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Research Paper

Assesment the adaptability of *Jacaranda mimosifolia* L. to Ahvaz climete condition under salinity and water stresses

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Abstract

To enrich the plant diversity of the landscape, introducing new ornamental trees such as Jacaranda tree is a useful solution. Therefore, it is essential to investigate Jacaranda compatibility with the limiting factors of different regions. This research was aimed at elucidating the influence of combined salinity levels (1, 2.5, 4, and 5.5 ds.m^{-1} NaCl) and low irrigation levels (100, 80, and 60% FC) on the some morpho-physiological characteristics, consist of fresh and dry weight of areal part, relative water content (RWC), malondialdehyde (MDA), electrolyte leakage (EL), sodium (Na) and potassium (K) content of Jacaranda plants under field condition as a factorial experiment based on randomized complete block design with 4 replicates in 2023. The results indicated that, the growth of Jacaranda decreased gradually under both salinity and drought stress depending on the severity of the stress. The fresh and dry weight of the aerial part showed the greatest reduction under 5.5 dS.m^{-1} NaCl and 60% (FC) compared to 1 dS.m^{-1} NaCl and 100% FC. Low irrigation as accompanied with salinity significantly affected on EL enhancement and the highest EL was attained in 5.5 ds.m^{-1} and 60%FC. Similarly, the highest MDA and Na content have been obtained in the interaction effect of 5.5 ds.m^{-1} NaCl×60% FC. Conversely, the plants exposed to drought and salinity, indicated lower RWC and K content by severity-dependent changes. Overall, to produce Jacaranda seedlings in tropical and sub tropical nurseries, one should carefully use non-saline water and soil.

Introduction

Abiotic stresses exhibit progressive development under the global climatic changes in the current era (Nadeem et al., 2019). These stresses often correlate with a reduction in the soil water and cultivable capacity of the soil (Bhat et al., 2021). Water deficit is one of the most important limiting factors in agronomic production especially in arid and semi-arid regions. Iran with about 250 mm annual rainfall average, is classified as an arid and semi-arid area in the world and thereby exposes to drought unquestionably (Fathian et al., 2015).

Water stress affecting plant growing and has negative consequences on plant growth parameters and metabolic pathways including water relations, photosynthetic assimilation, antioxidant defense and mineral absorption resulting in reduction of crop quality and yield considerably (De Vries et al., 2020). In a study, reduced growth resulted of drought stress caused changes in several morphological traits such as reduced shoot length, shoot diameter, leaf area and fresh weight of fig tree leaves. The authors explained the vegetative growth retardation in fig trees is related to the reduced relative water content (RWC) (Darwish et al., 2015).

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Drought negatively affected on plant water potential, cell division and photosynthesis, therefore both plant growth and yield are impacted by drought stress (Brito et al., 2019). The reason of the restriction in growth rate due to water deficit is ascribed to the adverse effect of this stress on the photosynthetic activity (Proietti et al., 2013). Reduced relative water content as an important indicator of water status in plants is directly associated with soil water content (Mohamed and Latif, 2017). Water deficit has a direct relationship with the amount of malondialdehyde (MDA) (Petridis et al., 2012). MDA is a main compound in making damage on membranes and cell death in stressed plants subjected to drought (Wu et al., 2015).

Soil salinization resulting from the accumulation of water-soluble salts in the soil (Munns and Tester, 2008). Worldwide, salt stress affects approximately 20% of the land and this rate has been steadily enhancing for a few decades (Khan et al., 2022). Upon exposure to salinity, the structure of cell wall changes. Leaf turgor pressure and photosynthesis exhibit the significant reduction and overall, leaf water and leaf area index decrease (Rodriguez Dominguez et al., 2016). The decrease of growth parameters like the reduced shoot length and diameter, the number of new shoots and dry weight of shoot and root was reported due to enhanced salinity level (Zhu et al., 2015). Salimpour et al. (2019) implied salt stress caused to decrease of leaf RWC as well as potassium (K) in 20-years fig stocks. Likewise, the increased electrolyte leakage (EL) as a result of salinity stress was confirmed by Akhter et al. (2021). In salinity stress and activation of reactive oxygen species (ROS), lipid peroxidation enhanced in membranes, the lipid peroxidation rate could be exhibited by MDA content. MDA rate is evident of cell stability in exposition to oxidative damage (Chen et al., 2018).

as a member of the dicot Bigniniaceae family, is considered as an endemic plant of South America. Then it distributed to the other tropical areas around the world (Sanchez, 2011). This deciduous tree often reach 20 m in height and can produce abundant, imazing, and long-lasting violet flowers (Pasiecznik, 2014).

To enrich the local plant species diversity, the introduction of new trees for urban landscape is inevitable necessity (Coban et al., 2021). To successfully cultivate a tree outside its natural environment, the assessment of its acclimation and good match with new condition is reasonably imperative (Lenzner et al., 2021). In order for a new plant to adapt to a new environment, it must be able to resist the limiting factors of this environment. Since the main limiting factors in the arid and semi-arid regions are the saline soil and water deficit, therefor, evaluation the resist of the new plant to these factrors is necessity for determining the adaptability rate to this regions. Therefore, it is essential to investigate Jacaranda compatibility with the limiting factors of different regions such as Ahvaz condition, which has a hot and dry climate with salty soil.

Materials and Methods

Experimental Site, Plant Materials, and Treatments

This experiment was conducted at the experimental field of the Horticultural Sciences Department in Shahid Chamran University of Ahvaz (31º19′ N, 48º40′ E, elevation above sea level: 20 m) in Iran (Figure 1). Murashige and Skoog medium (MS) free of hormones and sterile conditions were used for *in vitro* sowing of the seeds which had low germination capacity (Figure 2 A and B). After germination, the seedlings were maintained in controlled conditions including 25 °C and 16 h photoperiod for 6 months (Figure 2 D and E) and then transplanted to pots containing a mixture of agricultural soil, sand, and animal manure. After the seedlings were established in the field, low irrigation and salinity treatments were applied (Figure 2 F and G).

The treatments consisted of 90 days of low irrigation regimes including 100%, 80% and 60% FC, and salinity levels including 1 dS/m, 2.5 dS/m, 4 dS/m, and 5.5 dS/m NaCl. Also, the depth of irrigation water was 41 mm for all treatments. The maximum root depth was 27 cm and the pot area was 25 cm (Tables 1). Cosidering that the maximum tolerance to water salinity in this plant was 4 ds/m, and the salinity of the Karun River irrigation water between 2.5 to 4 dS/m, these salinity levels were selected.

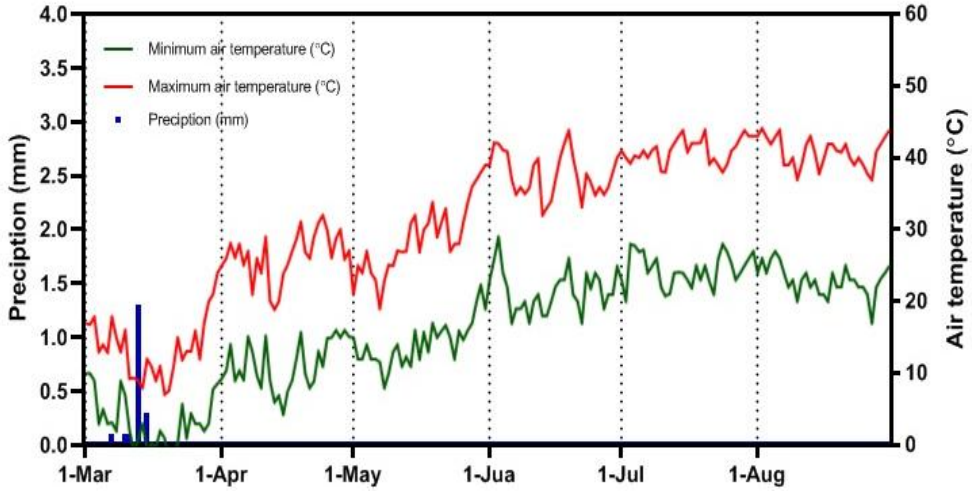


Fig. 1- Air temperature and precipitation during applying the treatments.



Fig. 2- Steps of the experiment: Desinfected jacaranda seeds (A), In vitro seed germination (B), Ex-vitro seedling (C), Seedlings transered to the soil (D), Seedlings ready to transfer to field (E), Seedlings under different Treatments (F) and the seedling after the end of the experiment (G).

Table 1- Soil property table

K (Exe) (mg.Kg^{-1})	*P (mg)*	*N (%)*	*Na (mg.L^{-1})*	*K (mg.Kg^{-1})*	*Ca (mg.L^{-1})*	*CCE (%)*	*OC (%)*	*CEC (mol.Kg^{-1})*	*EC (ds.m^{-1})*	*pH*	*Texture*
275	16	0.036	23	0.56	13.76	%48	0.53	14.4	3.8	7.72	Clay

Measured traits

At the end of the experiment, various morphological characteristics of the plants including the fresh and dry weight of aerial part and root, shoot and root diameter, internode distance, length of auxiliary shoot and root length, and RWC, MDA, EL, and sodium (Na) and K content were measured.

Na and K content were meausered in the dry-ashed jacaranda leaves were digested through the method of Benton-Jones (1977) by flame photometer (Jenway PSP7, England) at 500ºC. The MDA content was meausred according to Stewart and Bewley, 1980.

EL was measured according to Lutts et al. (1996). Leaf discs of the middle part of completely developed leaves washed three times with distilled water to eliminate surface contaminants, and were located in distilled water. The samples were shaken (150 rpm) at room temperature for 24 h. The EL of the solution (EL1) was determined by EC-meter (Jenway 4330, USA). The same samples were then autoclaved at 121 °C for 20 min, and after cooling, again EL measured (EL2). EL was calculated using equesion (1) and expressed as percentage.

$$EL1 \times 100 / EL2 \quad (1)$$

To measure the leaf RWC, initially, leaves were weighed (FW). Afterwards, the leaf samples were rehydrated for 20 hours and then weighted to obtain leaf turgid weight (TW). Eventually, dried for 48 hours at 80ºC and then weighted to attain dry weight (DW). RWC was calculated using equation (2) (Gucci et al., 1997).

$$RWC\ (\%) = [(FW - DW)/(TW - DW)] \times 100 \quad (2)$$

The water use efficiency was calculated based on ratio of leaf dry weight (Kg) on the water consumption (m^3) (Amanullah and Stewart. 2013).

Statistical analysis

The experiment was carried out based on a complete randomized block in a factorial arrangement with 4 replications. The experimental data were analyzed using SAS software (v.9.4). Statistical significance at ρ=0.05 level was elucidated with Duncan's multiple range test. Before starting the statistical tests, the obtained data was checked for normality and homogeneity of variance, then the statistical test was performed.

Results and Discussion

Fresh and dry weights of aerial part and root

The changes in morphological characteristics in Jacaranda affected by different salinity and drought levels are presented in Tables (2, 3 and 4). In 5.5 $dS.m^{-1}$ NaCl, aerial part fresh and dry weight revealed a 49% and 63% reduction respectively, versus 1 $dS.m^{-1}$ NaCl (Table 2). Additionally, exposure to salinity stress caused a significant decrease in root fresh and dry weight in a level-dependent manner with a 54% and 29% decline in 5.5 $dS.m^{-1}$ NaCl against 1 $dS.m^{-1}$ NaCl respectively.

Regardless of salinity stress, severe drought stress at 60% FC reduced the fresh and dry weight of the aerial parts as well as the fresh and dry weight of the roots by an average of 25%, 34%, 30% and 47% compared to 100% FC, respectively. In terms of significant interaction effects between drought and salinity, the combination of 1 $dS.m^{-1}$ NaCl and 100% FC resulted in the highest aerial part fresh and dry weight as well as root dry weight (Table 2). Sabah et al. (2022) found that reducing the salt concentration of the Murashige and Skoog (MS) medium to half or one-quarter of the standard level enhanced the shoot and root growth indices of Jacaranda plantlets respectively, *in vitro*.

Table 2- Effects of salinity and drought on aerial part fresh and dry weight and root fresh and dry weight of *Jacaranda mimosifolia*

Source of variance	Aerial part fresh weight (g)	Aerial part dry weight (g)	Root fresh weight (g)	Root dry weight (g)
Salinity				
1 ds.m^{-1} NaCl	68.59±8.37 a	52.84±8.32 a	42.24±8.70 a	20.62±6.73 a
2.5 ds.m^{-1} NaCl	58.98±6.99 b	43.48±7.31 b	32.75±6.95 b	18.41±5.24 b
4 ds.m^{-1} NaCl	48.49±10.36 c	34.79±10.58 c	29.03±6.87 c	17.84±4.51 b
5.5 ds.m^{-1} NaCl	34.81±5.13 d	19.41±5.56 d	19.37±2.86 d	14.59±3.42 c
Drought				
100% FC	59.86±14.10 a	44.69±14.17 a	36.14±11.01 a	23.35±3.84 a
80% FC	53.45±13.48 b	38.65±13.32 b	31.28±9.52 b	17.92±3.38 b
60% FC	44.84±12.95 c	29.55±12.61 c	25.11±7.93 c	12.32±2.37 c
Salinity*Drought				
1 ds.m^{-1} NaCl*100% FC	77.19±2.53 a	61.34±3.00 a	50.11±3.72 a	28.45±1.14 a
1 ds.m^{-1} NaCl*80% FC	68.71±3.83 b	52.55±3.25 b	42.56±4.41 b	19.98±2.42 cd
1 ds.m^{-1} NaCl*60% FC	59.88±6.25 c	44.62±6.93 c	34.04±8.01de	13.42±3.89 e
2.5 ds.m^{-1} NaCl*100% FC	63.01±5.74 bc	47.22±5.16 bc	37.42±4.62 c	23.38±1.70 b
2.5 ds.m^{-1} NaCl*80% FC	60.75±4.24 c	46.54±6.05 bc	34.91±5.69 e	19.62±3.60 d
2.5 ds.m^{-1} NaCl*60% FC	53.17±6.52 d	36.67±5.24 d	25.91±4.26 fg	12.22±1.49 e
4 ds.m^{-1} NaCl*100% FC	59.43±3.41 c	46.15±3.57 bc	35.63±5.24 d	22.89±1.47 bc
4 ds.m^{-1} NaCl*80% FC	50.05±5.31 d	35.97±5.41 d	28.02±4.29 f	18.23±1.35 d
4 ds.m^{-1} NaCl*60% FC	35.98±1.94 ef	22.24±2.36 e	23.43±4.45 g	12.41±1.38 e
5.5 ds.m^{-1} NaCl*100% FC	39.81±5.61 e	24.05±6.51 e	21.39±2.80gh	18.68±2.14 d
5.5 ds.m^{-1} NaCl*80% FC	34.29±0.98 ef	19.52±2.15 ef	19.65±2.43h	13.84±1.05 e
5.5 ds.m^{-1} NaCl*60% FC	30.33±1.08 f	14.65±1.30 f	17.06±1.18hi	11.24±0.96 e
Significance				
Salinity	**	**	**	**
Drought	**	**	**	**
Salinity*Drought	*	*	ns	*

ns, *, ** non-significant or significant at $p \leq 0.05$ and 0.01, respectively. Values represent means ± standard deviation of four independent replications (n = 4). Different letters within the same column indicate significant differences at $p \leq 0.05$ among the treatments, according to Duncan's multiple range test.

Table 3- Effects of salinity and drought on shoot diameter, number of node, average internode distance and average length of auxiliary shoot in *Jacaranda mimosifolia*

Source of variance	Shoot diameter (mm)	Number of node	Average internode distance (mm)	Average length of auxiliary shoot (cm)
Salinity				
1 ds.m^{-1} NaCl	8.74±1.59 a	20.33±6.65 a	20.93±6.41 a	7.76±1.96 a
2.5 ds.m^{-1} NaCl	7.77±1.82 b	17.92±5.25 b	18.30±5.29 b	5.99±1.69 b
4 ds.m^{-1} NaCl	5.69±1.81 c	17.50±4.39 b	17.97±4.51 b	4.28±1.49 c
5.5 ds.m^{-1} NaCl	4.60±1.39 d	14.08±3.43 c	14.32±3.50 c	3.36±1.87 d
Drought				
100% FC	8.25±2.02 a	22.94±3.85 a	23.36±4.11 a	7.19±1.96 a
80% FC	6.62±2.09 b	17.44±3.39 b	17.80±3.36 b	5.49±1.91 b
60% FC	5.24±1.83 c	12.00±2.42 c	12.48±2.35 c	3.36±1.73 c
Salinity*Drought				
1 ds.m^{-1} NaCl*100% FC	10.22±0.70 a	28.00±1.22 a	28.42±1.07 a	9.86±0.72 a
1 ds.m^{-1} NaCl*80% FC	8.96±0.66 b	19.75±2.49 cd	20.27±2.41 c	8.09±0.60 ab
1 ds.m^{-1} NaCl*60% FC	7.04±1.24 bc	13.25±3.96 e	14.09±3.62 d	5.33±0.53 c
2.5 ds.m^{-1} NaCl*100% FC	9.25±0.97 a	23.00±1.73 b	23.47±1.85 b	7.48±1.34 a
2.5 ds.m^{-1} NaCl*80% FC	7.77±1.59 b	19.00±3.54 d	19.32±3.49 c	6.13±0.97 ab
2.5 ds.m^{-1} NaCl*60% FC	6.30±1.45 c	11.75±1.48 e	12.11±1.46 d	4.35±0.96 c
4 ds.m^{-1} NaCl*100% FC	7.81±1.11 b	22.50±1.50 bc	23.28±1.67 b	5.90±0.73 b
4 ds.m^{-1} NaCl*80% FC	5.06±0.80 c	17.75±1.09 d	17.95±0.94 c	4.35±0.44 c
4 ds.m^{-1} NaCl*60% FC	4.21±0.90 d	12.25±1.30 e	12.67±1.08 d	2.59±0.69 e
5.5 ds.m^{-1} NaCl*100% FC	5.71±1.47 c	18.25±2.17 d	18.26±2.93 c	5.53±0.97 bc
5.5 ds.m^{-1} NaCl*80% FC	4.68±0.92 d	13.25±0.83 e	13.66±0.77 d	3.37±0.23 d
5.5 ds.m^{-1} NaCl*60% FC	3.41±0.38 e	10.75±0.83 e	11.05±0.93 d	1.18±0.19 f
Significance				
Salinity	**	**	**	**
Drought	**	**	**	**
Salinity*Drought	ns	*	*	ns

*ns, *, ** non-significant or significant at $p \leq 0.05$ and 0.01, respectively. Values represent means ± standard deviation of four independent replications (n = 4). Different letters within the same column indicate significant differences at $p \leq 0.05$ among the treatments, according to Duncan's multiple range test.*

Table 4- Effects of salinity and drought on root diameter, root volume, root length and electrolyte leakage in *Jacaranda mimosifolia*

Source of variance	Root diameter (mm)	Root volume (cm^3)	Root length (cm)	Electrolyte leakage (%)
Salinity				
1 $ds.m^{-1}$ NaCl	13.06±6.35 a	49.01±8.40 a	52.57±7.91 a	19.07±7.67 d
2.5 $ds.m^{-1}$ NaCl	10.81±5.40 b	39.72±6.85 b	44.06±6.99 b	27.12±11.38 c
4 $ds.m^{-1}$ NaCl	10.21±4.24 b	29.36±10.49 c	35.57±10.43 c	39.41±8.89 b
5.5 $ds.m^{-1}$ NaCl	6.42±3.38 c	15.55±5.21 d	19.80±5.56 d	50.21±6.98 a
Drought				
100% FC	15.53±3.81 a	40.50±14.12 a	44.68±13.79 a	26.65±13.19 c
80% FC	10.10±3.60 b	33.98±13.58 b	38.97±13.34 b	34.26±13.50 b
60% FC	4.74±2.34 c	25.75±12.78 c	30.35±12.49 c	40.96±14.12 a
Salinity*Drought				
1 $ds.m^{-1}$ NaCl*100% FC	20.25±0.74 a	57.41±3.95 a	59.70±4.20 a	13.55±3.99 g
1 $ds.m^{-1}$ NaCl*80% FC	12.81±2.86 cd	49.22±4.28 b	52.99±4.17 b	17.63±4.73 f
1 $ds.m^{-1}$ NaCl*60% FC	6.11±3.47 e	40.40±5.77 cd	45.03±6.70 d	26.11±7.50 ef
2.5 $ds.m^{-1}$ NaCl*100% FC	16.18±1.90 b	44.05±5.78 bc	48.14±5.21bc	17.71±4.56 f
2.5 $ds.m^{-1}$ NaCl*80% FC	11.84±3.23 d	40.77±4.13 cd	46.46±5.07cd	28.94±9.15 e
2.5 $ds.m^{-1}$ NaCl*60% FC	4.41±1.55 e	34.32±6.44 de	37.57±5.40de	34.72±11.59cd
4 $ds.m^{-1}$ NaCl*100% FC	15.15±1.53 bc	40.01±3.93 cd	46.58±3.98 cd	32.24±9.49 d
4 $ds.m^{-1}$ NaCl*80% FC	10.14±1.38 d	31.12±6.37 e	36.69±5.82 de	40.21±4.04 c
4 $ds.m^{-1}$ NaCl*60% FC	5.33±1.24 e	16.95±1.89 fg	23.45±2.69ef	45.77±6.18 bc
5.5 $ds.m^{-1}$ NaCl*100% FC	10.55±1.97 d	20.52±5.91 f	24.31±6.62 e	43.11±3.95c
5.5 $ds.m^{-1}$ NaCl*80% FC	5.61±0.89 e	14.80±1.34 fg	19.74±2.59 f	50.27±3.07 b
5.5 $ds.m^{-1}$ NaCl*60% FC	5.11±0.99 e	11.32±1.27 g	15.35±1.45fg	57.24±4.62 a
Significance				
Salinity	**	**	**	**
Drought	**	**	**	**
Salinity*Drought	*	*	ns	ns

*ns, *, ** non-significant or significant at $p \leq 0.05$ and 0.01, respectively. Values represent means ± standard deviation of four independent replications (n = 4). Different letters within the same column indicate significant differences at $p \leq 0.05$ among the treatments, according to Duncan's multiple range test.*

Shoot diameter, number of node, average internode distance and average length of auxiliary shoot

Salinity induced level-dependent reductions in shoot diameter, number of nodes, average internode distance and average length of auxiliary shoots in 5.5 $dS.m^{-1}$ NaCl, displaying a 47%, 31%, 31%, and 57% decrease respectively, compared to the respective 1 $dS.m^{-1}$ NaCl.

Severe drought (60% FC) induced the lowest shoot diameter and number of nodes, with a remarkable reduction of 36% and 48% compared to the respective controls respectively. Likewise, in 60% FC compared with 100% FC, significant retardation was realized in the average internode distance and average length of auxiliary shoots by 46% and 53% respectively.

The interaction effect of salinity and drought was significant in the number of nodes as well as the average internode distance, and the highest amounts of these traits were obtained in 1 $dS.m^{-1}$ NaCl × 100% FC (Table 3). Fauerharmel et al. (2020) reported similar results consistent with this study regarding Jacaranda shoot length and diameter under one-quarter strength Hoagland low-nutrient solution with a salt concentration of 1.5 $dS.m^{-1}$.

Root diameter, volume and length and electrolyte leakage

In Table (4), three morphological characteristics including root diameter, volume and length were significantly affected by salinity, with a severity-dependent decrease. After subjecting the Jacaranda plants to 5.5 $dS.m^{-1}$ NaCl, these traits declined by 51%, 68% and 62% in comparison with 1 $dS.m^{-1}$ NaCl respectively. In contrast, EL showed a considerable enhancement in dependence of salinity severity by 163% in 5.5 over 1 $dS.m^{-1}$ NaCl (Table 4).

Additionally, treatment with 60% FC (severe drought) caused a significant decrease in root diameter, volume, and length by 69%, 36% and 32% respectively, compared to the control (100% FC), while EL displayed a remarkable increase in 60% FC by 54% versus control (Table 4).

As shown in Table (4), the combination of salinity and drought showed a significant interaction effect on root diameter and volume. The highest amounts were achieved in 1 dS.m^{-1} NaCl at 100% FC, similar to other morphological parameters. Our results was in consistent with Fauerharmel et al. (2020).

RWC, MDA, sodium and potassium content

The RWC and K content significantly decreased due to salinity treatment by 43% and 21% and conversely, MDA and Na content increased by 33% and 48% in 5.5 dS.m^{-1} NaCl, respectively (Table 5).

Similar consequences were observed in the drought treatment by severity-dependent changes. The use of 60% FC induced a significant decrease in RWC and K content by 19% and 70% compared with the control (100% FC). In 60% FC, MDA exhibited the highest content with a 3-fold enhancement compared to 100% FC, and Na content showed a remarkable increase by 95% in severe drought conditions compared to natural conditions.

Significant interaction effects were observed only on MDA and Na content in Table (5), and the highest amounts were obtained in 5.5 dS.m^{-1} NaCl × 60% FC.

Table 5- Effects of salinity and drought on relative water content, malondialdehyde, sodium and potassium content in *Jacaranda mimosifolia*

Source of variance	Relative water content (%)	Malondialdehyde content (µM.g^{-1} FW)	Sodium content (%)	Potassium content (%)
Salinity				
1 ds.m^{-1} NaCl	79.26±7.55 a	3.30±1.92 d	0.23±0.06 c	4.23±1.68 a
2.5 ds.m^{-1} NaCl	69.96±7.09 b	3.83±1.77 c	0.30±0.08 b	4.04±1.86 a
4 ds.m^{-1} NaCl	61.46±9.57 c	4.19±1.93 b	0.30±0.10 b	4.14±1.57 a
5.5 ds.m^{-1} NaCl	45.40±5.73 d	4.39±1.76 a	0.34±0.11 a	3.33±1.93 b
Drought				
100% FC	70.46±13.57 a	1.46±0.52 c	0.20±0.04 c	5.77±0.41 a
80% FC	64.37±13.83 b	4.47±0.35 b	0.30±0.07 b	4.31±0.26 b
60% FC	57.22±13.27 c	5.85±0.51 a	0.39±0.07 a	1.72±1.04 c
Salinity*Drought				
1 ds.m^{-1} NaCl*100% FC	86.61±3.42 a	0.64±0.01 h	0.18±0.03 e	6.11±0.10 a
1 ds.m^{-1} NaCl*80% FC	80.21±2.96ab	4.15±0.00 e	0.23±0.01 e	4.51±0.22 c
1 ds.m^{-1} NaCl*60% FC	70.95±5.16bc	5.10±0.06 c	0.30±0.04 d	2.05±0.07fg
2.5 ds.m^{-1} NaCl*100% FC	74.05±5.54 b	1.49±0.17 g	0.21±0.03 e	6.14±0.08 a
2.5 ds.m^{-1} NaCl*80% FC	71.33±4.67bc	4.25±0.17 e	0.29±0.03 d	4.36±0.30cd
2.5 ds.m^{-1} NaCl*60% FC	64.48±7.04cd	5.74±0.16 b	0.39±0.03 b	1.63±0.05 g
4 ds.m^{-1} NaCl*100% FC	69.98±4.04 c	1.66±0.05 g	0.19±0.03 e	5.63±0.09 b
4 ds.m^{-1} NaCl*80% FC	61.33±5.69de	4.63±0.34 d	0.32±0.09 cd	4.27±0.17de
4 ds.m^{-1} NaCl*60% FC	53.05±9.12ef	6.28±0.21 a	0.38±0.03 bc	2.52±1.58 f
5.5 ds.m^{-1} NaCl*100% FC	51.20±5.77ef	2.04±0.07 f	0.22±0.06 e	5.21±0.23bc
5.5 ds.m^{-1} NaCl*80% FC	44.60±1.62fg	4.85±0.14 cd	0.34±0.04 bcd	4.10±0.10 e
5.5 ds.m^{-1} NaCl*60% FC	40.40±1.81g	6.27±0.15 a	0.47±0.02 a	0.67±0.05gh
Significance				
Salinity	**	**	**	**
Drought	**	**	**	**
Salinity*Drought	ns	**	*	ns

*ns, *, ** non-significant or significant at p ≤ 0.05 and 0.01, respectively. Values represent means ± standard deviation of four independent replications (n =4). Different letters within the same column indicate significant differences at p ≤ 0.05 among the treatments, according to Duncan's multiple range test.*

Potassium to Sodium Ratio

The effect of different levels of irrigation water and salinity on the potassium to sodium ratio (K/Na) in the aerial part of the Jacaranda plant was significant at the 1% level. The highest potassium to sodium ratio was observed in the 5.5 dS/m^{-1} salinity and 80% and 60% irrigation water treatment, and the lowest in the 2.5 dS/m^{-1} salinity and 80% irrigation water level treatment (Figure 3). The potassium to sodium ratio in plants has a significant effect on their growth and development, as an increase in sodium in the plant growth environment creates competition for potassium absorption and leads to potassium deficiency. Cheng et al (2024) also reported that the addition of sodium, sodium:potassium (1:1 ratio), or potassium to sunflower plants resulted in increased potassium levels in stem and leaf organs compared to the control. The same results were obtained by Hasani et al. (2021) for olive trees irrigated with water containing different concentrations of NaCl.

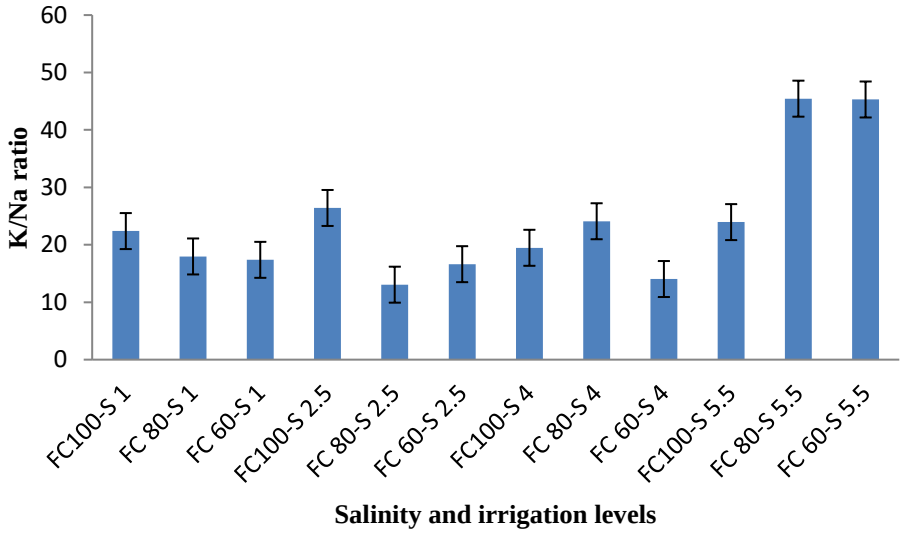


Fig. 3- Effects of different salinity and irrigation levels on potassium to sodium ratio in Jacaranda seedlings.

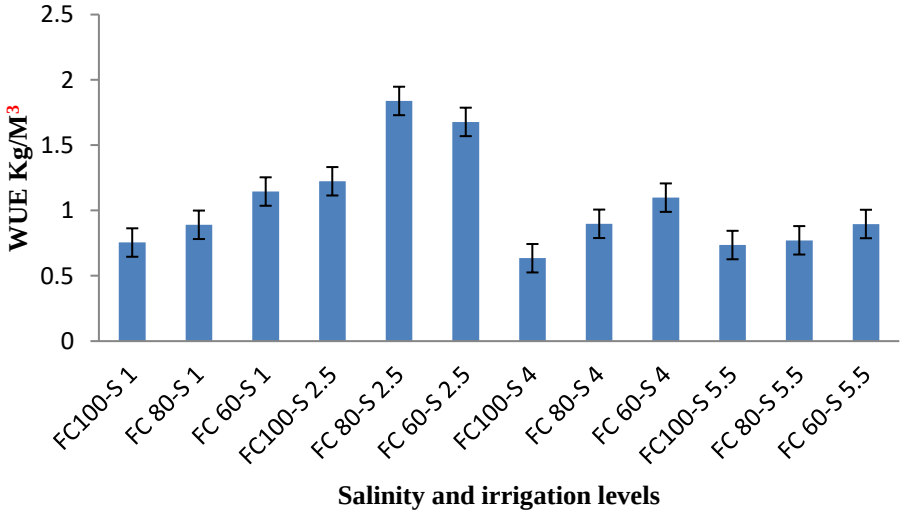


Fig. 4- Interaction effect of different levels of irrigation and salinity on average water use efficiency in Jacaranda seedlings.

Water use efficiency

The study on Jacaranda demonstrated that water use efficiency (WUE) was significantly influenced by the interaction of salinity and irrigation levels ($p < 0.01$). The highest WUE occurred at 2.5 dS/m^{-1} salinity with 80% FC irrigation, while the lowest was observed at 4 and 5.5 dS/m^{-1} and 80 and 100% FC irrigation (Figure 4). Similar results were found for olive trees by Dindarlou et al. (2019). They observed that the highest intrinsic water use efficiency was achieved under salinity levels of 2.2–7.7 dS/m^{-1} and at 75% of the water requirement. Yuan et al. (2018) also reported that the highest water use efficiency (WUE) in maize was achieved under low salinity conditions (0.71 g/L).

The results obtained indicated that exposure to both types of stress led to a progressive reduction in all morphological characteristics, depending on the severity. Drought stress resulted in a decrease in RWC and water potential in plants (De Campos et al., 2011). The reduction in growth parameters is possibly due to the decline in RWC and subsequent cell shrinkage, decreased meristematic cell division, blocked leaf production, accelerated leaf senescence and ultimately leaf drop (Osuagwu et al., 2010). The ability of the plant to maintain RWC in the optimal range is crucial for its tolerance to drought stress conditions. Proper water distribution in the plant, especially in the leaves, directly affects photosynthesis. Therefore, under conditions of water deficiency, the plant reduces leaf area and keeps the stomata closed in order to maintain RWC (Abdalla and Ahmed, 2021).

The major outcomes of water deficit in plants include a decline in cell division and expansion, differentiation of root and shoot length, changes in foliage dimensions, loss of fruit mass, altered stomatal movements, decreased mineral nutrition, plant yield, and water use efficiency (Aslani et al., 2023; Shomali et al., 2023). Water deficit causes an imbalance between ROS production and their scavenging, resulting in oxidative stress in plant cells. This failure in ROS scavenging leads to the over-accumulation of ROS, resulting in the peroxidation of lipid membranes by active mechanism and increase in MDA (Huang et al., 2023; Ihtisham et al., 2023). The Proline reduces ROS-induced oxidative damage through direct ROS scavenging (Apel and Hirt, 2004; Nkomo et al., 2022). It is documented that drought stress could induce stomatal limitation, directly suppressing photosynthesis throutgh reduce activity of the photosynthetic enzymes and causing chlorophyll degradation due to the release ROS. Likewise, water deficit negatively affects plant growth and development through declined cell division, differentiation, and cell enlargement (Elkelish et al., 2020; Huang et al., 2023). Drought causes a decline in the uptake of various minerals such as K (Ahmad et al., 2018).

The decrease in K uptake was observed under water deficit conditions. As an immediate response of plants exposed to drought and to reduce water loss, stomatal closure occurs, and as a result, the reduction in transpiration leads to a decrease in nutrient uptake along with water absorption ultimately restricting the plant's ability for dry matter production (Singh et al., 2017; Johnson et al., 2022). In other words, the reduction in nutrient uptake due to water deficit could slow the flow of elements and have a negative impact on growth (Hosseini et al., 2021). The reduction in K uptake is attributable to decreased K mobility, weakened function of root membrance transporters and a decreased transpiration rate (Hu and Schmidhalter, 2005; Johnson et al., 2022). Water deficit inhibits genes involved in K transport (Li et al., 2009). Recently, Azeem et al. (2022), found 43 K transport system in cotton genome including 25 transporter and 18 K ion channels.

Conclusions

The results obtained indicated the detrimental effects of abiotic stresses (deficit irrigation and salinity) on the morphological characteristics and RWC of Jacaranda. The Jacaranda seedlings were sensitive to water salinity and water stress. Therefore, to produce Jacaranda seedlings in tropical and sub tropical nurseries, one should carefully use non-saline water and soil.

Conflict of Interest

The authors declared no potential conflicts of interest concerning the research, authorship, and publication of this article.

Confirmation

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Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' contribution

First Author: Khalil Asadivafa, Collecting data and writing the first draft of the article.
Second Author: Mousa Mousavi, Reading and revising the initial draft.
Third Author: Abdul-kadhm N. S. Al-Showily, Reading and revising the initial draft.
Fourth Author: Mohammad Albaji, Reading and revising the initial draft.
Fifth Author: Naser Alemzadeh Ansari, Reading and revising the initial draft.

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