

Importance of Silicon in the Growth of *Jatropha curcas* L. Plants Irrigated With Salina Water

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Abstract

The use of silicon in plant cultivation is one of the strategies to mitigate the negative effects of salinity. This study aimed to evaluate the effect of silicate fertilization on the morphophysiological, biochemical and nutritional characteristics of *Jatropha curcas* L. plants under saline stress. The work was carried out in a greenhouse at the State University of Goiás. The experiment was set up in a completely randomized design in a 5 × 2 factorial arrangement (plants irrigated with salt water with sodium chloride (NaCl) and electrical conductivities equal to 0 dS m⁻¹; 2 dS m⁻¹; 4 dS m⁻¹; 6 dS m⁻¹ and 8 dS m⁻¹ applied at 80 days after emergence (DAE) and absence or presence of silica fertilization of 1 g L⁻¹ with Si applied at 80 and 95 DAE by volume of 30 mL of the solution with the aid of a spray manual), five replicates and experimental plot of one plant per pot. The evaluations were carried out at 130 DAEs. The absence of differences in the concentrations of photosynthetic pigments and visible damages is indicative of the absence of severe toxic effects caused by salinity. The tolerance of *Jatropha curcas* L. plants to salinity is independent of silicon. The *Jatropha curcas* L. plant tolerates salinity by minimizing transpiration and remaining hydrated through the water stored in the succulent stem. In addition, the plants control sodium uptake and eliminate toxic compounds through increases in Calcium concentration and antioxidative metabolism respectively.

Keywords: electric conductivity, abiotic stress, nutrition

1. Introduction

Global warming resultant from the intensifications of greenhouse effect through anthropic activity has compromising the natural resources and points to urgent need of approve actions to reduce the damages in the environment. The fuels from vegetable oils became an alternative to current world energy sources, using cleaner, sustainable and wealth generators sources (Silva et al., 2020).

The interest by growth oilseed plants intensified after the implementation of National Plan for the Production and Use of Biodiesel in Brazil, however, the program is set in only one raw material, soybean, with 78% participation of all vegetable oil designated to biodiesel production (ANP, 2021). The renewable sources corresponds to 43.8% of all Brazilian energy sources with hydraulic, eolic and biomass energy corresponding to 67.9%, 6.5% and 9% respectively (MME, 2021). Therefore, there is a need to diversify the sources of raw material to produce renewable energy, like biodiesel through promising species such as *Jatropha curcas* L. (Dos Anjos et al., 2017).

The *Jatropha curcas* specie is a perennial oilseed from Central America belonging to Euphorbiaceae (Reddy et al., 2018). It is an important agricultural option of multiple utilities to produce soap, cosmetic and drugs with antibiotic, anticancer and anti-inflammatory activity in latex and especially by seeds containing 22% to 42% of oil of excellent physical-chemical quality (Matos et al., 2018). *J. curcas* is a xerophyte resistant to dry conditions, however is expect that the maximum yield and growth are obtained with adequate water supply, nonetheless, facing the lack of water of good quality in many Brazilian reservoirs, the usage of saline water can be important alternative to irrigation of this specie (Matos et al., 2017).

Salinity is one of the abiotic stresses that most limit growth and yield in plants, it harms seed germination, yield and fruit quality (Lima et al., 2019). The agricultural silicon (Si) usage shows as a feasible and beneficial alternative to plants under biotic and abiotic stresses, with reactions as: resistance to pests and diseases; tolerance

to toxicity by heavy metals; tolerance to drought and saline stress and specially increases the yield (Alovisi et al., 2020).

The Si has a crucial role in the plant-environment relations and considered an anti-stress element, providing to the species that can accumulate in the tissues, better conditions to support edaphoclimatic and biological adversities (Almeida et al., 2017). Studies that used Si sources provided increases in *Solanum lycopersicum* L. and *Capsicum chinense* plants with saline stress and emergence of *Triticum aestivum* L. seeds (Rodrigues et al., 2018; Sousa, 2019; Júnior et al., 2018).

The intense anthropic actions of deforestation, environmental pollution and accentuation of the greenhouse effect interfere with water resources, and the increasing agricultural expansion instigate the development of management practices that allows the exploration of species irrigated with saline water. The silicon fertilization constitutes an effective alternative to attenuate the negative effects of saline stress. This study aimed to evaluate the effect of silicate fertilization on the morphophysiological, biochemical and nutritional characteristics of *Jatropha curcas* L. plants under saline stress.

2. Material and Methods

2.1 Experimental Design

The experiment was carried out in a greenhouse covered with transparent plastic and shade cloth on the sides with 50% of light interception at Universidade Estadual de Goiás, Ipameri-unit (Lat. 17°43'19" S, Long. 48°09'35" W, Alt. 773 m), Ipameri, Goiás, Brazil. The plants were growth in eight liters pot with substrate containing a mix of soil, sand and manure with 3:1:0.5 proportion, respectively. The substrate chemical analysis report the following values: pH(CaCl₂) 6.5; 21 g dm⁻³ of organic matter; 22.5 mg dm⁻³ of P; 0.55 cmolc dm⁻³ of K (Mehlich-1); 2.4 cmolc dm⁻³ (Buffer SMP) of H + Al; 1.8 cmolc dm⁻³ of Ca; 0.8 cmolc dm⁻³ of Mg; 9.7 mg dm⁻³ of Zn; 3.12 cmolc dm⁻³ of BS; 5.32 cmolc dm⁻³ of CEC; and 59.62% of base saturation. After the chemical analysis, it was performed fertilization seven days after emergence (DAE) according to recommendations to physic nut species (Matos et al., 2014).

The experiment was set up in completely randomized design with 5 × 2 factorial arrangement (plants irrigated with saline water with electrical conductivity of 0 dS m⁻¹; 2 dS m⁻¹; 4 dS m⁻¹; 6 dS m⁻¹ and 8 dS m⁻¹ and the lack and presence of silicon fertilization of 1 g L⁻¹), five replications and one plant per experimental plot. The levels of water electrical conductivity were obtained using sodium chloride (NaCl) and measured with conductivity meter and supplied 80 DAE. The plants were irrigated with a volume of water corresponding to 100% of the evapotranspiration. The crop coefficient (Kc) was not determined for *Jatropha curcas* L. crops grown in the region of Ipameri, thus, a Kc of 1.00 was used, as recommended by the FAO 56 (Allen et al., 1998) for several crops at initial developmental stages. The water volume used was calculated by determining the reference evapotranspiration and the crop coefficient, according to the equation $ET_c = ET_o \times K_c$, where ET_c is the crop evapotranspiration, K_c is the crop coefficient, and ET_o is the reference evapotranspiration.

The daily ET_o was calculated through the Penman-Monteith method, as recommended by the FAO (Smith et al., 1991), using daily data of maximum and minimum air temperatures, relative air humidity, insolation, and wind speed collected by a meteorological station of the Brazilian National Institute of Meteorology (INMET) installed in Ipameri. The silicon supply occurred at 80 and 95 DAE in 30 mL solution with a hand sprayer. The analysis occurred at 130 DAE with the respective analysis: plant height, stem diameter, number of leaves, leaf area, biomass, transpiration, water relative content, photosynthetic pigments, biochemical and nutritional analysis.

2.2 Growth Variables

The number of leaves, plant height and stem diameter were measured using a graduated ruler and a digital pachymeter. Leaf area was measured through width and length of all leaves following recommendations of Severino et al (2007). The destructive analysis was performed when root, stem and leaves were separated and set up in an oven at 72 °C to dry until achieve constant dry weight, then weighted and calculated the biomass.

2.3 Transpiration and Relative Water Content (RWC)

The total daily plant transpiration was measured by the difference in pot weight. Initially each pot was inserted into a plastic bag fixed with rubber to the plant stem, leaving only the aerial part (leaves and stem) external to the bag, then the plant and plastic bag were weighed all at once (mass 01), and 24 hours later weighed again (mass 02). Total transpiration was estimated by the difference between mass 01 and mass 02 (Dos Anjos et al., 2017).

To obtain the relative water content, ten leaf discs of 7 mm in diameter for each repeat were removed in fully expanded leaves, weighed to record the fresh mass (FM) and placed to saturate for 4 hours in petri dishes with

distilled water. Then, were weighted and placed to dry at 70 °C for 72 hours. After getting dry mass data, the relative water content was calculated.

2.4 Photosynthetic Pigments and Biochemical Variables

Chlorophylls and carotenoids were quantified with readings in spectrophotometer at 470 nm, 646 nm and 663 nm following recommendations of Lichtenthaler (1987).

The activity of antioxidant enzymes were performed using the methodology described by Zhu et al. (2004). Approximately one gram of leaf was homogenized. The supernatant was used to determine the enzymatic activity and protein content.

The catalase activity (CAT) was obtained with readings at 240 nm absorbance in a substance containing potassium phosphate (15 mM, pH 7.0, H₂O). Guaiacol peroxidase (POD) activity was obtained using guaiacol as substrate. The enzymatic activity was measured by guaiacol oxidation in tetraguaiacol by the increase of absorbance to 470 nm. Superoxide dismutase (SOD) activity was measured according to spectrometric method described by Giannopolitis and Ries (1977). The soluble protein content was determined conform Bradford (1976).

To sugar analysis, approximately 200 mg of leaf tissue was submerged in ethanol 80% and warmed at 65 °C for 30 minutes. The ethanolic extract was used to quantify the total soluble sugars by phenol-sulfuric method with readings at 490 nm length, using sucrose standard curve and the reduced sugars were determined conforming dinitrosalicylic method following Miller (1959) recommendations, at 540 nm absorbance and using glucose standard curve. The non-reduced sugars were estimated by the difference between the content of total soluble sugars and the reduced sugars.

2.5 Analysis of Mineral Elements

The leaves of each experimental plot were placed in paper bags and settled in an oven at 65 °C until achieve constant dry mass. The leaves were grounded, prepared and submitted to nitroperchloric digestion and determined the content of Zinc (Zn), Iron (Fe), Potassium (K), Magnesium (Mg) and Calcium (Ca) by spectrophotometer and atomic absorption and by calorimetry as determined Phosphor (P) according to Tedesco et al. (1995) recommendations. To quantify the content of Chlorine (Cl) Sodium (Na) was used ICP-OES (Inductively Coupled Plasma-Optical Emission Spectroscopy). To silicon (Si) analysis, the material was submitted to silicon-molybdenum yellow method described by Korndörfer et al. (2004).

2.6 Statistical Proceedings

The variables were submitted to variance analysis following the completely randomized design in a 5 × 2 factorial arrangement (five levels of salinity × presence and lack of silicon fertilizing) with five replications and one plant per experimental plot. The differences between the treatments were analyzed using Newman-Keuls test and, additionally, executed linear and quadratic regression analysis with respective coefficient of determination (R²). In the lack of significant interaction between salinity and silicon, the regression curves were processed with mean values. The statistical analysis and the graphic formation was used the R Software 3.4 version (R Core Team, 2021). The multivariate analysis was performed through multiple regression using Forward Stepwise model (Sokal & Rolf, 1995) and STATISTICA Software (STATSOFT, 2007).

3. Results and Discussion

The summary of the variance and regression analysis for plant height, stem diameter, number of leaves, leaf area, relative water content, transpiration of physic nut plants are in Table 1. Silicon did not intervene significantly in growth of physic nut plants, however, stem diameter and transpiration adjusted with linear regression model according to salinity of water. The benefit of silicon to attenuate the abiotic stresses in accumulating plants seems not occur in same magnitude in physic nut. According to Dos Anjos et al. (2017), silicon plays little effect on growth of physic nut plant for being a Si non-accumulator plant.

Table 1. Analysis of variance, mean and regression test for plant height (PH), stem diameter (SD), number of leaves (NL), leaf area (LA), relative water content (RWC) and transpiration (E) in *J. curcas* plants irrigated with saline water and fertilized with silicon. Ipameri, Goiás

Variation Source	DF	Mean square					
		PH (cm)	SD (mm)	NL	LA (m ²)	RWC (%)	E (g H ₂ O dia ⁻¹)
Silicon	1	46.08 ^{ns}	1.07 ^{ns}	1956.25 ^{ns}	0.25 ^{ns}	82.53 ^{ns}	873.62 ^{ns}
Salinity	4	33.92 ^{ns}	6.80 ^{**}	1036.77 ^{**}	4.80 ^{**}	144.08 ^{ns}	78016.33 ^{**}
Si*Sal	4	33.98 ^{ns}	2.03 ^{ns}	395.32 ^{ns}	1.52 ^{ns}	196.56 ^{ns}	793.97 ^{ns}
Residue	40	24.40	1.81	25.30	0.78	176.09	1029.57
CV (%)		7.98	3.81	11.48	11.31	17.54	16.00
Treatments		Means					
Without Silicon		62.88a	35.24a	40.08a	2.95a	74.38a	124.44a
With Silicon		60.96a	35.54a	37.57a	2.81a	76.95a	116.08a
Regression							
Linear		ns	*	ns	ns	ns	*
Quadratic		ns	ns	ns	ns	ns	ns

Note. * significant at 5% probability; ** significant at 1% probability; ns = not significant by the F test. Means followed by the same lowercase letter inside the column do not differ at 5% probability by the Newman-Keuls test.

The summary of variance and regression analysis for chlorophyll and carotenoids, biomass, silicon percentage, sodium and potassium on physic nut leaves are in Table 2. Silicon did not intervene significantly in the variables, however, biomass and Na leaf content adjusted to linear regression model related to saline variation in the water. The results confirm the hypothesis that physic nut is a Si non-accumulator specie and, by that, the physiological effects are not very evident (Dos Anjos et al., 2017).

Table 2. Analysis of variance, mean and regression test for total chlorophyll (Chl *a* + *b*), carotenoids (Car), total biomass (TB), silicon (Si) and sodium (Na) in *J. curcas* plants irrigated with saline water and fertilized with silicon. Ipameri, Goiás

Variation Source	DF	Mean square					
		Chl <i>a</i> + <i>b</i> (g Kg ⁻¹)	Car (g Kg ⁻¹)	TB (g)	Si (%)	Na (mg L ⁻¹)	K (g kg ⁻¹)
Silicon	1	1.41 ^{ns}	0.005 ^{ns}	35.33 ^{ns}	0.04 ^{ns}	163.84 ^{ns}	0.09 ^{ns}
Salinity	4	0.97 ^{ns}	0.030 ^{ns}	11784.49 ^{**}	0.18 ^{**}	12281.02 ^{**}	31.29*
Si*Sal	4	4.66 ^{ns}	0.020 ^{ns}	22.96 ^{ns}	0.10 ^{ns}	63.85 ^{ns}	9.62*
Residue	40	0.45	0.014	52.40	0.05	62.43	1.41
CV (%)		12.24	9.71	4.79	17.90	12.63	12.79
Treatments		Means					
Without Silicon		5.31a	1.21a	151.96a	1.26a	60.76a	9.33a
With Silicon		5.65a	1.23a	150.28a	1.31a	64.38a	9.24a
Regression							
Linear		ns	ns	ns	ns	**	ns
Quadratic		ns	ns	*	ns	ns	ns

Note. Statistics according to Table 1.

The summary of variance and regression analysis for content of phosphorus, calcium, magnesium, iron, zinc and chlorine in physic nut plants are in Table 3. Silicon did not intervene significantly on the variables, however, the content of calcium and chlorine adjusted to quadratic regression model related to saline variation in the water. Plants irrigated with saline water can increase the absorption of chlorine and sodium and show unbalance nutrition and/or cell damage. According to Matos et al. (2019), salt can generate cell disturb and enzyme inactivation, nonetheless, detoxification driven by increased calcium content, represents an important mechanism for saline tolerance in physic nut plants.

Table 3. Analysis of variance, mean and regression test for phosphorus (P), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn) and chlorine (Cl) of the leaf tissue of *J. curcas* plants irrigated with saline water and fertilized with silicon. Ipameri, Goiás

Variation Source	DF	Mean square					
		P (g Kg ⁻¹)	Ca (g Kg ⁻¹)	Mg (g Kg ⁻¹)	Fe (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Cl (mg g ⁻¹)
Silicon	1	0.02 ^{ns}	11.02 ^{ns}	41.95 ^{ns}	1.21 ^{ns}	100.13 ^{ns}	1.20 ^{ns}
Salinity	4	0.01 ^{ns}	46.34 ^{**}	67.40 ^{ns}	0.60 ^{ns}	140.17 ^{**}	4.63 ^{**}
Si*Sal	4	0.04 ^{ns}	9.98 ^{ns}	28.51 ^{ns}	0.60 ^{ns}	420.85 ^{ns}	0.03 ^{ns}
Residue	40	0.02	4.93	59.02	0.24	27.65	0.31
CV (%)		10.80	10.09	39.55	16.70	18.56	14.86
Tratments		Means					
Without Silicon		1.36a	21.53a	18.51a	2.74a	29.75a	3.94a
With Silicon		1.32a	22.47a	20.34a	3.09a	26.92a	3.63a
Regression							
Linear		ns	ns	ns	ns	ns	ns
Quadratic		ns	*	ns	ns	ns	*

Note. Statistics according to Table 1.

The summary of variance and regression analysis for activity of guaiacol peroxidase, catalase, superoxide dismutase, protein, reducing sugar and non-reducing sugar in physic nut plants are in Table 4. Silicon did not intervene significantly in these variables, however, the activity of guaiacol peroxidase and catalase adjusted to linear regression model related to water salinity variation. The salinity provokes osmotic imbalance and reduction of absorption of soil solution due to increased stomatal closure, less carboxylation and higher dissipation of harmful energy of excitation. In these conditions, physic nut activate the defense enzymes to eliminate the toxic compounds and protect the photosynthetic machinery. The plant tolerance to abiotic stress is related with expression of genes from antioxidant metabolism (Matos et al., 2019).

Table 4. Analysis of variance, mean test and regression for guaiacol peroxidase (POD)⁽¹⁾, catalase (CAT)⁽¹⁾, superoxide dismutase (SOD)⁽¹⁾, protein (PRO)⁽¹⁾, reducing sugar (RS)⁽¹⁾ and non-reducing sugar (NRS)⁽¹⁾ of leaf tissue from plants of *J. curcas* irrigated with saline water and fertilized with silicon. Ipameri, Goiás

Variation Source	DF	Mean square					
		POD	CAT	SOD	PRO	RS	NRS
Silicon	1	0.006 ^{**}	0.13 ^{ns}	0.16 ^{ns}	0.48 ^{ns}	0.32 ^{ns}	0.03 ^{ns}
Salinity	4	0.019 ^{**}	1.09 ^{**}	0.13 ^{ns}	0.86 ^{ns}	0.74 ^{**}	1.52 ^{**}
Si*Sal	4	0.004 ^{**}	0.08 ^{ns}	0.11 ^{ns}	3.20 ^{ns}	0.27 ^{ns}	0.09 ^{ns}
Residue	40	0.008	0.11	0.08	0.20	0.01	0.01
CV(%)		14.96	7.82	9.83	8.51	9.38	12.70
Tratments		Means					
Without Silicon		0.20a	1.31a	2.93a	5.37a	0.81a	0.77a
With Silicon		0.18b	1.41a	3.04a	5.17a	0.97a	0.82a
Regression							
Linear		*	**	ns	ns	ns	ns
Quadratic		ns	ns	ns	ns	ns	ns

Note. ⁽¹⁾ POD measured in $\mu\text{mol de tetraguaiacol min}^{-1} \text{mg}^{-1}$ of protein; CAT measured in $\text{nmol min}^{-1} \text{mg}^{-1}$ of protein; SOD measured in U mg^{-1} of protein; PRO measured in mg ml^{-1} ; RS measured in percentage (%); NRS measured in percentage (%). Statistics according to Table 1.

The results of regression analysis for leaf content of chlorine and sodium, biomass, stem diameter, transpiration, calcium leaf content, guaiacol peroxidase and catalase activity are in Figure 1. The lower absorption of soil solution under reduced water osmotic potential increased the stomatal closure and diminished the transpiration, assimilating more CO_2 and growth of physic nut plants. The reduction of biomass accumulation is a strategy to

survive for less demand of maintenance energy under limited CO₂ influx. These conditions the dissipation of excitation energy from photosystem produce harmful compounds to membranes and proteins as hydrogen peroxide (H₂O₂). In physic nut plants the saline tolerance run through protection of these structures from the increase of enzyme activity as ascorbate peroxidase and catalase and eradication of H₂O₂. The capability of plants in break down H₂O₂ and protect the photosynthetic machinery is an indicative of tolerance to saline stress (Mittler, 2017).

The linear increment of chlorine and sodium leaf content is a suggestive that physic nut does not have efficient mechanism to control absorption of these elements in roots. As reported by Larcher et al. (2016), chlorine competes in sites of absorption with anions as nitrate and can cause serious nutritional deficiency, whenever absorbed in large amounts. Sodium can be a strong denaturant, can promote enzymatic activity when accumulated in large concentrations in cytosol (Taiz & Zeiger, 2017). The increment of leaf calcium content until 4 dS m⁻¹ electrical conductivity might be associated with H⁺-ATPase activation and sodium detoxify mechanism in plasmatic membrane and reduction of this element, nonetheless, under irrigation with saline water above 4 dS m⁻¹ of conductivity the calcium concentration was reduced, and in this circumstances, conforming Taiz and Zeiger (2017), sodium itself inactivate the detoxify system and the effects of salt become more intense.

The lack of differences in content of photosynthetic pigments and visible damages suggest the inexistence of severe toxic effects caused by salinity. Possibly physic nut plants accumulated sodium and chlorine in vacuole and by that avoid the toxic effect to enzymes in cytosol and organelles and, in addition, use the active mechanism by calcium and control the absorption of sodium and antioxidant metabolism to eliminate the toxic compounds produced by the excess of excitation energy.

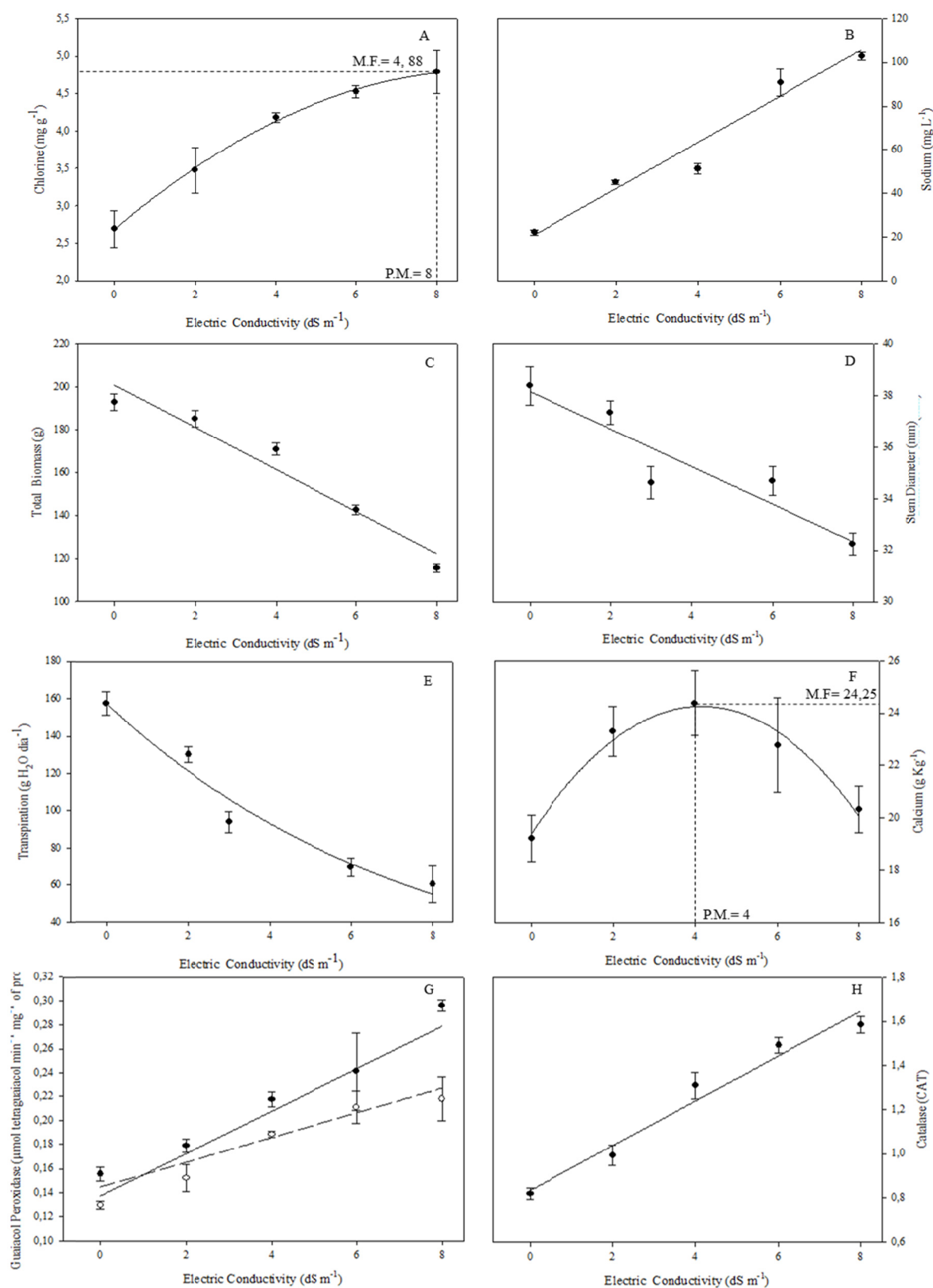


Figure 1. Regression equations for chlorine “A” ($Y = 2.72 + 0.51x - 0.03x^2$; $R^2 = 0.98^*$), sodium “B” ($y = 20.08 + 10.62x$; $R^2 = 0.93^{**}$), total biomass “C” ($y = 200.85 - 9.83x$; $R^2 = 0.87^*$), stem diameter “D” ($y = 38.16 - 0.72x$; $R^2 = 0.89^*$), transpiration “E” ($y = 157.39 - 0.13x$; $R^2 = 0.97^{**}$), calcium “F” ($y = 19.41 + 2.33x - 0.28x^2$; $R^2 = 0.97^{**}$), guaiacol peroxidase “G” (Sem Si $y = 0.13 + 0.01x$; $R^2 = 0.86^{**}$; Com Si $y = 0.14 + 0.01x$; $R^2 = 0.87^{**}$) and catalase “H” ($y = 0.77 + 0.11x$; $R^2 = 0.86^{**}$) for physic nut plants irrigated with saline water and subjected to silicate fertilization. *, ** significant at 5% and 1% probability by the F test

The multiple regression analysis represents 35% of biomass variation and indicates that the cellular concentrations of potassium and proteins are determinant to *J. curcas* growth for enable more biomass accumulation, since under saline stress the sodium absorbed act like a strong denaturant and compromise potassium absorption.

Table 5. Multiple regression model to evaluate the importance of the variables in biomass of *J. curcas* plants under irrigation with saline water and silicon fertilization

Biomass	R ² = 0.35*		F (04.45) = 5.95		p < 0.0006	
	Beta	Std.Err. of Beta	B	Std.Err. of B	t (45)	p-level
Intercept			64.948	23.678	2.954	0.005
Potassium (K)	0.371	0.116	5.299	1.655	3.201	0.003*
Proteins	0.280	0.120	19.895	8.540	2.329	0.024*
Zinc (Zn)	0.169	0.120	0.610	0.433	1.406	0.166
Chlorophyll	-0.127	0.116	-2.303	2.109	-1.092	0.281

Note. * significant at 5% of probability; ** significant at 1% of probability; ns = not significant by the F test.

4. Conclusions

The plant of *J. curcas* L. is a species that does not accumulate silicon and, therefore, this mineral element is not accumulated in large quantities and, therefore, does not have significant importance in the tolerance of *J. curcas* L. to salinity. The species tolerates salinity by minimizing transpiration and staying hydrated through the water stored in the succulent stem. In addition, plants control sodium absorption and eliminate toxic compounds by increasing calcium concentration and antioxidant metabolism, respectively.

References

- Almeida, L. H. C., Klein, P. H., Oliveira, E. C., & Miglioranza, E. (2017). Silício e disponibilidade de fósforo no crescimento e desenvolvimento de mudas de café. *Cultura Agrônômica*, 26(2), 123-131. <https://doi.org/10.32929/2446-8355.2017v26n2p123-131>
- Alovisi, A. A., Luz, R. A., Alovisi, A. M. T., Tokura, L. K., Gomes, C. F., & Cassol, C. J. (2020). Silicatagem no solo e na produtividade da cultura do milho. *Revista Gestão & Sustentabilidade Ambiental*, 9(SP), 933-950. <https://doi.org/10.19177/rgsa.v9e02020933-950>
- ANP (Agência Nacional do Petróleo). (2021). *Biocombustíveis*. Retrieved January 30, 2021, from http://www.anp.gov.br/wwwanp/images/publicacoes/Anuario_Estatistico_ANP_2017.pdf
- Bradford, M. M. (1976). A rapid and sensitive method for the qualification of microgram quantities of protein utilizing the principle of protein dye binding. *Analytical Biochemistry*, 7, 248-254. [https://doi.org/10.1016/0003-2697\(76\)90527-3](https://doi.org/10.1016/0003-2697(76)90527-3)
- Dos Anjos, R. A. R., Santos, L. C. S., Oliveira, D. B., Amaro, C. L., Rios, J. M., Rocha, G. T., ... Matos, F. S. (2017). Initial growth of *Jatropha curcas* plants subjected to drought stress and silicon (Si) fertilization. *Australian Journal of Crop Science*, 11(4), 479-484. <https://doi.org/10.21475/ajcs.17.11.04.377>
- Júnior, S. G. O., Ferreira, E. A., Nery, M. C., Silva, R. F. C., Melo, S. G. F., & Fialho, C. M. T. (2018). Aplicação foliar de silício em plantas de trigo associado a qualidade fisiológica de sementes. *Revista Brasileira de Agropecuária Sustentável*, 8(1), 9-16. <https://doi.org/10.21206/rbas.v8i1.455>
- Korndörfer, G. H., Pereira, H. S., & Nolla, A. (2004). *Análise de silício no solo, planta e fertilizante* (2nd ed., p. 34). Instituto de Ciências Agrárias, Uberlândia, MG.
- Larcher, M. V., Pasquier, E., Macdonald, S., & Wellinger, R. J. (2016). Ku binding on telomeres occurs at sites distal from the physical chromosome ends. *Plos Genetics*, 12(1), 1-29. <https://doi.org/10.1371/journal.pgen.1006479>
- Lichthenthaler, H. K. (1987). Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. *Methods in Enzymology*, 148, 350-382. [https://doi.org/10.1016/0076-6879\(87\)48036-1](https://doi.org/10.1016/0076-6879(87)48036-1)
- Lima, G. S., Dias, A. S., Soares, L. A., Gheyi, H. R., Nobre, R. G., & Silva, A. A. R. (2019). Eficiência fotoquímica, partição de fotoassimilados e produção do algodoeiro sob estresse salino e adubação nitrogenada. *Revista de Ciências Agrárias*, 42(1), 214-225.

- Matos, F. S., Borges, L. P., Amaro, C. L., de Oliveira, D. B., do Carmo, M. S., & Torres Junior, H. D. (2019). *Folha Seca: Introdução à Fisiologia Vegetal* (1st ed., p. 189). Curitiba, PR, Apris.
- Matos, F. S., Ciappina, A. L., Rocha, E. C., & Almeida, L. M. (2018). Factors that influence in *Jatropha curcas* L. latex production. *Bragantia*, 77(1). <https://doi.org/10.1590/1678-4499.2016468>
- Matos, F. S., Ribeiro, R. P., Neves, T. G., Dos Anjos, R. A., da Silveira, P. S., Cruvinel, C. K. L., ... Torres Júnior, H. D. (2017). Growth of *Jatropha curcas* L. plants under salt and nutrition stress. *Australian Journal of Crop Science*, 12(30), 2468-2474. <https://doi.org/10.5897/AJAR2016.12401>
- Matos, F. S., Rosa, V. R., Ribeiro, R. P., Borges, L. F. O., Cruvinel, C. K. L., & Dias, L. A. S. (2014). Response of *Jatropha Curcas* plants to changes in the availability of nitrogen and phosphorus in oxissol. *African Journal of Agricultural Research*, 9(49), 3581-3586.
- Miller, G. L. (1959). Use of dinitrosalicylic acid reagent for determination of reducing sugar. *Analytical Chemistry*, 31(3), 426-428. <https://doi.org/10.1021/ac60147a030>
- Mittler, R. (2017). Ros are good. *Trends in Plant Science*, 22(1), 11-19. <https://doi.org/10.1016/j.tplants.2016.08.002>
- MME (Ministério de Minas e Energia). (2021). *Renováveis devem manter participação de 43% na matriz energética em 2017*. Retrieved January 30, 2021, from <http://www.mme.gov.br>
- R Core Team. (2021). *R: A language and environmental for statistical computing*. Vienna, Austria. Retrieved January 30, 2021, from <http://www.R-project.org>
- Reddy, A. N. R., Saleh, A. A., Islam, M. S., & Hamdan, S. (2018). Active razor shell CaO catalyst synthesis for jatropha methyl ester production via optimized two-step transesterification. *Journal of Chemistry*, 2017(1), 1-20. <https://doi.org/10.1155/2017/1489218>
- Rodrigues, A. J. O., Nunes, L. R. L., Nunes, A. M. C., & Uchôa, K. S. A. (2018). Efeito da adubação silicatada no cultivo de tomateiro sob estresse salino. *Agropecuária Científica no Cerrado*, 14(2), 141-148. <https://doi.org/10.30969/acsa.v14i2.977>
- Sá, F. V. S., Mesquita, E. F., Souza, F. M., Mesquita, S. O., Paiva, E. P., & Silva, A. M. (2017). Depleção de água e composição do substrato na produção de mudas de melancia. *Revista Brasileira de Agricultura Irrigada*, 11(3), 1398-1406. <https://doi.org/10.7127/rbai.v11n300550>
- Severino, L. S., Vale, L. S., & Beltrão, N. E. M. (2007). Método para medição da área foliar do pinhão manso. *Revista Brasileira de Oleaginosas e Fibras*, 14(1), 73-77. <https://doi.org/10.30612/agrarian.v13i47.8711>
- Silva, L. M., Felicio, R., Amorim, V. A., Silveira, P. S., & Matos, F. S. (2020). *Jatropha curcas* growth and productivity under phosphorus doses. *Revista Agrarian*, 13(47), 63-73.
- Sokal, R. R., & Rolf, F. J. (1995). *Biometry* (3rd ed.). W. H. Freeman, New York.
- Sousa, V. F. O. (2019). Efeito da adubação silicatada em pimenteira sob estresse salino. *Open Journal Systems*, 1(2), 042-046. <https://doi.org/10.15809/irriga.2018v1n2p29-33>
- Statsoft, Inc. (2007). *Statistica (Data Analysis Software System)* (Version 7). Retrieved June 17, 2019, from <http://www.statsoft.com/Products/STATISTICA-Features>
- Taiz, L., & Zeiger, E. (2017). *Fisiologia vegetal* (6th ed., p. 858). ArtMed, Porto Alegre.
- Tedesco, M. J., Gianello, C., Bissani, C. A., Bohnen, H., & Volkweiss, S. J. (1995). *Análise de solo, plantas e outros materiais* (2nd ed., p. 174). Departamento de Solos da Universidade Federal do Rio Grande do Sul, Porto Alegre, RS.
- Zhu, Z., Wei, G., Li, J., Qian, Q., & Yu, J. (2004). Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). *Plant Science*, 167, 527-533. <https://doi.org/10.1016/j.plantsci.2004.04.020>

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