



PROTECTED CULTIVATION AND WATER SALINITY IN THE FORMATION OF *Erythrina velutina* Willd SEEDLINGS

Geocleber Gomes de Sousa², Claudivan Feitosa de Lacerda³, Jonnathan Richeds da Silva Sales^{4*}, Francisco Barroso da Silva Junior⁵, Andreza de Melo Mendonça⁵, and Thales Vinícius de Araújo Viana³

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2 Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Instituto de Desenvolvimento Rural, Redenção, CE, Brasil. E-mail: <sousagg@unilab.edu.br>.

3 Universidade Federal do Ceará, Departamento de Engenharia Agrícola, Fortaleza, CE, Brasil. E-mail: <cfeitosa@ufc.br> and <thales@ufc.br>.

4 Universidade Federal do Ceará, Programa de Pós-Graduação em Engenharia Agrícola, Fortaleza, CE, Brasil. E-mail: <jonnathanagro@gmail.com>.

5 Universidade Federal do Ceará, Programa de Pós-Graduação em Fitotecnia, Fortaleza, CE, Brasil. E-mail: <juniorbarroso_99@hotmail.com> and <andreza.melo2911@gmail.com>.

*Corresponding author.

ABSTRACT

Protected cultivation can reduce the harmful effects of salt stress on the development of plant species. The objective of this study was to evaluate the growth and morphophysiological responses of *E. velutina* seedlings grown under saline stress in two growing environments. The experiment was conducted in an experimental area belonging to the Federal University of Ceará, in Fortaleza, Ceará. The experimental design was entirely randomized in subdivided plots, where the plots were represented by the growing environments (closed-screen greenhouse - CSG and open-sided greenhouse chapel - OSG), the subplots by the irrigation waters (0.8 and 5.0 dS m⁻¹) and in the subplots the collection seasons (20, 40, 60 and 80 DAS), with four replications. Saline stress inhibited the growth of *E. velutina* seedlings in terms of height, leaf area, number of leaves and dry mass of the aerial part, but provided greater root dry mass throughout the growing season. It also affected gas exchange after 50 days of cultivation. The seedlings grown in the open shade environment on the sides and with lower salinity water had a higher Dickson quality index.

Keywords: Caatinga; Forest restoration; Salt stress.

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CULTIVO PROTEGIDO E SALINIDADE HIDRÍCA NA FORMAÇÃO DE MUDAS DE *Erythrina velutina* Willd

RESUMO – O cultivo protegido pode reduzir os efeitos nocivos do estresse salino sobre o desenvolvimento de espécies vegetais. Objetivou-se com o presente trabalho avaliar o crescimento e as respostas morfofisiológicas de mudas de *E. velutina* cultivado sob estresse salino em dois ambientes de cultivo. O experimento foi conduzido em área experimental pertencente à Universidade Federal do Ceará, em Fortaleza, Ceará. O delineamento experimental foi inteiramente casualizado em parcela subdivididas, onde as parcelas eram representadas pelos ambientes de cultivo (estufa do tipo telada fechada - ETF e estufa do tipo capela aberta nas laterais - ETAL), as subparcelas pelas águas de irrigação (0,8 e 5,0 dS m⁻¹) e na subsubparcelas as épocas de coletas (20, 40, 60 e 80 DAS), com quatro repetições. O estresse salino inibiu o crescimento das mudas de *E. velutina* em altura, área foliar, número de folhas e massa seca da parte aérea, porém proporcionou maior massa seca da raiz durante toda a época de cultivo. Além disso, afetou as trocas gasosas após 50 dias de cultivo. As mudas produzidas no ambiente telado aberto nas laterais e com água de menor salinidade apresentaram maior índice de qualidade de Dickson.

Palavras-Chave: Caatinga; Restauração florestal; Estresse salino.

1. INTRODUCTION

Erythrina velutina Willd is a species native to Brazil belonging to the Fabaceae family. It is a tree-like species that grows to heights of 8 to 12 m and is commonly found in the humid floodplains and riverbanks of the Caatinga (Cunha; Gomes, 2015). According to Cavalcante et al. (2016), it has potential for timber use, urban afforestation and for restoring vegetation in degraded areas. The Northeast region of Brazil has 70% of its territory covered by the Caatinga biome, which is the main phytogeography that occurs in the Brazilian semi-arid region (Silva et al., 2019a).

The production of seedlings for reforestation

and recovery of degraded areas, as well as for urban afforestation, has seen a growing increase in demand due to global concern about environmental preservation (Lourenço et al., 2016), especially in degraded areas such as the Caatinga.

However, the predominant climate in this region is semi-arid, characterized by high spatial and temporal variability of rainfall (below 800 mm year⁻¹) concentrated in the first 4 months of the year and high average temperatures (Rodrigues et al., 2018).

In order to produce quality seedlings, it is necessary to provide the plant with suitable conditions for its development, including adequate nutrition, environment and good quality water (Silva Junior et al., 2020; Veloso et al., 2021). Due to water scarcity in semi-arid regions, some nurserymen end up resorting to brackish water sources, which depending on the level of salinity limit plant growth and development (Figueiredo et al., 2019).

The effects of salinity are linked to a reduction in the soil's osmotic potential, limiting water absorption and negatively influencing plant nutrition and physiology (Silveira et al., 2016; Pinho et al., 2022). Silva et al. (2019b) state that increasing the salinity of irrigation water harms the emergence process and initial development of *E. velutina*.

An alternative that has been tested to mitigate saline stress is the use of different protected environments. This technique makes it possible to protect and reduce the adverse effects of high levels of radiation and extremes of air temperature (Reis et al., 2012). Sousa et al. (2021), evaluating the use of saline water on pitaya seedlings (*Hylocereus undatus*) and Silva Junior et al. (2020) on watermelon seedlings (*Citrullus lanatus*), grown in a protected environment with a 50% shading screen, found a positive effect for the management of these seedlings under saline stress.

In view of the need to produce seedlings of native species for the recovery of degraded areas of the Caatinga, especially in areas affected by salinity, the objective of this study was to evaluate the growth and morphophysiological responses of *E. velutina* seedlings grown under saline stress in two growing environments.

2. MATERIAL AND METHODS

The experiment was conducted in the experimental area of the Agrometeorological Station belonging to the Federal University of Ceará (UFC), in Fortaleza, Ceará, (3°45'S; 38° 33'W and altitude 19 m). According to

the Köppen classification, the experiment area is located in an Aw' climate region. The average rainfall in the city is 1465.7 mm per year, mostly distributed during the months of February to May 2016. The meteorological data obtained during the experiment is shown in Table 1.

Table 1. Average values of relative humidity (RU) and air temperature (T) in the open-sided greenhouse (OSG) and closed-sided greenhouse (CSG) during the experiment period.

Tabela 1. Valores médios de umidade relativa do ar (UR) e temperatura do ar (T) em ambiente com estufa do tipo capela aberta nas laterais - OSG e estufa do tipo telada fechada - CSG, durante o período do experimento.

Environments	OSG				CSG			
	RU (%)		T (°C)		RU (%)		T (°C)	
Months	Min	Max	Min	Max	Min	Max	Min	Max
February	40	58	22.4	28.6	42	56	26.4	30.8
March	42	56	21.8	29.8	44	54	25.2	31.8
April	41.1	44	23.21	30.24	40	49.5	26.4	31.9
May	36.5	41.2	24.8	31.6	41	48.2	28.8	32.1

The experimental design was entirely randomized in sub-subdivided plots, in two growing environments (closed-screen greenhouse - CSG and open-sided greenhouse chapel - OSG), the subplots by irrigation water (0.8 dS m⁻¹ and 5.0 dS m⁻¹) and the sub-subplots by collection seasons (20, 40, 60 and 80 days after sowing - DAS), with four repetitions. During the experimental period, the daily averages for temperature and relative humidity were 26.5 °C and 63% for CSG and 24.7 °C and 59% for OSG, respectively.

The closed greenhouse was arched, 12 m long by 6 m wide, with a ceiling height of 1 meter, with a plastic cover and 50% shade under the cover, with temperature and relative humidity controlled by a data logger (HOBO® U12-012 Temp/RH/Light/Extension).

The material used as a substrate came from soil in the experimental area of the Agrometeorological Station belonging to the UFC, in Fortaleza - CE. The soil was classified as Argissolo Vermelho Amarelo, collected in the 0-20 cm depth layer, passed through a 2 mm mesh sieve, with the following chemical and physical characteristics: pH = 7.0; CEes = 0.54 dS m⁻¹; Ca²⁺ = 1.0 cmolc kg⁻¹; Mg²⁺ = 0.8 cmolc kg⁻¹; K⁺ = 0.15 cmolc kg⁻¹; Na⁺ = 0.63 cmolc kg⁻¹; sandy loam textural class and soil

density = 1.47 g cm⁻³.

To form the seedlings, *Erythrina velutina* seeds from fruit collected in the municipality of Mulungu-CE underwent dormancy breaking by manually scarifying the area opposite the hilum with sandpaper number 10. The seedlings were then transplanted into plastic pots with a capacity of 10 kg.

The saline solution was prepared from 0.8 dS m⁻¹ water, obtaining the desired salinity by adding soluble salts (NaCl, CaCl₂.2H₂O and MgCl₂.6H₂O), in the equivalent ratio of 7:2:1 between Na, Ca and Mg, following the relationship between CEes and their concentration (mmolc L⁻¹ = EC × 10), according to the methodology described by Richards (1954). Irrigation was applied manually using a graduated becker, adopting a 15% leaching fraction according to Ayers and Westcot (1999), on a daily basis, calculated according to the drainage lysimeter principle (Bernardo et al., 2019), keeping the soil at field capacity.

For the growth variables, destructive samples were taken at the end of each collection season (20, 40, 60 and 80 DAS), assessing the following parameters: number of leaves (NL) - direct counting of the leaves;

leaf area - LA (Scanner method - an image scanner (Scanner) was used, coupled to a microcomputer, where the image was analyzed by Sigmascan® software to calculate the area); plant height (H) - metric tape measure graduated in centimeters.

Gas exchange was assessed at the end of each collection period (20, 40, 60 and 80 DAS), evaluating the following variables: stomatal conductance, net photosynthesis rate, transpiration, internal CO₂ concentration and leaf temperature, using an open-system infrared gas analyzer, mod. Lci, ADC, Hoddesdon, UK, equipped with an artificial radiation source with an intensity set at 2000 μmol m⁻¹ s⁻¹. Measurements were taken between 8 and 10 a.m. on fully expanded leaves.

To assess biomass, samples were identified according to treatment and packed in paper bags. They were then dried in a forced-air circulation oven at 60 °C for 72 hours. The shoot dry mass (SDM) and root dry mass (RDM) were then measured using a 0.0001 g analytical balance.

The Dickson quality index (DQI) was determined as a function of shoot height (H), stem diameter (SD), shoot dry mass (SDM) and root dry mass (RDM), according to the equation proposed by Dickson; Leaf; Hosner (1960):

$$DQI = \frac{TDM (g)}{\frac{H (cm)}{SD (mm)} + \frac{SDM (g)}{RDM (g)}} \quad (\text{Eq. 1})$$

The results were subjected to analysis of variance and regression and the means were compared using the Tukey test with p < 0.05, using the ASSISTAT program. 7.7 Beta.

3. RESULTS

The analysis of variance (Table 2) shows that there was a significant interaction (p < 0.01) between the salinity (S) x collection seasons (E) factors for the following variables: leaf area (AF), plant height (H), stomatal conductance (gs), photosynthesis (A), transpiration (E), leaf temperature (TF), shoot dry mass (SDM), root dry mass (RDM) and Dickson quality index (DQI). For the H and DQI variables, there was statistical significance (p < 0.01) in the growing environments (A) x collection seasons (E) interaction. The interaction between growing environments (A) and salinity (S) only influenced the leaf temperature variable (p < 0.05). The NF was only significantly influenced by the salinity factor (S) (p < 0.05).

It can be seen in (Figure 1A) that the leaf area increased linearly with the increase in

Table 2. Summary of the analyses of variance for the following variables: leaf area (LA), number of leaves (NL), plant height (H), stomatal conductance (gs), photosynthesis (A), transpiration (E), leaf temperature (LT), shoot dry mass (SDM), root dry mass (RDM) and Dickson quality index (DQI) of *Erythrina velutina* Willd plants evaluated at different collection seasons, irrigated with different salinities in different growing environments.

Tabela 2. Resumo das análises de variância para as variáveis: área foliar (AF), número de folhas (NF), altura de plantas (H), condutância estomática (gs), fotossíntese (A), transpiração (E), temperatura foliar (TF), massa seca da parte aérea (SDM), massa seca da raiz (RDM) e índice de qualidade de Dickson (DQI) de plantas de *Erythrina velutina* Willd avaliadas em diferentes épocas de coletas, irrigadas com diferentes salinidades em diferentes ambientes de cultivos.

SV	DF	Mean square									
		LA	NL	H	gs	A	E	LT	SDM	RDM	DQI
Environment (E)	1	272.94 ns	18.78 ns	11.98 ns	0.21 *	85.63 *	10.14 *	2.02 ns	1.28 ns	0.03 ns	0.22 ns
Residue (E)	6	409.29	30.55	12.29	0.01	4.09	1.23	1.34	2.64	0.26	0.06
Salinity (S)	1	223.11 **	75.11 *	17.58 **	1.26 *	35.01 *	22.79 ns	9.59 ns	16.91 **	3.39 **	1.26 **

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SV	DF	Mean square									
		LA	NL	H	gs	A	E	LT	SDM	RDM	DQI
Interaction (E x S)	1	489.85 ns	11.11 ns	60.71 *	0.02 ns	5.77 ns	9.33 ns	17.79 *	4.43 ns	0.32 ns	0.07 ns
Residue (S)	6	7670.01	6.31	5.72	0.08	44.16	8.63	1.25	0.18	0.05	0.01
Season (SS)	3	735.41 **	152.72 ns	61.33 **	0.04 ns	8.04 ns	3.27 ns	1.79 ns	53.91 **	4.62 **	2.51 **
Interaction (E x SS)	3	516.79 ns	19.58 ns	91.36 **	0.02 ns	7.68 ns	5.02 ns	2.61 ns	0.19 ns	0.21 ns	0.08 **
Interaction (S x SS)	3	125.64 **	34.28 ns	42.17 **	1.71 **	17.96 *	55.31 *	19.16 **	9.79 **	0.93 **	0.65 **
Interaction (E x S x SS)	3	109.53 ns	7.63 ns	8.88 ns	0.11 ns	13.24 ns	5.55 ns	1.58 ns	1.51 ns	0.16 ns	0.02 ns
Residue (S)	36	138.48	22.35	13.61	0.19	38.01	14.39	1.98	0.32	0.02	0.01
CV (%) A		29.44	23.08	23.93	18.72	11.95	10.66	3.51	27.75	28.74	26.16
CV (%) S		24.64	15.03	11.65	22.05	29.25	28.25	3.39	23.37	22.42	24.76
CV (%) E		26.57	28.3	17.96	23.76	26.41	26.48	4.26	20.96	23.11	21.71

SV = Sources of variation; DF - Degrees of freedom; CV = Coefficient of variation; * significant at 5% in the Tukey test; ** significant at 1% in the Tukey test; ns - not significant.

the days of the collection periods, however, there was an inhibition of up to 48.8% in the leaf area when the plants were irrigated with water of 5.0 dS m⁻¹ compared to the control treatment (0.8 dS m⁻¹). These results show that the effect of salinity is more severe when prolonged during the crop cycle. With regard to the number of leaves (Figure 1B), it can be seen that the use of 5.0 dS m⁻¹ water resulted in a 12.2% decrease in the number of *E. velutina* leaves.

The growth in height of *E. velutina* plants was partially limited when water with higher salinity was used (Figure 1C). For the evaluations at 40, 60 and 80 DAS compared to the 20 DAS data, there were increases per unit time of 19.1; 46.9 and 26.2% for the 0.8 (dS m⁻¹) control treatment. For the high salinity treatment (5.0 dS m⁻¹) there were increases of 7.9, 43.5 and 5.2%.

It can be seen in Figure 1D that, with the exception of the first collection date (20 DAS), the CSG environment favored greater plant height for all the evaluations carried out, showing superiority in relation to the OSG environment of 8.1, 16.3 and 39.1%, for the 40, 60 and 80 DAS collections, respectively.

Stomatal conductance fitted a quadratic

polynomial model for both irrigation water electrical conductivities over the course of the growing days (Figure 2A). The gs averages of the seedlings irrigated with 0.8 dS m⁻¹ water showed a reduction of 0.07 mol m⁻² s⁻¹ each growing day. As for the seedlings irrigated with 5.0 dS m⁻¹ water, there was a maximum value for stomatal conductance (0.88 mol m⁻² s⁻¹) at 50 days of cultivation, with a subsequent reduction in the averages. In relation to the environments (Figure 2B), it can be seen that the OSG environment showed higher gs averages when compared to the CSG environment, which showed a reduction of 18.4%.

For the photosynthesis variable, the *E. velutina* seedlings showed a quadratic behavior for both salinity levels over the course of the growing days (Figure 2C). It can be seen that with the application of 5.0 dS m⁻¹, there was an increase in the photosynthetic rate of the plants until the 50th day, when the highest photosynthetic rate was observed (17.35 μmol m⁻² s⁻¹) followed by a decrease in the averages. With regard to the environments, the CSG environment showed the lowest photosynthesis averages, with a 14.6% reduction compared to the OSG environment (Figure 2D).

Transpiration followed the same trend as

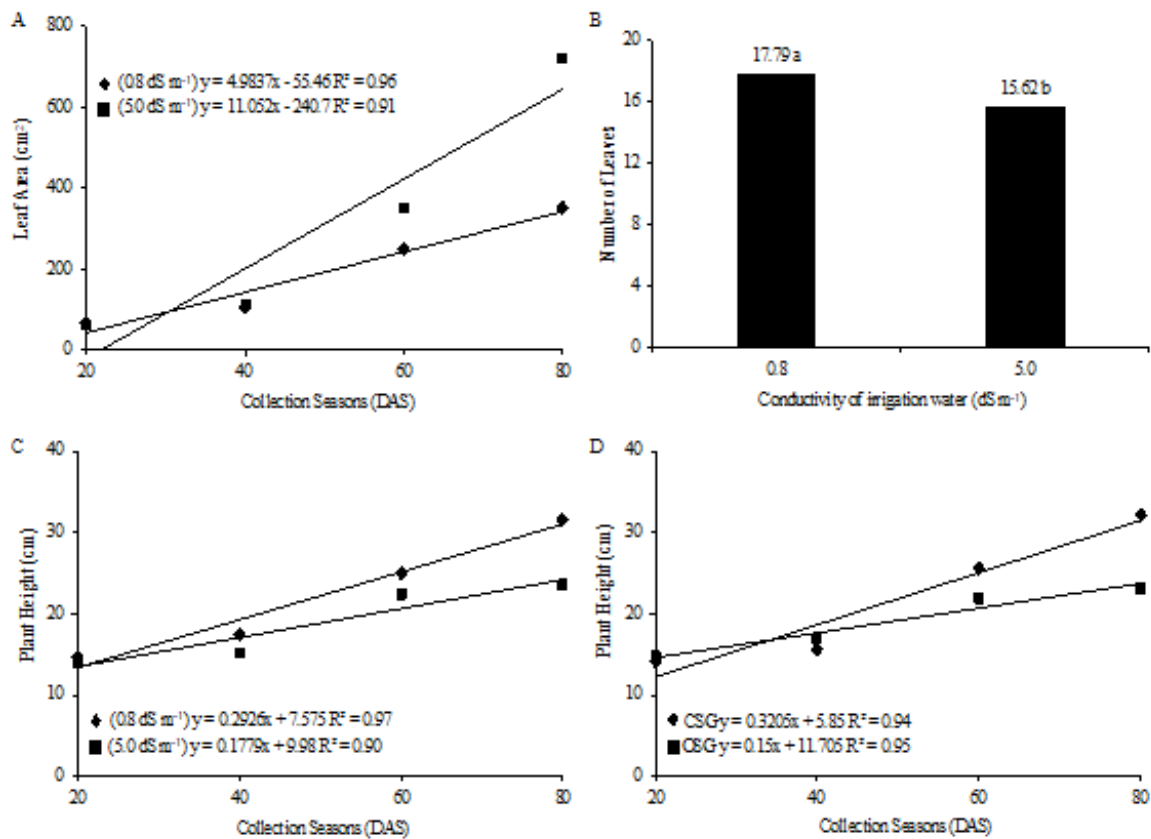
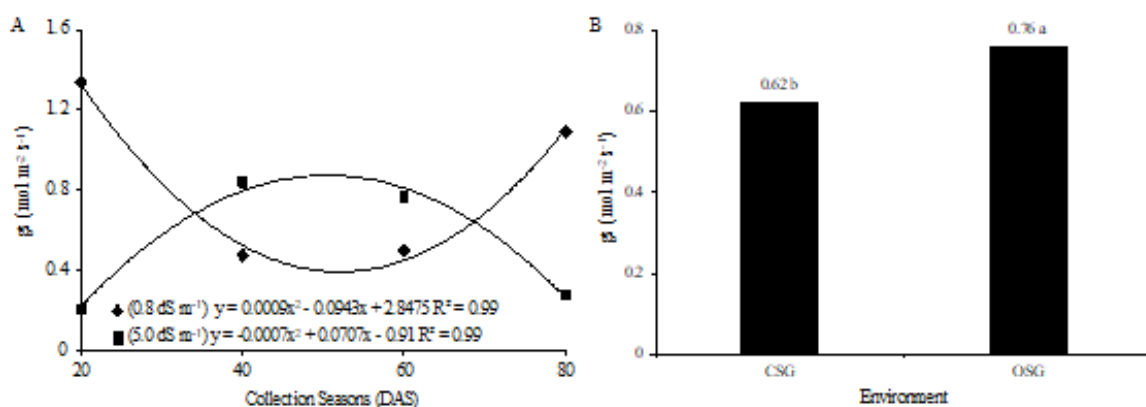


Figure 1. Leaf area (A and B) and number of leaves (C and D) of *Erythrina velutina* Willd plants assessed at different collection seasons (A and C) and irrigated with different irrigation water conductivities (B and D).

Figura 1. Área foliar (A e B) e número de folhas (C e D) de plantas de *Erythrina velutina* Willd avaliadas em diferentes épocas de coletas (A e C) e irrigadas com diferentes condutividades da água de irrigação (B e D).



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Figure 2. Stomatal conductance - g_s (A and B), photosynthesis - P_n (C and D) and transpiration - E (E and F) of *Erythrina velutina* Willd plants assessed at different collection seasons, irrigated with different salinities (A, C and E) and grown in different agricultural environments (B, D and F).

Figura 2. Condutância estomática - g_s (A e B), fotossíntese - P_n (C e D) e transpiração - E (E e F) de plantas de *Erythrina velutina* Willd avaliadas em diferentes épocas de coletas, irrigadas com diferentes salinidades (A, C e E) e cultivadas em diferentes ambientes agrícolas (B, D e F).

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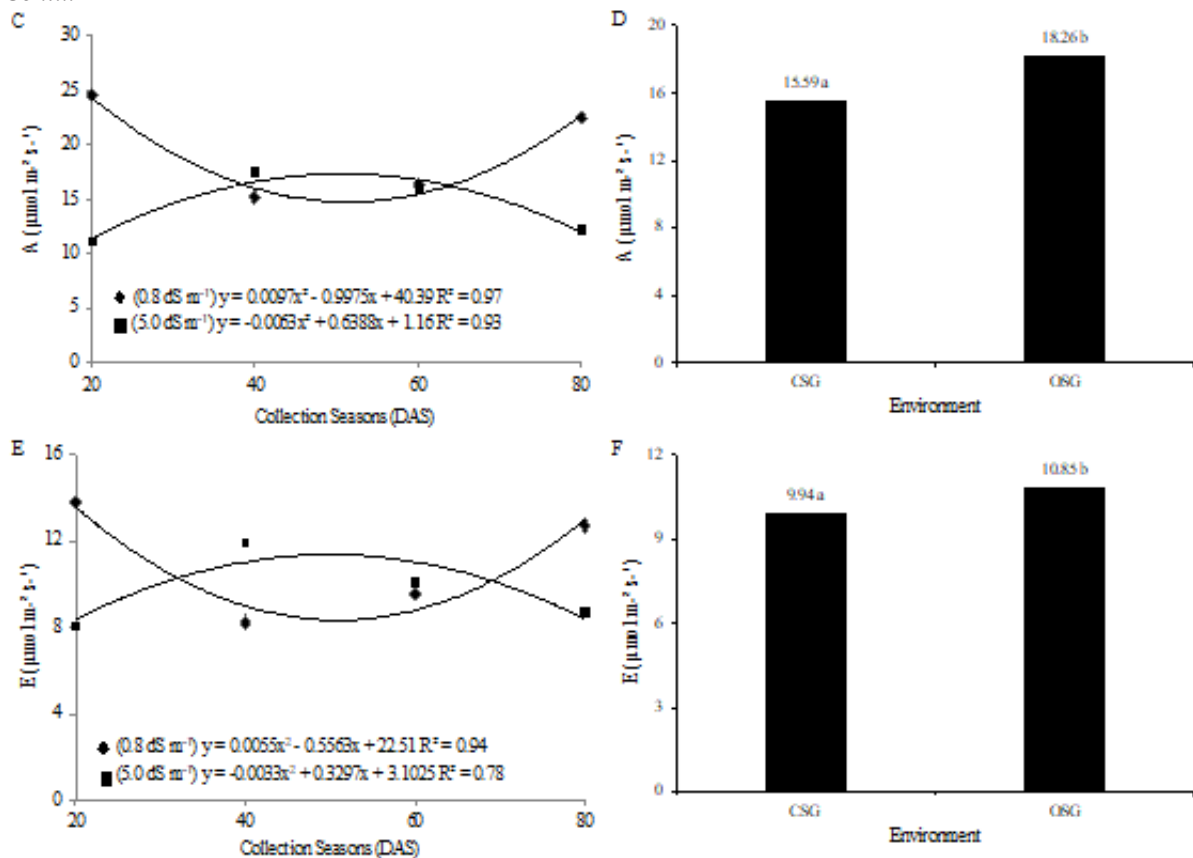


Figure 2. Stomatal conductance - g_s (A and B), photosynthesis - A (C and D) and transpiration - E (E and F) of *Erythrina velutina* Willd plants assessed at different collection seasons, irrigated with different salinities (A, C and E) and grown in different agricultural environments (B, D and F).

Figura 2. Condutância estomática - g_s (A e B), fotossíntese - A (C e D) e transpiração - E (E e F) de plantas de *Erythrina velutina* Willd avaliadas em diferentes épocas de coletas, irrigadas com diferentes salinidades (A, C e E) e cultivadas em diferentes ambientes agrícolas (B, D e F).

stomatal conductance, with maximum values at 5.0 dS m⁻¹ of 11.34 µmol m⁻² s⁻¹ at 50 days of cultivation (Figure 2E). With regard to the environments, environment 2 showed averages 8.4% higher than those of environment 1 (Figure 2F).

Leaf temperature was higher in the closed greenhouse at 40 and 60 days of cultivation, with a maximum value of 34.2 °C (Figure 3A). With regard to salinity, the highest average temperatures were observed in the seedlings that were in the CSG environment for the salinity level of 5.0 dS m⁻¹, whereas the CEa of 0.8 showed the lowest average leaf temperatures (Figure 3B).

The SDM showed higher values in the treatments irrigated with the water with the lowest electrical conductivity (0.8 dS m⁻¹), with

an increase of 0.038 g for each unit increase in evaluation time. The seedlings irrigated with water of 5.0 dS m⁻¹ grew less strongly, with an increase in the averages of 0.01 g (Figure 4A). RDM was higher in the seedlings irrigated with 5.0 dS.m⁻¹ water, with a maximum value of 2.55 g at 40 days of cultivation. The lowest RDM came from seedlings irrigated with 0.8 dS m⁻¹ water, with a maximum value of 1.29 g at 60 days of cultivation (Figure 4B).

The DQI fitted an increasing linear model for the greenhouse with a closed roof (CSG), showing an increase of 0.0129 over the growing seasons, while for the greenhouse open on the sides (OSG) the averages fitted a quadratic model, with increases of 0, 0227 each growing day (Figure 5A) With regard to salinity (Figure 5B), it can be seen that the averages of the seedlings irrigated with

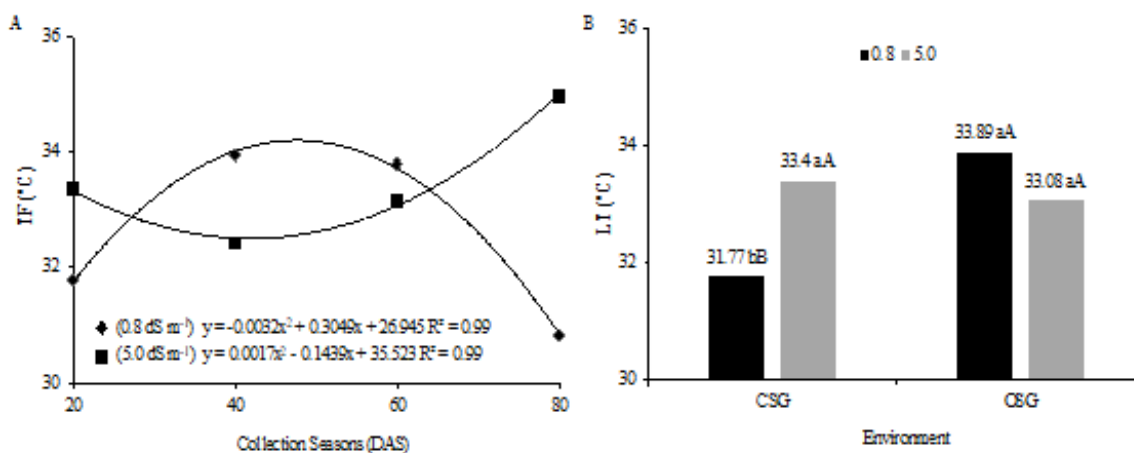


Figure 3. Leaf temperature of *Erythrina velutina* Willd plants assessed at different collection seasons, irrigated with different salinities (A) and cultivated in different growing environments (B)

Figura 3. Temperatura foliar de plantas de *Erythrina velutina* Willd avaliadas em diferentes épocas de coletas, irrigadas com diferentes salinidades (A) e cultivadas em diferentes ambientes de cultivos (B).

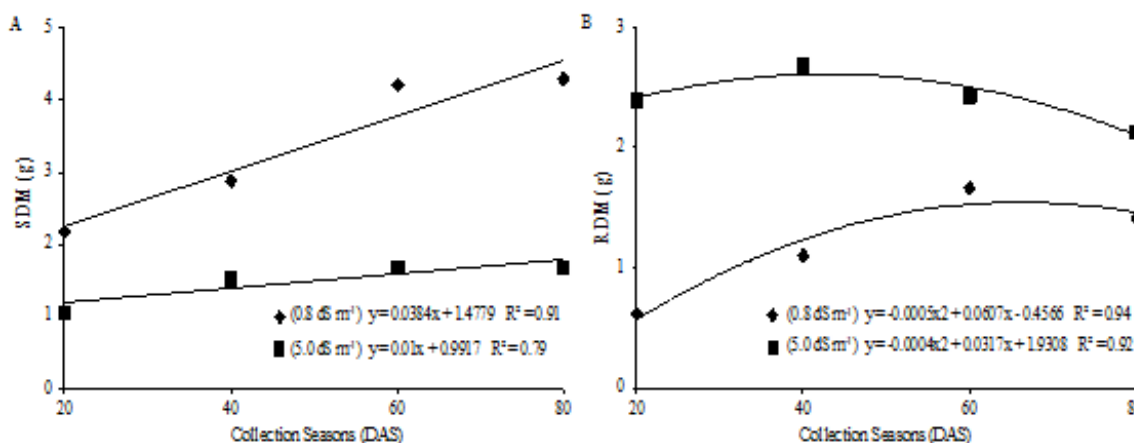


Figure 4. Shoot dry mass (A) and root dry mass (B) of *Erythrina velutina* Willd plants assessed at different collection seasons, irrigated with different salinities (A) and cultivated in different growing environments (B).

Figura 4. Massa seca da parte aérea (A) e massa seca da raiz (B) de plantas de *Erythrina velutina* Willd avaliadas em diferentes épocas de coletas, irrigadas com diferentes salinidades (A) e cultivadas em diferentes ambientes de cultivo (B).

0.8 dS m⁻¹ water fitted a quadratic model, with increases of 0.0268, while for the 5.0 dS m⁻¹ water there was a linear behavior, with increases of 0.007 each growing day.

4. DISCUSSION

Salt stress reduced the number of leaves and leaf area of mulungu (*Erythrina velutina* Willd) plants (Figure 1A and 1B), promoting less leaf expansion, CO₂ uptake and consequently a

physiological imbalance in the plants (Pereira Filho et al., 2019). It should be noted that saline stress can affect the osmotic potential of the soil solution, which affects the availability of water for plants, hindering its absorption and causing lower turgor pressure, in addition to the particular effect on cell elongation resulting in a reduction in the emission of new leaves (Veloso et al., 2021).

Results in which salinity reduced leaf

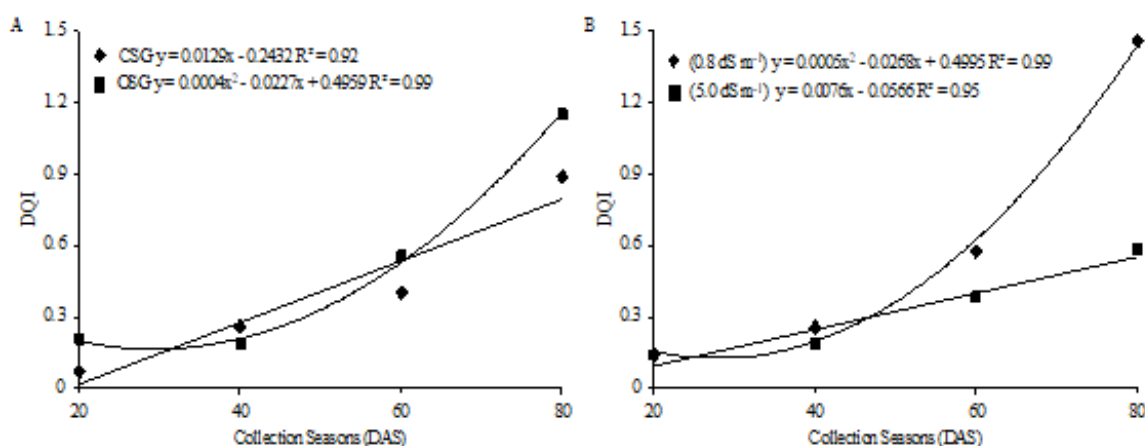


Figure 5. Dickson Quality Index of *Erythrina velutina* Willd plants assessed at different collection seasons, irrigated with different salinities (A) and grown in different growing environments (B).

Figura 5. Índice de Qualidade de Dickson de plantas de *Erythrina velutina* Willd avaliadas em diferentes épocas de coletas, e irrigadas com diferentes salinidades (A) e cultivadas em diferentes ambientes de cultivo (B).

area were obtained by Sousa et al. (2020), who, working with catingueira (*Caesalpinia pyramidalis*) seedlings, observed a reduction of up to 46.9% when comparing the CEa of (4.0 and 0.8 dS m⁻¹). The reducing effect of salinity on the number of leaves was also found for other natives such as oiticica (*Licania rigida* Benth) (Cavalcante et al., 2016).

Evaluating the growth of mulungu (*Erythrina velutina* Willd) seedlings, Guimarães et al. (2013) also found a reduction in the number of leaves in response to salinity; there was an effect of salinity from 2.5 dS m⁻¹ onwards, with 5.91 leaves being obtained per plant. The lowest values were obtained at a salinity of 7.5 dS m⁻¹, with 3.18 leaves per plant, resulting in a total reduction of 46.21%.

The reduction in plant height may have been caused by the stomatal closure caused by the osmotic effect of the salts in the irrigation water, as a way of reducing water loss through transpiration, restricting the plant's photosynthetic capacity and consequently limiting its development (Taiz et al., 2017). However, reductions in growth can also be due to changes in cell walls, which inhibit cell expansion under conditions of salt stress.

Results similar to those of this study were reported by Guimarães et al. (2013) when working with *E. velutina*. The authors state that the greatest heights were observed when the seedlings were irrigated with water with

a salinity of 0.5 dS m⁻¹ (24.43 cm). When irrigated with high salinity water (7.5 dS m⁻¹), the plants reached an average height of 7.5 cm.

In line with the results reported by Guimarães et al. (2013) and those obtained in this study, it can be inferred that mulungu (*E. velutina*) seedlings are sensitive to salinity in irrigation water and cannot tolerate water salinities above 0.5 and 0.8 dS m⁻¹, respectively, without losing seedling quality.

In relation to the growing environments, higher humidities such as those provided by the CSG environment favored a better water status of the plants, enabling an improvement in their photosynthetic activity and turgidity, parameters that are necessary for their growth (Pacheco et al., 2013).

This behavior is due to the different temperatures in both environments. It was found that the CSG environment had the highest temperatures and the lowest relative humidity values, causing a greater vapor pressure deficit than the OSG environment. Consequently, the plants grown in this environment used partial stomata closure as a mechanism to adapt to the conditions imposed, as a way of reducing water loss and maintaining cell turgidity.

In relation to the growing conditions, there was a higher photosynthetic rate in the plants that were in the OSG environment, due to the higher stomatal conductance also observed in

this environment when compared to the CSG environment, favoring a greater diffusion of CO₂ in the stomatal cells, increasing the photosynthetic rate.

The application of water with an electrical conductivity of 5.0 dS m⁻¹ at 50 DAS favored greater stomatal opening, benefiting the acquisition of CO₂ for photosynthesis. However, there were reductions in *g_s* as the days went by, indicating that there was a greater supply of salts to the soil due to the frequency of irrigation, inducing the closure of stomata to reduce water loss since its absorption was restricted, while also preventing the absorption of toxic ions such as Na⁺ and Cl⁻, reducing toxicity by specific ions (Taiz et al., 2017).

With regard to the environments, the increase in evaporative demand in the CSG environment occurred due to the higher temperature values, possibly inducing a lower supply of water to the plant than the losses, leading to stomatal closure as a way of avoiding a reduction in the leaf's water potential (Rocha et al., 2017). Bessa et al. (2017) also observed reductions in stomatal conductance in *E. velutina* as salinity increased, with consequent reductions in photosynthetic rate and transpiration.

The increase in photosynthetic rate up to 50 days of cultivation may be due to an adaptation of the plants' survival to the saline environment. However, as time goes by, the soil's electrical conductivity tends to increase due to continuous irrigation with high electrical conductivity water, causing limitations in its development parameters. The photosynthetic rate of plants under salt stress can be inhibited both by the high accumulation of sodium in the chloroplasts, affecting the biochemical processes involved in photosynthesis (Taiz et al., 2017) and by the stomatal closure forced by the accumulation of salts (Na⁺ and Cl⁻) to conserve water (Zanetti et al., 2019).

It can be seen that the behavior of the photosynthetic rate was similar to that of stomatal conductance, indicating that the drop in net CO₂ assimilation was due to the partial closure of the stomata, caused by the osmotic effect. However, the increase in the concentration of Na⁺ and Cl⁻ ions in leaf tissues also contributes to the reduction in photosynthetic rate under salinity conditions, since it reduces the turgidity of leaf tissues, causing damage to enzymes and membrane structures, affecting photosynthetic

performance (Lima et al., 2017).

Zapelini et al. (2020) also observed reductions in the photosynthetic rates of *Eucalyptus camaldulensis* Dehnh plants over the course of days when subjected to salinity, where they emphasized that this behavior is attributed to the species' adaptation to saline conditions.

Like photosynthesis, transpiration is regulated by stomatal opening. Thus, when stomata open to acquire the CO₂ needed for photosynthesis, water is automatically lost to the environment. In addition, transpiration is closely related to leaf area. With the reduction in leaf area when irrigated with 5.0 dS m⁻¹ water, there was also a reduction in transpiration. Lopes et al. (2019) describe that the smaller leaf area, as observed and represented in Figure 1A of this work, can be attributed to the toxicity caused by the increased concentration of salts in the soil. The reduction in leaf area as a result of salt stress occurs so that there is less water loss through transpiration, and consequently less absorption of water with high salt levels.

It is important to note that the higher transpiration rate during some evaluation periods in the plants that were irrigated with 5.0 dS m⁻¹ water may be a strategy of the species to regulate cellular water potential and adapt to unfavorable environmental conditions (Sá et al., 2019).

Leaf temperature followed the same trend as transpiration rate and stomatal conductance, precisely because transpiration is the main mechanism involved in its regulation. Thus, with the reduction in stomatal opening as a mechanism of adaptation to the stress exposed, there was also a reduction in leaf transpiration, consequently raising the temperature of the leaf tissue (Feitosa et al., 2016). Prazeres et al. (2015) point out that if there are fewer stomata openings, there will be a reduction in transpiration with a consequent increase in leaf temperature.

It can be seen that the highest temperatures were found in the plants that were in the CSG environment. As this environment had higher temperatures and lower relative humidity values, soil humidity was consequently reduced, affecting transpiration and reducing the dissipation of latent heat, resulting in an increase in leaf temperature (Oliveira et al., 2020). Simões et al. (2018) point out that the

increase in leaf temperature also contributes to a reduction in the photosynthetic rate, mainly due to a reduction in enzymatic activity.

The lower SDM in the 5.0 dS m⁻¹ water is mainly due to the osmotic effect of the salts, which causes a water deficit condition. Thus, under water restriction, the plant has a constant stomatal closure and consequently less CO₂ uptake, as previously observed. As a result, there is less production of photoassimilates and, consequently, plant development is reduced (Cruz et al., 2020). Sá et al. (2017) state that when plants are subjected to salt stress, they tend to decrease leaf emission and elongation as a way of adapting to unfavorable environments for their development, consequently contributing to a reduction in RDM.

Similar results were observed by Ribeiro et al. (2017) in *E. velutina*, where they attributed this behavior to the physiological drought caused by the osmotic effect of the salts in the irrigation water, since changes occur in the plant's metabolism, affecting its development. Guimarães et al. (2013), also working with *E. velutina*, observed a reduction in dry mass, noting that the production of aerial biomass is inversely proportional to the increase in salinity. The authors also found that mulungu does not tolerate salinity above 0.5 dS m⁻¹ in its initial development phase without a loss in seedling quality.

For the RDM, according to Silva et al. (2019b), when stress is imposed, root growth is immediately reduced as a result of changes in cell water parameters. In addition, the roots are the organs of the plant that have direct contact with the salts, leading to deleterious effects on growth, since greater energy expenditure is required to absorb water.

However, Silveira et al. (2016) state that there are some mechanisms that allow the osmotic potential to be reduced and the turgidity potential of the cells to be increased, which will favor water absorption and preserve root development. Thus, even when in contact with the salts in the medium, root growth is less affected than the aerial part. Lopes et al. (2019) point out that the reduction in the dry mass of the aerial part and the dry mass of the root are caused by reduced water absorption and ion toxicity, which consequently cause metabolic imbalance when concentrated in plant tissues.

The Dickson quality index (DQI) is a good indicator of seedling quality, as it takes into account several important morphophysiological parameters and allows you to select those that have the greatest potential for development in the field.

It is possible that the milder temperatures in the open greenhouse on the sides provided better development conditions for the mulungu seedlings, favoring the plants' water status and reflecting on their development and survival potential. Meanwhile, in the closed greenhouse, the higher vapor pressure deficit reduced the availability of water for the seedlings, as can be seen in Figs. 2B and 2F, consequently affecting their development and reflecting on the quality of the seedlings.

With regard to the growing environments, it can be seen that the seedlings grown in an open greenhouse on the sides showed DQI values above the minimum established from 20 DAS and increasing steadily until 80 DAS. On the other hand, the seedlings grown in the closed greenhouse had a DQI below the minimum value established in the first collection period (20 DAS), indicating that these seedlings did not yet have the potential to establish themselves in the field. However, as the growing days went by, the quality of the seedlings from this environment improved increasingly.

It can be seen that salinity (Figure 5B) affected the quality of *E. velutina* seedlings, which showed the lowest DQI values during all the collection periods compared to the 0.8 dS m⁻¹ level. This reduction is mainly due to the reduction in growth variables observed earlier, such as plant height and biomass production, parameters that are used to calculate the DQI.

This suggests the possibility of using brackish water to produce seedlings of this species, but with moderate salinity levels (2.0 to 3.0 dS m⁻¹), which predominate in underground wells in the Brazilian semi-arid region. Melo Filho et al. (2017) observed negative effects of irrigation water salinity on the production of pitombeira (*Talisia esculenta* (A. St. Hil) Radlk) seedlings, where at high salinity levels, there was a drastic reduction in the Dickson quality index.

5. CONCLUSION

Salinity in irrigation water causes reductions

in vegetative growth and gas exchange in *E. velutina* plants, culminating in the formation of lower quality seedlings.

The seedlings produced in the open shade environment on the sides and with water of lower salinity showed a higher Dickson quality index.

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AUTHOR CONTRIBUTIONS

G.G.S. - Conceptualization, investigation, supervision, review and editing; C.F.L. - Conceptualization, investigation, supervision, review and editing. J.R.S.S. - writing, reviewing and editing. F.B.S.J. - writing, reviewing and editing. A.M.M. - writing, reviewing and editing. T.V.A.V. - Conceptualization, investigation, review and editing.

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