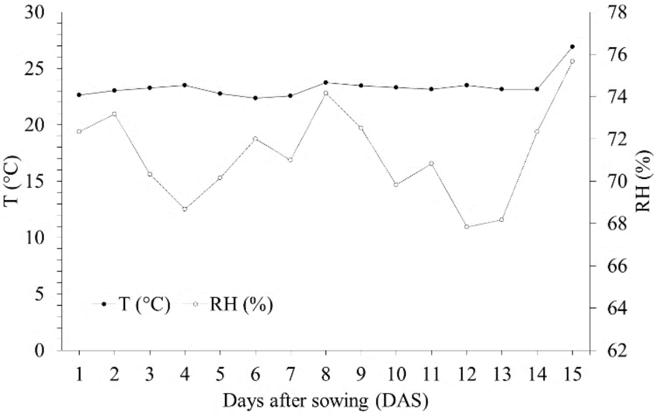


Figure 1. Mean temperature (°C) and relative humidity of air (%) during the experimental period

Saline water levels were obtained by dissolution of NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts, in an equivalent proportion of 7:2:1, following the relationship between ECw and their concentration ($mmol_c L^{-1}$ = ECw × 10) according to Richards (1954). The proportion of salts used in the water is an approximate representation of cations present in groundwater in the Brazilian semi-arid region. The ECw of 0.5 dS m^{-1} was obtained by mixing groundwater (ECw of 0.8 dS m^{-1}) from a shallow well located in the experimental area and stored rainwater (ECw of 0.1 dS m^{-1}).

The hydrogel concentrations in the substrate were obtained by homogenizing the substrate with dry Polyter® hydrogel, obtaining concentrations of 1.0, 2.0, and 3.0 g L^{-1}. The substrate consisted of a mixture of arisco (light-textured sandy material normally used in constructions in Northeast Brazil) and earthworm humus in the proportion of 4:2 (v:v). The electrical conductivity measured in the saturation extract of substrate was 1.66 dS m^{-1}.

The ornamental plant used was *Tagetes patula* L. (French marigold), classified as an annual shrub and often found in landscaping, gardens, and interior decoration of tropical regions and classified as moderately sensitive to salinity (Bezerra et al., 2020). The seeds were acquired from the Isla Seeds© company. Sowing was performed with one seed per cell, in substrate previously moistened with the respective salt concentrations. Irrigation was performed by applying 300 mL of water in each experimental unit every two days, in order to maintain the substrate at maximum water storage capacity.

One day after sowing, the number of emerged seedlings began to be counted until stabilization (12 days after sowing - DAS), using the emergence of expanded cotyledon leaves as a criterion. The variables analyzed were emergence speed index (ESI), emergence percentage (EP) (Maguire, 1962), number of living plants at the end of the experiment (NLP), mean speed of emergence (MSE) (Carvalho & Carvalho, 2009) and mean time of emergence (MTE) (Labouriau, 1983).

At 15 DAS (seedling stage), measurements of the seedling's height and radicle length, as well as manual counting of the number of fully expanded leaves were performed. Then, the fresh mass of leaves, stems, and roots was obtained on a precision scale and placed in paper bags properly identified and deposited in a forced-air circulation oven at 65 °C, to obtain the dry mass of leaves and total dry mass (leaves, stem, and root).

Canopy temperature (Tcanopy) was obtained through thermal image capture using the FLIR ONE PRO® thermographic camera. The readings were performed at 15:00 hours, without cloud shading, at 15 DAS, and at a distance of 1.0 m from the plants. The thermographic camera has thermal sensitivity between -20 and 120 °C, with an accuracy of ± 3 °C and a thermal resolution of 160 × 120 pixels. Thermal images were analyzed in FLIR Tools software to obtain the mean canopy temperature. Air temperature (°C) was obtained using a thermo-hygrometer (THAL-300 model) positioned on each tray. After obtaining these data, the thermal index (ΔT) was estimated by the difference between canopy temperature and air temperature (Eq. 1).

$$\Delta T = \text{Tcanopy} - \text{Tair} \quad (1)$$

The data were subjected to analysis of variance by the F test at 0.05 probability level to check the existence of individual effects and interaction between water salinity and hydrogel concentration factors. Regression analysis was used to evaluate the individual effects, while the interaction was evaluated by response surface. The statistical analyses were performed using the statistical program SISVAR version 5.6 (Ferreira, 2019).

RESULTS AND DISCUSSION

The variables emergence speed index, emergence percentage, and number of living plants were influenced by water salinity factor ($p \leq 0.01$), while mean time of emergence (MTE) and mean speed of emergence (MSE) showed interaction between water salinity and hydrogel factors ($p \leq 0.01$). The variables emergence speed index (ESI), emergence percentage (EP), mean speed of emergence (MSE), and mean time to emergence (MTE) were influenced by hydrogel factor ($p \leq 0.01$) and number of living plants (NLP) obtained an average of 14.88 plants for all hydrogel concentrations.

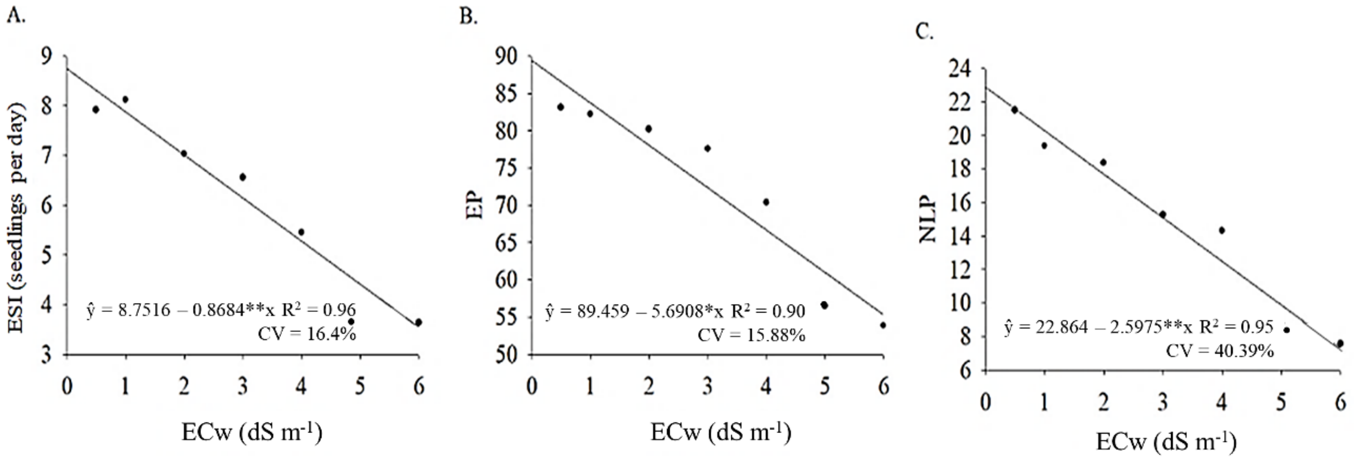
The variables ESI, EP, and NLP decreased linearly with the increase in irrigation water salinity, with reduction of less than 30% in the treatment with electrical conductivity up to 3.0 dS m^{-1} (Figure 2). ESI and EP showed unit reductions of 0.86 seedlings per day (Figure 2A) and 5.69% (Figure 2B), respectively, with reductions of 57.37 and 36.13, respectively, and 66.24% in NLP (Figure 2C) at maximum salinity (6.0 dS m^{-1}).

The increase in salinity of irrigation water delayed the soaking of seed coat by water due to the unavailability of water caused by the osmotic effect, compromising the germination process (Nogueira et al., 2020). This fact can be observed in the emergence speed and emergence percentage, which tended to decrease with the increase of salinity of irrigation water. Emergence percentage can be used as an indicator of the tolerance of species to excess salts (Nogueira et al., 2020), as the seeds remain dormant without losing viability, germinating under reduced concentrations of salt (Fanti et al., 2004).

The highest number of living plants was verified in treatments irrigated using water with ECw of 0.5 dS m^{-1} (21.56 seedlings), which tolerated salinity well up to ECw of 2.0 dS m^{-1} (17.66 seedlings), with a reduction of 18.06% according to Fageria (1985) (Figure 2C). These results were similar to those obtained by Sun et al. (2018), showing that water salinity affects plants negatively from germination to the production stage and may cause lesions in leaves, decrease in height and death in extreme cases, due to changes in metabolic processes and nutritional imbalance.

According to Dias et al. (2016), the increase in salt concentration in the substrate causes reduction in the osmotic potential of the soil and consequent reduction in water potential. Plants absorb water when the imbibition forces in the root tissue are greater than the water retention forces in the soil. The decrease in osmotic potential caused by excess salts in the soil can reach a level at which plants are not able to absorb water even in moist soil.

The combination of 1.21 g L^{-1} of hydrogel with ECw of 0.5 dS m^{-1} resulted in the maximum speed of emergence (0.32 seedlings per day). The high MSE was maintained even with the use of ECw of 3.0 dS m^{-1} combined with 1.0 g L^{-1} (0.28 seedlings per day), with a reduction of 12.17% compared to the maximum value (Figure 3A). The lowest MSE values were recorded at ECw of 6.0 dS m^{-1}, being practically equal at 0, 1.0, 2.0, and 3.0 g L^{-1} of hydrogel (0.23, 0.23, 0.23, and 0.22 per days), with reductions of 27.45, 26.78, 27.06, and 28.36%,



** *- Significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test

Figure 2. Emergence speed index-ESI (A), emergence percentage-EP (B), and number of living plants-NLP (C) of *Tagetes patula* L. as a function of the electrical conductivity of irrigation water (ECw), 15 days after sowing

respectively, compared to the MSE obtained in the control treatment (ECw of 0.5 dS m^{-1}) (Figure 3A).

Thus, the use of brackish water can affect the uniformity of the emergence of *Tagetes patula* L. seeds. According to Silva et al. (2017), when the osmotic potential of the solution decreases in comparison to the osmotic potential of embryo cells, there is a reduction in the mean speed of germination associated with excess salts in the substrate.

The shortest time required for seedlings to emerge was verified in the combination of 1.30 g L^{-1} polymer and ECw of 0.5 dS m^{-1} (3.10 days). MTE showed an intermediate value in the treatment with ECw of 3.0 dS m^{-1} combined with 1.0 g L^{-1} of hydrogel (3.97 days), with an increase of 27.75% compared to ECw of 0.5 dS m^{-1} combined with 1.0 g L^{-1} of hydrogel. The highest mean time required for the emergence of *Tagetes patula* L. seedlings was verified in the absence and presence of 3.0 g L^{-1} of hydrogel and irrigation with ECw of 6.0 dS m^{-1} (Figure 3B). The results indicate that the low concentration of hydrogel (1.0 g L^{-1}) positively influence the mean speed of emergence.

Ferraz et al. (2016) evaluated the emergence of *Tagetes patula* L., *Petunia* × *hybrid*, and *Torenia fournieri* subjected to salt concentrations of 0, 25, 50, 75, and 100 mM (0.65, 2.15, 4.31, 6.32, and 8.0 dS m^{-1}, respectively), and verified that when subjected to irrigation with 0.65 dS m^{-1} (0 mM) the species *Tagetes patula* L. required two days to emerge, while the species *Patunia* × *hybrida* and *Torenia fournieri* needed five days. However, with increasing salinity, the emergence percentage reduced by 26.0, 53.4, and 35.0% in *Tagetes patula* L., *Petunia* × *hybrida*, and *Torenia fournieri* respectively, showing that the seeds of *Tagetes patula* L. are more tolerant to salinity than the seeds of the other species tested.

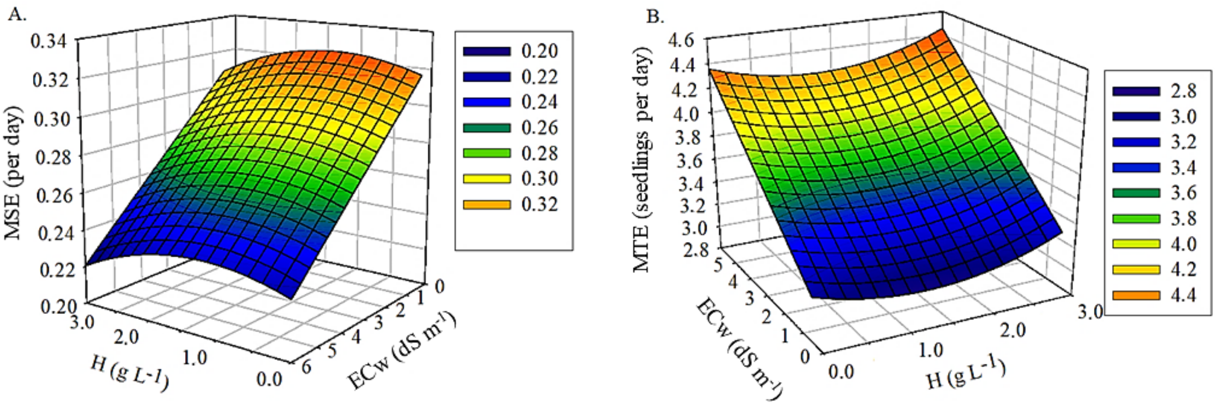
The variables seedling height, root length, leaf dry mass, and total dry mass showed significant differences caused by the interaction between water salinity and hydrogel factors ($p \leq 0.01$). For the number of leaves, there were significant differences caused by water salinity and hydrogel factors individually ($p \leq 0.01$).

For seedling height in the presence of 3.0 g L^{-1} of hydrogel, it was verified that at ECw of 2.0, 4.0, and 6.0 dS m^{-1} there were reductions in SH of 9.09, 21.22, and 33.36%, respectively, compared to ECw of 0.5 dS m^{-1}. Thus, it is observed that the highest seedling height was obtained in the presence of 3.0 g L^{-1} of the polymer with ECw of 0.5 dS m^{-1} (5.46 cm) (Figure 4A).

When comparing the seedling heights obtained at ECw of 0.5 dS m^{-1} between hydrogel concentration of 0 and 3.0 g L^{-1}, an increase of 151.81% was observed for the highest concentration. When comparing the values at ECw of 6.0 dS m^{-1} between hydrogel concentration of 0 and 3.0 g L^{-1}, an increase of 158.95% was obtained for the highest concentration. Thus, there was interaction between salinity and hydrogel treatments, and even at the highest ECw (6.0 dS m^{-1}), the hydrogel concentration of 3.0 g L^{-1} promoted an increase in height compared to the treatments without the water-retaining polymer, indicating a possible effect of mitigation of the damage caused by water salinity (Figure 4A). This result indicates that 3.0 g L^{-1} of hydrogel in the substrate was the amount that best reduced the water retention forces caused by excess salts, promoting lower energy expenditure for water absorption compared to the other treatments with water-retaining polymer (Navroski et al., 2015).

Maximum root length was obtained in the absence of hydrogel (0 g L^{-1}), followed by the concentration of 1 g L^{-1} of the water-retaining polymer (3.96 and 3.68 cm, respectively) combined with water of ECw 0.5 dS m^{-1}, reducing RL by only 11.08 and 11.94% respectively in seedlings irrigated using water with ECw of 3.0 dS m^{-1}. It is also verified that the presence of 3.0 g L^{-1} of the water-retaining polymer resulted in shorter root length (Figure 4B). Although the hydrogel concentration of 3.0 g L^{-1} favored shoot growth, it disfavored root length. This can be justified by the greater water retention in the substrate in this treatment, with no need for the plant to invest in length of root system, partitioning more carbon for shoot growth (Navroski et al., 2015).

The adhesion of the water-retaining polymer to the substrate particles, keep the substrate moist for longer period due to the storage of water in its structure (hydration), providing better conditions for the absorption of water and nutrients (Navroski

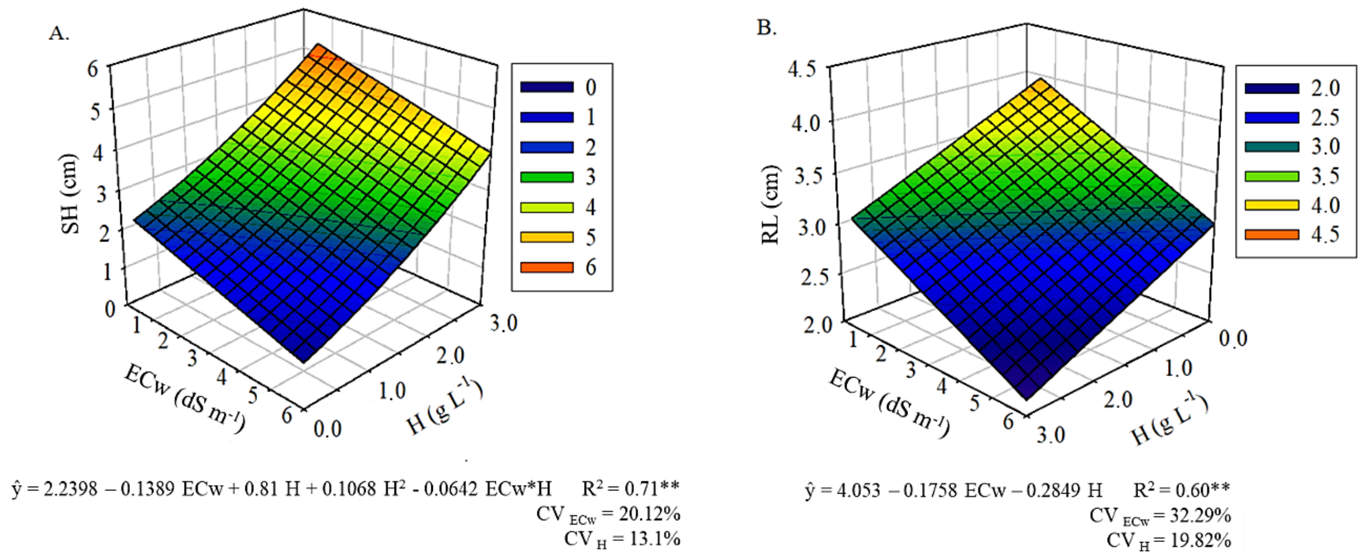


$\hat{y} = 0.32611 - 0.01588\ ECw + 0.01358\ H - 0.00566\ H^2\ R^2 = 0.60^*$
$CV_{ECw} = 8.26\%$
$CV_H = 9.83\%$

$\hat{y} = 3.205 + 0.0786\ ECw - 0.221\ H - 0.0215\ ECw^2 + 0.0850\ H^2\ R^2 = 0.62^*$
$CV_{ECw} = 8.6\%$
$CV_H = 10.64\%$

*- Significant at $p \leq 0.05$ by the F test

Figure 3. Mean speed of emergence (A) and mean time of emergence (B) of *Tagetes patula* L. as a function of the electrical conductivity of irrigation water (ECw) and hydrogel concentration (H) in the substrate



** - Significant at p≤ 0.01 by the F test

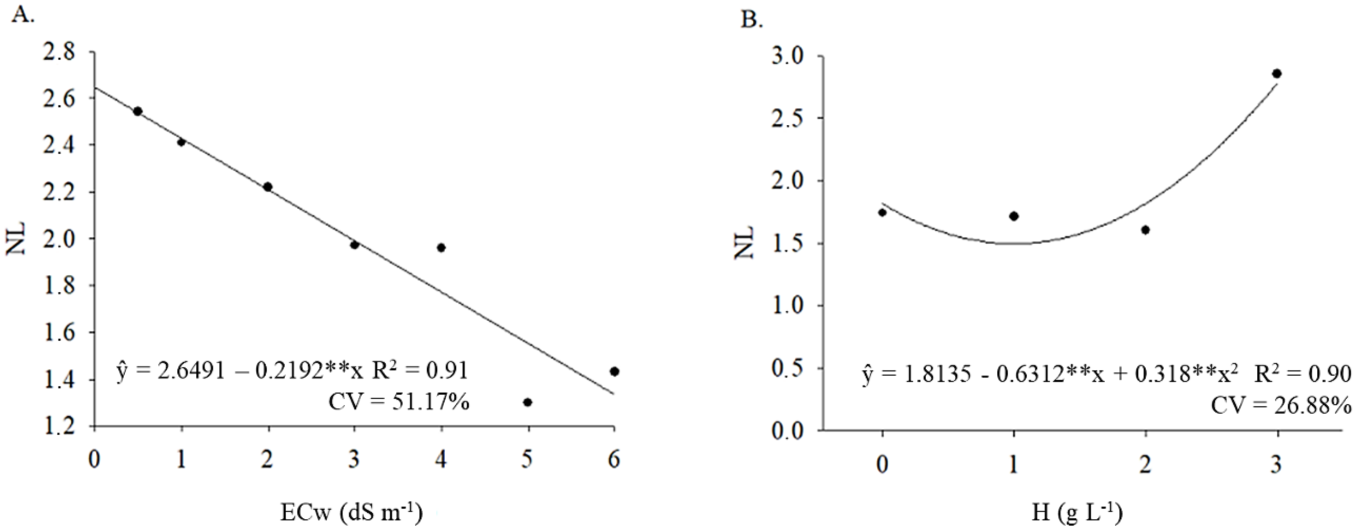
Figure 4. Seedling height (A) and root length (B) of *Tagetes patula* L. seedlings as a function of the electrical conductivity of irrigation water (ECw) and hydrogel concentration (H) in the substrate

et al., 2016). Under water deficit conditions, the reduction of growth occurs due to the greater energy expenditure for the absorption of water and nutritional elements, which may cause limitation of cell expansion due to increased water retention by the substrate (Braz et al., 2019).

Oliveira et al. (2017), studying the effects of irrigation with brackish water on ornamental plants, observed that the increase in electrical conductivity of irrigation water reduced the growth of *Catharanthus roseus*, *Allamanda cathartica*, *Ixora coccinea*, and *Duranta erecta* due to the osmotic effect and accumulation of potentially toxic ions in cells, causing a direct effect on plant metabolism when the limit of accumulation of salts in the cells was exceeded.

The number of leaves decreased linearly with the increase in irrigation water salinity (Figure 5A). The electrical conductivity of irrigation water of 0.5 dS m^{-1} led to the highest number of leaves (2.54 leaves), tolerating water salinity up to 4.0 dS m^{-1} (1.77 leaves), with a reduction of 30.21% (Figure 5A). On the other hand, regardless of water salinity treatments, the hydrogel concentration of 1.0 g L^{-1} resulted in a lower number of fully expanded leaves (1.50 leaves). The highest concentration of the water-retaining polymer (3.0 g L^{-1}) maintained positive conditions for water and nutrient absorption by the roots and distribution to the leaves, resulting in the highest NL (2.78 leaves), regardless of water salinity with an increase of 53.39% compared to the absence of the polymer (Figure 5B).

The result presented in Figure 5 is in accordance with Yonezawa et al. (2017), who showed that seedlings produced in the presence of hydrogel need to be irrigated with a volume of water appropriate to the growing conditions. Thus, the greater water availability leads to good absorption of water by the roots, which is directed to the leaves, enabling the occurrence of cell turgor and expansion. According to Dias et al. (2016), the reduction in the number of leaves in plants subjected to severe salt stress may be a consequence of the negative interference of salinity on the development of young leaves,



**- Significant at p ≤0.01 by the F test

Figure 5. Number of leaves in *Tagetes patula* L. seedlings as a function of the electrical conductivity of irrigation water (A) and hydrogel concentration (H) in the substrate (B)

consequently leading to reductions of transpiration and entry of salts through the roots.

For leaf dry mass, it was verified that at ECw of 2.0, 4.0, and 6.0 dS m^{-1} in the presence of 3.0 g L^{-1} of hydrogel there were reductions of 19.97, 39.61, and 62.25%, respectively, compared to ECw of 0.5 dS m^{-1}. Thus, the highest value of leaf dry mass was obtained in the presence of 3.0 g L^{-1} of the water-retaining polymer with ECw of 0.5 dS m^{-1} (1.46 g) (Figure 6A).

When comparing the values of leaf dry mass obtained at ECw of 0.5 dS m^{-1} between hydrogel concentrations of 0 and 3.0 g L^{-1}, an increase of 171.63% was observed for the highest concentration. On the other hand, when comparing the values obtained at ECw of 6.0 dS m^{-1} between the water-retaining polymer concentrations of 0.0 and 3.0 g L^{-1}, an increase of 32.07% was obtained for the highest concentration. Thus, it is observed that, even at the highest ECw (6.0 dS m^{-1}) the water-retaining polymer led to increase in leaf dry mass compared to treatments without the polymer, indicating a possible effect of mitigation of damage caused by salinity of water (Figure 6).

It was verified that the increase in water salinity reduces leaf dry mass, but the highest concentration of hydrogel (3.0 g L^{-1}) attenuated this effect, resulting in the highest leaf dry mass compared to the other treatments with lower water-retaining polymer concentrations, indicating a strong association between the increase in water content and the use of hydrogel, demonstrating that the greater the water availability, the greater the dry mass accumulation due to the alleviation of water deficit caused by osmotic stress. According to Navroski et al. (2015) the water availability caused by the hydrogel affects the mass accumulation in the plants, due to the proven influence on the height and stem diameter. However, high doses of the polymer increase the water retention in the substrate and can reduce the aeration of the root medium.

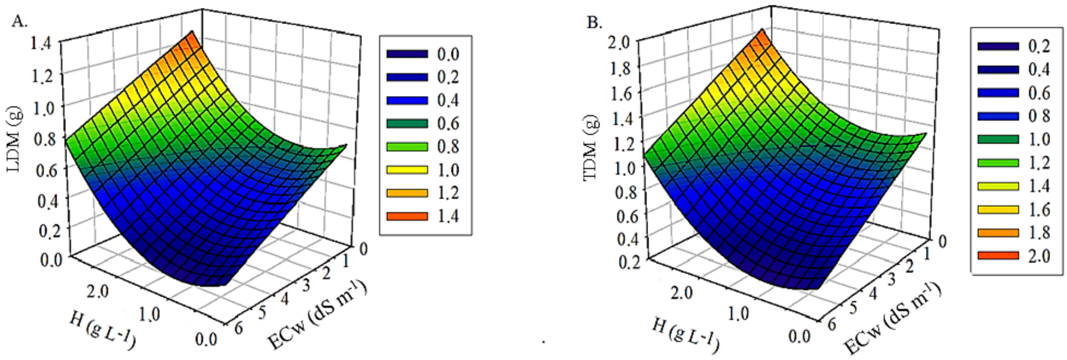
For total dry mass, it was verified that, at ECw of 2.0, 4.0, and 6.0 dS m^{-1} in the presence of 3.0 g L^{-1} of hydrogel, there were reductions of 16.99, 39.64, and 62.29%, respectively, compared to the ECw of 0.5 dS m^{-1}. Thus, it can be observed that the use of 3.0 g L^{-1} and irrigation using water with ECw of 0.5 dS m^{-1} resulted in the highest (2.08 g) TDM (Figure 6B).

When comparing the values of total dry mass obtained at ECw of 0.5 dS m^{-1} between the hydrogel concentrations of 0 and 3.0 g L^{-1}, an increase of 127.03% was observed for the highest concentration. On the other hand, when comparing the values obtained at ECw of 6.0 dS m^{-1} between the water-retaining polymer concentrations of 0 and 3.0 g L^{-1}, an increase of 11.35% was obtained for the highest concentration. Thus, it can be verified that, even at the highest ECw (6.0 dS m^{-1}), the water-retaining polymer led to increase in the total dry mass compared to treatments without the polymer, indicating a possible effect of mitigation of the damage caused by water salinity (Figure 6B). However, this beneficial effect decreases at high salinity levels, when the limitation caused by salt stress is not compensated by the manipulation of another production factor (Lacerda et al., 2016).

The higher moisture in the substrate promoted by the presence of 3.0 g L^{-1} of hydrogel reduced the need of seedlings to invest in root growth, which inhibited the entry of salts through the root system, leading to lower phytotoxicity caused by salts to the organs of the seedlings, resulting in seedlings with higher height, higher number of leaves, and greater phytomass accumulation. It was also verified that the total dry mass showed a behavior similar to that of leaf dry mass at concentration 3.0 g L^{-1}, since this variable contributed with a greater amount of phytomass. Navroski et al. (2016), when evaluating the total dry mass production in *Eucalyptus dunni* seedlings, concluded that the polymer promoted greater water retention capacity and water availability to the substrate, favoring seedling growth.

The salinity of irrigation water and hydrogel influenced the thermal index of seedlings in opposite ways (Figure 7). The thermal index for seedlings under low salinity of irrigation water (0.5 dS m^{-1}) was -5.33 °C. The increase in electrical conductivity caused a linear increase (0.18 °C for each unit increase in irrigation water salinity). Seedlings irrigated using water with ECw of 5.0 and 6.0 dS m^{-1} showed 15.45 and 18.89% higher thermal indices, respectively, compared to those under ECw of 0.5 dS m^{-1}, with values of -4.51 and -4.33 °C, respectively (Figure 7A).

Due to the lower water salinity, the seedlings irrigated with ECw of 0.5 dS m^{-1} absorbed and transpired more water, increasing thermal comfort on their surface, while at higher salinities water absorption was reduced by the osmotic effect.



$\hat{y} = 0.5519 - 0.0220\ \mathrm{ECw} - 0.0448\ \mathrm{H} + 0.1261\ \mathrm{H}^2 - 0.0481\ \mathrm{ECw*H}\ \mathrm{R}^2 = 0.61^{**}$

$\mathrm{CV}_{\mathrm{ECw}} = 46.51\%$

$\mathrm{CV}_{\mathrm{H}} = 44.33\%$

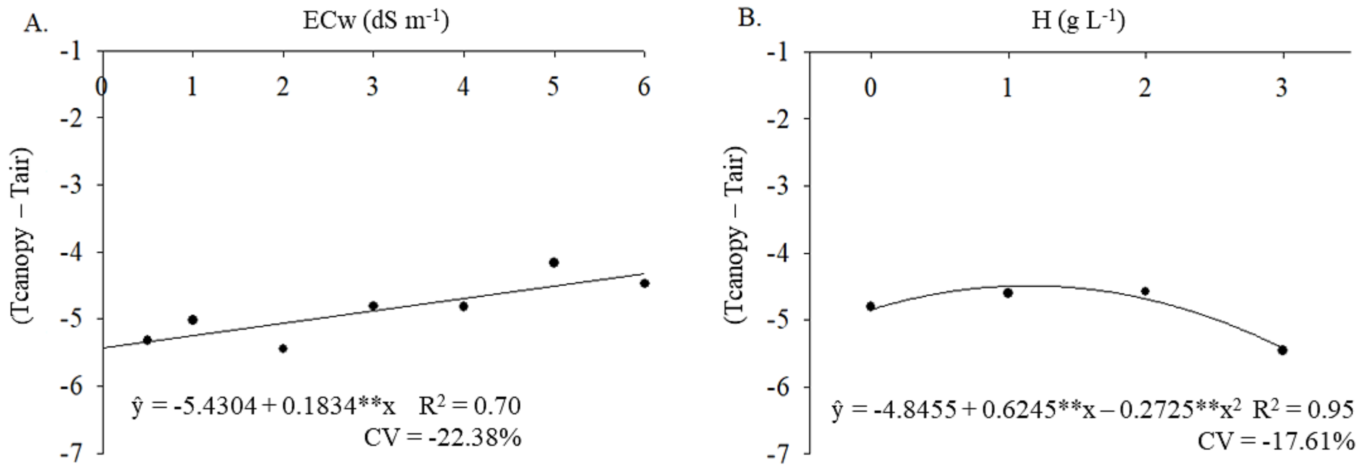
$\hat{y} = 0.937 - 0.0386\ \mathrm{ECw} - 0.006\ \mathrm{H} + 0.1425\ \mathrm{H}^2 - 0.0658\ \mathrm{ECw*H}\ \mathrm{R}^2 = 0.60^{**}$

$\mathrm{CV}_{\mathrm{ECw}} = 37.18\%$

$\mathrm{CV}_{\mathrm{H}} = 39.01\%$

**- Significant at p≤ 0.01 by the F test

Figure 6. Leaf dry mass (A) and total dry mass (B) of *Tagetes patula* L. seedlings as a function of the electrical conductivity of irrigation water (ECw) and hydrogel concentration (H) in the substrate



**- Significant at $p \leq 0.01$ by the F test

Figure 7. Thermal index of *Tagetes patula* L. seedlings subjected to different electrical conductivities of the water (ECw) (A) and hydrogel concentration (H) in the substrate (B)

The increase in the thermal index ΔT is an indication of water deficit, due to the amount of light absorbed, emitted, and reflected by the canopy, influencing the increase in temperature, causing it to be higher than the air temperature (Costa et al., 2019).

Conversely, the maximum concentration of hydrogel (3.0 g L^{-1}) resulted in the lowest thermal index (-5.42 °C) (Figure 7B) compared to the other treatments with polymer, with a decrease in the magnitude of the thermal index of 11.94% compared to the absence of the water-retaining polymer (-4.84 °C). The higher moisture in the substrate allowed seedlings to absorb more water and release into the atmosphere through transpiration, reducing leaf temperature. When water is lost by transpiration through the stomatal openings, this process reduces leaf temperature due to heat dissipation, so the detection of water stress through infrared thermography depends, in large part, on the transpiration rate (Saraiva et al., 2014).

CONCLUSIONS

1. The increase in irrigation water salinity reduced emergence percentage and caused death of seedlings, regardless of the hydrogel concentration applied.

2. Application of 3 g of hydrogel L^{-1} of substrate increased leaf production and reduced the thermal index independently of the increased substrate salinity.

3. The use of 3.0 g L^{-1} hydrogel promotes increase in seedling height, leaf dry mass, and total dry mass compared to treatments without water-retaining polymer, even at moderate (2.0 to 3.0 dS m^{-1}) and high (4.0 to 6.0 dS m^{-1}) levels of irrigation water salinity, thus indicating possible effect of mitigation of damage caused by salinity. However, the intensity of this mitigating effect decreases at the highest levels of salt stress.

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