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ARTICLE

Emergence and initial growth of *Celosia argentea* L. cultivated under irrigation with brackish water

Emergência e crescimento inicial de *Celosia argentea* L. cultivada sob irrigação com água salobra

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Abstract: Salinity is a recurring abiotic stress in arid and semi-arid regions, which negatively affects the establishment and growth of plants, however, the cultivation of ornamental species such as *celosia argentea* can tolerate saline conditions. The objective of this work was to evaluate the emergence and seedling growth of *Celosia argentea* cultivated under different electrical conductivities of irrigation water. The experiment was carried out in a greenhouse, in the month of July 2021. The experimental design was completely randomized with five treatments and four replications. The treatments were five electrical conductivities of irrigation water (ECw), being: 0.5; 1.5; 2.5; 3.5 and 4.5 dS m^{-1}. They were analysed the emergence variables (percentage of emergence, average emergence time, average emergence velocity and emergence velocity index) and the growth variables (seedling height, number of leaves, stem diameter, primary root length, shoot dry weight and root dry weight) at seedling start. Moderate salinity improves seed vigor, increasing the percentage of *C. argentea* seedlings that emerge, culminating in satisfactory initial growth. The electrical conductivity ECw 2.5 dS m^{-1} is the salinity threshold that keeps the salinity-tolerant *C. argentea* species above the threshold and becomes sensitive to salts.
Keywords: floriculture, salt stress, seedling, semiarid.

Resumo: A salinidade é um estresse abiótico recorrente em regiões áridas e semiáridas, que afeta negativamente o estabelecimento e crescimento das plantas, porém, o cultivo de espécies ornamentais como a *Celosia argentea* pode tolerar condições salinas. Objetivou-se com este trabalho avaliar a emergência e o crescimento de plântulas de *Celosia argentea* cultivada sob diferentes condutividades elétricas da água de irrigação. O experimento foi conduzido em casa de vegetação, no mês de julho de 2021. O delineamento experimental foi inteiramente casualizado com cinco tratamentos e quatro repetições. Os tratamentos foram cinco condutividades elétricas da água de irrigação (CEa), sendo: 0,5; 1,5; 2,5; 3,5 e 4,5 dS m^{-1}. Foram analisadas as variáveis de emergência (porcentagem de emergência, tempo médio de emergência, velocidade média de emergência e índice de velocidade de emergência) e as variáveis de crescimento (altura de plântula, número de folhas, diâmetro do caule, comprimento da raiz primária, massa seca da parte aérea e massa seca de raiz). 1- A salinidade moderada melhora o vigor das sementes, aumentando a porcentagem de mudas de C. argentea que emergem, culminando em crescimento inicial satisfatório. A condutividade elétrica 2,5 dS m^{-1} é o limiar de salinidade que mantém a espécie *C. argentea* tolerante, acima do limiar torna-se sensível aos sais.
Palavras-chave: estresse salino, floricultura, plântula, semiárido.

Introduction

The species *Celosia argentea* L. belongs to the Amaranthaceae family, and is known by the popular names, cock's crest, plumosa, sigh or feathered crest, being an important tropical ornamental species. It is native to the Asian continent, more specifically, India (Alam et al., 2022). The inflorescences have the property of remaining colorful and decorative for a long time after harvesting, being often used as evergreens. This species is also used in traditional medicine as an anti-inflammatory, antioxidant, antidiabetic and antimicrobial agent, in addition to being considered unconventional edible plants (PANC) in Brazil (UNIRIO, 2019). Bezerra et al. (2020) elucidate that this species has moderate tolerance to salinity during the seedling production phase.

Among the productive sectors that depend on irrigation, at least part of the year, the areas of gardens and landscaping could be supplied mainly with brackish water or sewage due to the water shortage of good quality water for irrigation (Neves et al., 2018; Cerqueira et al., 2021). In Brazil, the cultivation of ornamental plants is an important economic activity due to the climatic diversity (humid, semi-arid, hot, cold), presenting a progressive development, due to the increase of the internal market and the presence of strategic points for its commercialization (Lacerda et al., 2020).

In northeastern Brazil, especially in the semi-arid region, irregular rainfall and high evapotranspiration are common, generally higher than the precipitated volume, resulting in scarcity of water resources (Ferreira et al., 2021). Therefore, the guarantee of water supply for irrigated agriculture in the semi-arid region must necessarily involve the use of lower quality water, such as brackish water (Bezerra et al., 2020).

Based on this scenario, the study of salinity tolerance in plants, especially in ornamental species, it is of fundamental importance, since salts are a limiting factor for agricultural production, causing osmotic and ionic stress, which affect the absorption of nutrients, metabolic activity and growth (Harter et al., 2014). Osmotic stress caused by salinity can lead to initial effects such as cellular dehydration that negatively affects many basic physiological processes and this triggers a reduction in cell expansion, these effects being derogatory regarding the emergence and initial growth of seedlings (Taiz et al., 2017).

Some studies on irrigation management of ornamental plants with lower quality water were developed by Oliveira et al. (2017), Moore et al. (2019), Bezerra et al. (2020) and Xing et al. (2021) and observed that the increase in the electrical conductivity of irrigation water reduced the growth of the ornamental species *Catharanthus roseus, Allamanda cathartica, Ixora coccinea, Duranta erecta, Coleus hybridus, Acalypha wilkesiana, Ficus benjamina, Jasminium multiflorum* and *Plumbago auriculata*. Although there are species that develop satisfactorily in saline conditions, most species are sensitive to excess salts in irrigation water, requiring studies to evaluate better management strategies (Oliveira et al., 2017).

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The hypothesis of the present study is that higher saline levels in irrigation water will impair the emergence and initial growth of *Celosia argentea*. In this context, this work aimed to evaluate the emergence and initial growth characteristics of *Celosia argentea* seedlings under different salt concentrations in the irrigation water.

Material and Methods

The experiment was carried out in a greenhouse, at the Weather Station of the Department of Agricultural Engineering, Campus of Pici, Federal University of Ceará, in the municipality of Fortaleza-CE, Brazil (3º 44' 44" S; 38º 34' 50" W; mean altitude of 19.6 m), in the month of July 2021. The temperature and relative humidity data were monitored using a Data Logger (model HOBO® U12-012 Temp/RH/Light/Ext). The average air temperature ranged from 27.4 to 31.1ºC, while the relative humidity ranged from 56.7 to 67.5%.

The experimental design was completely randomized with five treatments and four replications. Each treatment consisted of a tray divided into four equal parts and each replication was composed of 25 cells, totaling 20 experimental units and 500 observational units. The treatments were five electrical conductivities of irrigation water (ECw), being: 0.5 (control); 1.5; 2.5; 3.5 and 4 .5 dS m^{-1}. The treatments were prepared using NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$ salts in a proportion equivalent to 7:2:1, respectively, being a representative approximation of most water sources available for irrigation in the Northeast region of Brazil (Pinho et al., 2022).

For sowing, polyethylene trays of 200 cells with a volume of 50mL/cell were used, in each cell a seed of *Celosia argentea* var. cristata (Isla Sementes LDTA) was placed. The substrate used was arisco (sandy material with light texture normally used in constructions in Northeast Brazil) + organic compound in the proportion 4:2 (Table 1).

Tab. 1. Chemical characteristics of the substrate used in the experiment.

Chemical characteristics													
(O.M	N)	(Ca^{2+}	K^+	Mg^{2+}	Na^+	H^+ Al^{3+}	Al	SB)	P	CEC	V	ECSSe	pH
(g/kg)		---------------------------- (cmolc/kg) --------------------------							(mg/kg)	(cmolc/kg)	(%)	(dS m^{-1})	Water
14.07	0.89	4.3	0.83	1.9	0.36	1.49	0.1	7.39	342	8.88	83	2.04	6.2

O.M - Organic matter; SB - Sum of bases (Ca^{2+} + Mg^{2+} + Na^+ + K^+); CTC - Cation exchange capacity - [Ca^{2+} Mg^{2+} Na^+ K^+ (H^+ Al^{3+})]; V - Base saturation - (SB/ CTC) x 100; ECSSe – Electrical conductivity saturation extract of substrate.

Irrigation was manually performed at a daily interval (once a day), until the water drained from the bottom of the trays (Marouelli and Braga, 2016). In order to avoid contamination between the different irrigations with brackish water, an individual tray was adopted for each treatment. No fertilization was carried out in view of the initial stage of the species.

The counting of the number of emerged seedlings started on the third day after sowing (DAS) always at the same time until the ninth day (DAS) following the methodology proposed by Maguire (1962), evaluating the emergence speed index (ESI seedlings/day), percentage of emergence (EP%), mean of emergence time (MET days) and mean of emergence speed (MES day^{-1}).

At the end of the first phenological phase seedling establishment (21 DAS), seedling height (SH), number of leaves (NL), stem diameter (SD) and root length (RL) were measured. Seedling height was measured with a ruler graduated in centimeters (cm), stem diameter was measured using a digital caliper with a result expressed in millimeters (mm), and the number of leaves was counted manually. Then all the sampled parts were placed in duly identified paper bags, taken to the forced air circulation oven at ±65°C for a period of 72 hours, after drying all the samples were weighed, obtaining the shoot dry weight (SDW) and root dry weight (RDW).

The results were submitted to analysis of variance by the F Test at 1% and 5%, when significant they were submitted to regression analysis. The data were submitted to correlation analysis between the analyzed variables. Statistical analyses were performed using the AgroEstat statistical program (Barbosa and Maldonado Junior, 2015).

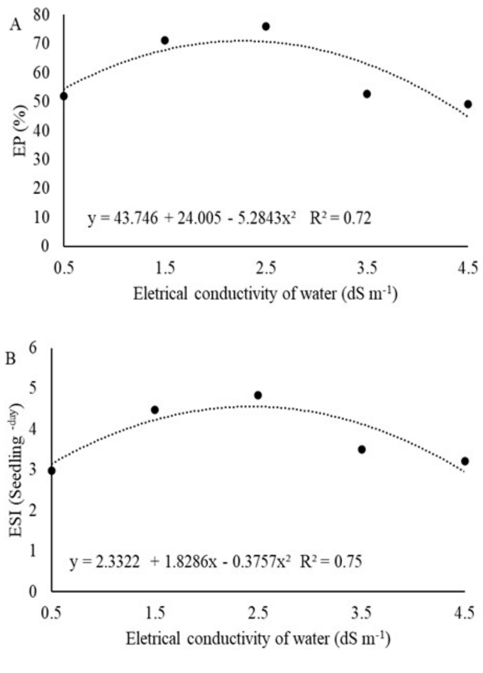

Fig. 1. Effect of electrical conductivity of water on emergence percentage (EP) (A) and emergence speed index (ESI) (B) of seedlings of *Celosia argentea* L. cultivated in greenhouse.

Results and Discussion

The variables emergence percentage (EP) and mean of emergence time (MET) were influenced by salinity at 1% probability, while the variables mean of emergence time (MET) and mean of emergence speed (MES) were significant by salinity at 5 % probability.

The variables emergence percentage (EP) and emergence velocity index (ESI) were better adjusted to the quadratic polynomial regression model, thus the maximum EP was obtained at electrical conductivity of water (ECw) 2.27 dS m^{-1}, with 71% of emerged seedlings (Figure 1A) and the maximum ESI was obtained at ECw 2.43 dS m^{-1} yielding 4.55 seedlings day^{-1} (Figure 1B).

Based on the parameters mentioned above, up to moderate levels of electrical conductivity, the species *C. argentea* showed tolerance to salinity. However, with the continuous increase of ECw, there were restrictions on the emergence of this species.

According to Nogueira et al. (2020) the percentage of emergence may indicate the species' tolerance to salinity, since the increase in the concentration of salts in the substrate is attributed to salts dissolved in the irrigation water. Salinity can delay the imbibition of water by the seed coat of plants, caused by the reduction in osmotic potential, leading to the impairment of the physiological processes of the seeds and consequently a reduction in the emergence speed index (Leal et al., 2019; Guerra and Machado, 2022).

The average emergence time is the average time that a set of seeds needs to emerge (Borghetti and Ferreira, 2004), thus the shortest time necessary for the seeds to emerge (4.34 days) was obtained in seeds hydrated with water of ECw 3.78 dS m^{-1} according to the best-fit quadratic polynomial model (Figure 2A). The maximum average emergence speed was obtained in hydrated seeds with ECw 4.2 dS m^{-1} requiring 0.22 day^{-1} (Figure 2B).

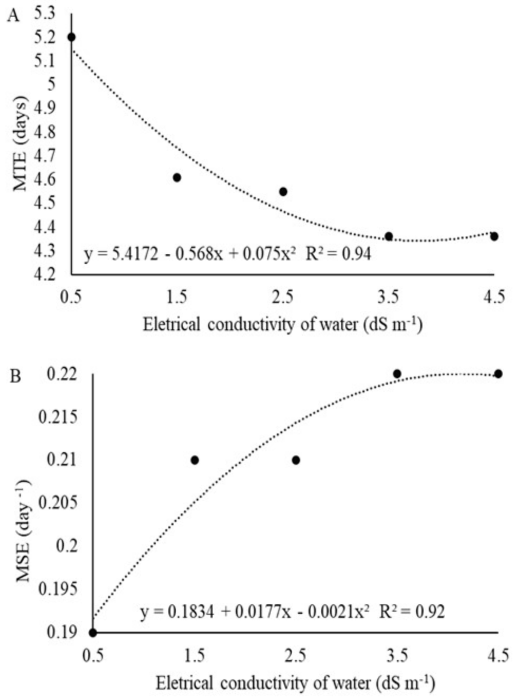

Fig. 2. Effect of electrical conductivity of water on the mean emergence time (MET) (A) and mean emergence speed MES (B) of seedlings *Celosia argentea* L. cultivated in greenhouse.

This indicates that ECw 2.27 dS m^{-1} provides conditions for maximum seedling emergence vigor, maintaining seed quality up to ECw 4.2 dS m^{-1}, with no impediment to seedling emergence. According to Oliveira et al. (2009), the percentage and average speed of emergence are parameters that can be used to evaluate seed vigor and quality in the field.

For our results, there was an increase up to a certain salinity and after that point there was a decrease in salinity for percentage emergence. This result differs from Nogueira et al. (2020) as they found that the emergence percentage and the average emergence speed decreased as the water salinity increased from 0.5 dS m^{-1} to 6.5 dS m^{-1}. According to these authors, this can be explained by the reduction in water potential caused by the accumulation of salt concentrations in the substrate, resulting in less water absorption by the seeds and, consequently, lower germination capacity.

The emergence speed index of *Tagetes patula* L. as a function of the electrical conductivity of the irrigation water, 15 days after sowing, showed a unitary reduction of 0.86 seedlings per day, with a maximum reduction of 57.37% when using an ECw of 6.0 dS m^{-1} compared to the control treatment, according to the study of Sousa et al. (2022).

The variables seedling height (SH), number of leaves (NL), stem diameter (SD), root length (RL), shoot dry weight (SDW) and root dry weight (RDW) showed a significant effect for salinity at 1% probability.

Seedling height reduced linearly by 0.50 cm with each salinity increment. At ECw 1.5, 2.5, 3.5 and 4.5 dS m^{-1} the SH reduced by 12.81; 25.63; 38.44 and 51.26% respectively in relation to ECw 0.5 dS m^{-1} (3.95 cm) (Figure 3A). It is observed that at the maximum ECw 4.5 dS m^{-1} the seedlings showed an intense reduction in height, indicating the sensitivity of the species to salts.

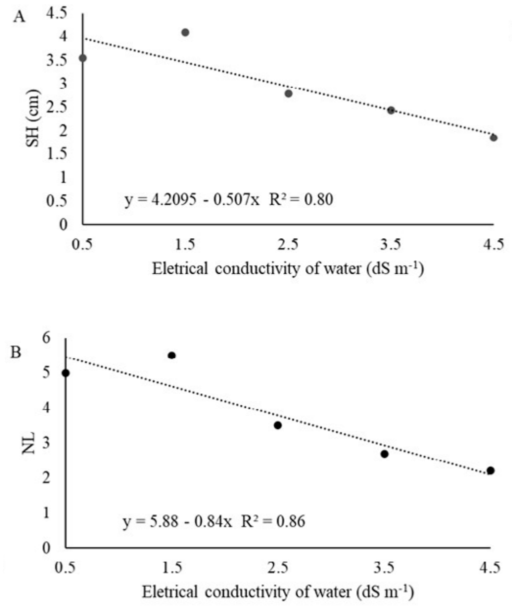

Fig. 3. Effect of electrical conductivity of water on seedling height (SH) (A) and number of leaves (NL) (B) of *Celosia argentea* L. cultivated in greenhouse

The number of leaves (NL) reduced by 0.84 units with each increase in salinity. It is verified that at ECw 1.5, 2.5, 3.5 and 4.5 dS m^{-1} the NL reduced 15.38; 30.76; 46.15 and 61.53% respectively in relation to ECw 0.5 dS m^{-1} (5.46 units) (Figure 3B). This result indicates that leaf production in *Celosia argentea* L. seedlings is moderately tolerant to salinity up to ECw 2.5 dS m^{-1}, reducing salt tolerance with increasing electrical conductivity of the water. Thus, based on this saline concentration, seedlings need to reduce leaf production more intensely in an attempt to reduce water losses to the atmosphere through transpiration.

In a saline environment, plants reduce the number of leaves as an adaptive strategy to reduce transpiration and maintain cell turgor in water deficit caused by salts, in an attempt to maintain osmotic balance by protecting cells against dehydration and cell death (Taiz et al., 2017). For Diniz et al. (2018) high salt concentrations affect the absorption of water and nutrients by plant roots, interfering with cell elongation and seedling development.

On the other hand, it agrees with Oliveira et al. (2017) found a reduction in plant height in *Catharanthus roseus*, *Allamanda cathartica*, *Ixora coccinea* and *Duranta erecta* with an increase in the electrical conductivity of irrigation water 1,2; 1.8; 2.4; 3.0 and 3.6 dS m^{-1} compared to 0.5 dS m^{-1}.

Stem diameter (SD) linearly reduced 0.10 mm for each unit increment of salinity. At ECw 1.5, 2.5, 3.5 and 4.5 dS m^{-1} SD reduced by 10.60; 21.21; 31.82 and 42.43% respectively in relation to ECw 0.5 dS m^{-1} (1.01 mm) (Figure 4A).

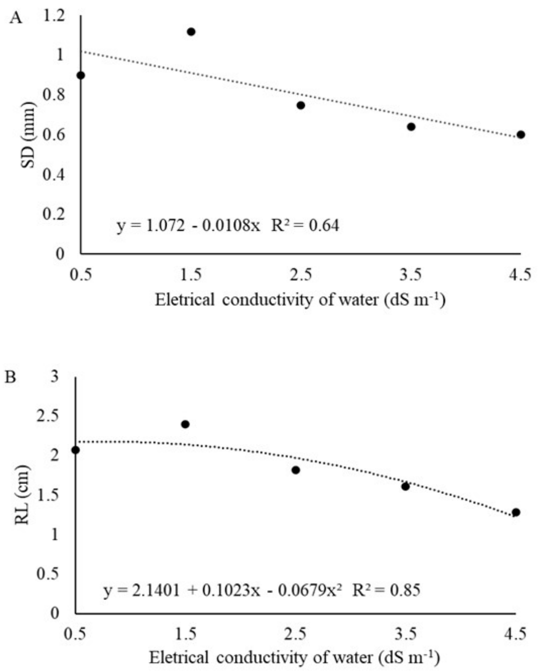

Fig. 4. Effect of electrical conductivity of water on stem diameter (SD) (A) and primary root length (B) of seedlings (RL) of *Celosia argentea* L. cultivated in greenhouse

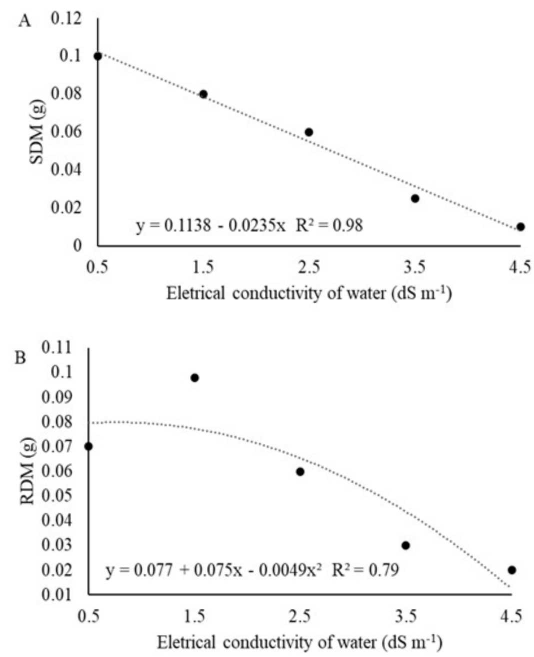

Fig. 5. Effect of electrical conductivity of water on shoot dry mass (A) and root dry mass (B) of seedlings of *Celosia argentea* L. cultivated in greenhouse.

It is observed that the increase in salt concentrations in the irrigation water possibly provided favorable conditions for the accumulation of salts in the substrate, making it difficult for the roots to absorb water, inducing the species to morphological adjustment to reduce water losses to the atmosphere, consequently, there is a reduction in the number of leaves and leaf area for CO_2 capture to carry out photosynthesis and displacement of photoassimilates to the stem. Thus, according to Santos Junior et al. (2016) the thickness of the stem diameter is of great relevance in the resistance and support of the plant, which can cause tipping problems in crops.

Evaluating salinity tolerance in the production of seedlings of *Catharanthus roseus*, *Tagetes patula* and *Celosia argentea* irrigated with different brackish waters, Bezerra et al. 2020 found that there were significant reductions in the stem diameter of these species.

The maximum primary root length (RL) was obtained at ECw 0.75 dS m^{-1}, obtaining a length of 2.17 cm (Figure 4B). According to Taiz et al. (2017) the accumulation of salts near the roots results in a shorter root length, in order to reduce the absorption of dissolved salts by water, as a strategy to reduce the accumulation of toxic ions in tissues.

This result agrees with Lima et al. (2015), since they submitted albizia seedlings to different brackish concentrations and obtained the greatest root length in seedlings with a larger shoot part. Cavalcante et al. (2019) state that saline stress, mainly in direct contact with the roots, reduces the development of plant tissue by changing the seedling height.

The shoot dry weight (SDW) reduced by 0.02 g with each increment of salinity. At ECw 1.5, 2.5, 3.5 and 4.5 dS m^{-1} the SDW reduced by 23.02; 46.05; 69.08 and 92.11% respectively in relation to ECw 0.5 dS m^{-1} (0.10g) (Figure 5A). On the other hand, the root dry weight (RDW) was maximum at ECw 0.76 dS m^{-1} obtaining 0.07g (Figure 5B).

This demonstrates that the toxic effects of the salts were more severe in the root zone of *C. argentea*, due to the direct contact with the salts, resulting in a smaller length and accumulation of dry mass, showing sensitivity of the roots to salinity. On the other hand, the species shows sensitivity to salts in the SDW accumulation from ECw 3.5 dS m^{-1} due to the increase in the accumulation of salts in the substrate, raising the osmotic potential, inducing the seedlings to increase their energy expenditure to remove water and nutrients, due to this direction of energy for the physiological maintenance of the seedlings, there was a reduction in the accumulation of dry biomass reserves in the aerial part.

The increase in osmotic potential reduces water potential (Araújo et al., 2018), negatively influencing plant growth by promoting changes in the metabolic, anatomical and physiological functions of plants (Dutra et al., 2017) due to the difficulty in absorbing water and nutrients. Thus, although the emergence process occurs, the osmotic potential hinders the absorption of water by the roots, impairing the quality and development of seedlings (Nogueira et al., 2018). The reduction in biomass production under saline conditions may be indicative of the degree of tolerance of ornamental species to salinity, essential information for the producer to choose the most suitable species for the soil and available water (García-Caparrós and Lou, 2018).

Similar results were recorded by Nogueira et al. (2020) whose root dry mass progressively decreased with the increase in the electrical conductivity of the water from 0.5 to 6.5 dS m^{-1}. Gomes Filho et al. (2019) observed that bean seedlings are sensitive to NaCl, the more negative the osmotic potential, the lower the shoot length values, since the accumulation of salts in the plant tissue inhibits the physiological and metabolic processes of the plants, negatively interfering with development of the aerial part of the seedlings.

Correlation is a widely used tool that allows quantitatively assessing the relevance of the characteristics of the measured variable in relation to another variable (Küster et al., 2018). All correlations presented in the present study were statistically significant.

Thus, the shorter the average time of emergence (MTE) of *C. argentea* seedlings, the greater the mean emergence speed (MSE), the emergence speed index (ESI) and the percentage of emergence (EP), that is, the shorter the average time required for the seedlings to emerge, the greater the speed, the number of seedlings emerged per day and the percentage of seedlings emerged (Table 2).

Tab. 2. Correlation matrix of variables analyzed in seedlings of *Celosia argentea* L. under the effect of electrical conductivity of irrigation water.

	EP	ESI	MTE	MSE	SDM	RDM	SH	SD	NL
ESI	0.95								
TEM	-0.31	-0.29							
MSE	0.06	0.3	-0.94						
SDM	0.42	0.32	0.36	-0.38					
RDM	0.43	0.36	0.1	-0.11	0.78				
SH	0.48	0.38	0.33	-0.33	0.93	0.77			
SD	0.41	0.29	0.33	-0.31	0.87	0.87	0.86		
NL	0.39	0.27	0.42	-0.43	0.94	0.76	0.96	0.87	
RL	0.39	0.27	0.31	-0.3	0.78	0.76	0.82	0.83	0.82

Emergency Speed Index (ESI); Emergency percentage (EP); Average emergency speed (MSE); Mean of emergence time (MET); Seedling height (SH); Number of leaves (NL); Stem diameter (SD); Primary root length (RL); Shoot dry mass (SDM); Root dry mass (RDM)

It is also verified that the faster the seedlings of *C. argentea* emerged (MSE), the smaller the measurement of seedling height (SH), number of leaves (NL), stem diameter (SD), primary root length (RL), shoot dry weight (SDW) and root dry weight (RDW) due to the longer time that the seedlings were exposed to the toxic effect of ions (Na^+ and CL^-) and water stress caused by the osmotic effect. On the other hand, there was also a positive relationship between shoot dry weight (SDW) and root dry weight (SDW).

The increase in the root/shoot ratio is considered a plant reaction to stress, either by increasing the formation of phytomass in the roots to increase the exploration of the possible soil volume and improve water absorption or by decreasing the accumulation of dry matter in the aerial part to reduce the entrance of salts (Sá et al. 2013). According to Silva Neta et al. (2022) this relationship also indicates the level of contribution of reserves stored in the root system in order to contribute to the growth and production of phytomass.

The response to the effects of salinity varies between species, cultivars of the same species, conditions under which they are submitted, such as irrigation and plant development stage. Thus, the result of the correlations is directly related to the interference of salts in plant processes, which happens when high concentrations of cations, mainly sodium, also interfere with soil properties, affecting the normal growth of plants under these conditions. (Taiz et al., 2017).

Conclusions

Moderate salinity improves seed vigor, increasing the percentage of C. argentea seedlings that emerge, culminating in satisfactory initial growth. The electrical conductivity ECw 2.27 dS m^{-1} is the threshold salinity that enhances seedling emergence. The electrical conductivity CEa 2.5 dS m^{-1} is the salinity threshold that keeps the species *C. argentea* tolerant to salinity, above the threshold and becomes sensitive to salts.

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Author contributions

A.G.S.F and **J.R.S.S.**: fieldwork and data capture. **C.M.P.**; **O.R.O.P.**; **L.G.C.S.**: data processing and analysis, literature review and writing. **A.G.S.F.**; **J.R.S.S.**; **C.M.P.** and **C.F.L.**: literature review and writing, translation into English.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available on request.

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