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Yield of prickly pear cactus irrigated with saline water in soils of the semi-arid region

Produtividade de palma forrageira irrigada com águas salinizadas em solos da região semiárida

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Highlights

Irrigation water salinity reduced plant width by 22.41%.
There was no interaction between the water electrical conductivities and soils used.
The water with electrical conductivity of 7.5 dS m^{-1} reduced fresh weight by 21.45%.
The chromic Luvisol and Solonetz soils had the best results.

Abstract

Knowing the tolerance of plants grown in the Brazilian semi-arid region to salt stress is of paramount importance for the sustainability of regional agriculture. This study was developed to examine the growth and yield of prickly pear cactus 'Orelha de Elefante Mexicana' (*Opuntia stricta* Haw) irrigated with increasing water salinity levels (0.75, 3.0, 5.25 and 7.50 dS m^{-1} to 25 ºC) and grown on soils representative of the Brazilian semi-arid region (chromic Luvisol, Solonetz and Fluvisol). Total fresh weight decreased linearly, with a 21.42% reduction when we compare the average fresh weight per plant in the lowest and highest saline level treatments. The chromic Luvisol and Solonetz soils showed the best fresh weight and dry matter yields under the present experimental conditions.

Key words: *Opuntia stricta.* Electrical conductivity. Chromic Luvisol. Solonetz. Fluvisol.

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Resumo

Conhecer a tolerância das plantas cultivadas na região semiárida brasileira ao estresse salino, é de fundamental importância para a sustentabilidade da agricultura regional. Este trabalho objetivou avaliar o crescimento e produtividade de palma forrageira 'Orelha de Elefante Mexicana' (*Opuntia stricta* Haw), irrigada com níveis crescentes de salinidade da água (0,75; 3,0; 5,25; e 7,50 dS m^{-1} a 25 ºC) e cultivada sobre solos representativos da região semiárida brasileira (Luvissolo crômico, Planossolo nátrico e Neossolo flúvico). A massa verde total apresentou efeito linear decrescente havendo uma redução de 21,42 % ao comparar a massa verde média por planta do tratamento de menor nível com o tratamento de maior nível salino. Os solos Luvissolo crômico e Planossolo nátrico apresentaram as melhores produtividades de massa verde e massa seca nas condições deste experimento.
Palavras-chave: *Opuntia stricta.* Condutividade elétrica. Luvissolo crômico. Planossolo nátrico. Neossolo flúvico.

Introduction

Prickly pear (*Opuntia ficus-indica* (L.) Mill) is a cactus native to Mexico, a country that has exploited it since the pre-Hispanic period, with the greatest variety of cultivars in the world (Reyes-Aguero, Aguirre-Rivera, & Hernández, 2005). At present, Brazil has the largest cactus cultivated area for forage purposes in the world. In the country, about 600,000 ha are planted with this crop, of which 500,000 are located in the northeast region, whose main producing states are Bahia, Sergipe, Alagoas, Pernambuco and Paraíba (Pereira, 2013).

Among the existing genera, the most cultivated in Brazil are *Opuntia* and *Nopalea,* mainly variety Gigante (*Opuntia ficus-indica*). However, this scenario has displayed a drastic change in vegetative material as a consequence of a pest that devastates palm groves throughout the Brazilian Northeast, the cochineal scale (*Dactylopius opuntiae*). Three varieties resistant to the insect/pest are indicated, namely, 'Orelha de Elefante Mexicana' (*Opuntia stricta*); 'Miúda' (*Nopalea cochenillifera*) and 'Baiana' (*Nopalea* sp). Nevertheless, little is known about the behavior of these varieties in different soil-climatic conditions (Silva et al., 2021).

In cactus-producing regions, when local rainfall does not reach the levels deemed ideal, irrigation is necessary to meet the water requirement of that crop (Pereira, Silva, Zolnier, Morais, & Santos, 2015). It should be considered, however, that the practice of irrigation entails the incorporation of salts into the soil (Gheyi, Dias, Lacerda, & Gomes, 2016), with the risk of salinization resulting from inadequate management of water, soil and crop.

Cacti will generally develop in all types of soil, but their growth is limited by the presence of NaCl in it (Nobel & Bobich, 2002). Felix et al. (2018) concluded that saline treatments with 3.0, 4.5 and 6.0 dS m^{-1} negatively influenced the growth of prickly pear cactus. According to Munns and Tester (2008), a plant's response to salinity depends on species, genotype, phenological stage and time of exposure to salts. Accordingly, the different soils are expected to influence the impacts of using saline water on the prickly pear genotypes.

In this scenario, this study was undertaken to examine the growth and yield of prickly pear cactus 'Orelha de Elefante Mexicana' irrigated with water containing increasing levels of salinity and grown in different soils of the Brazilian semi-arid region.

Material and Methods

The experiment was conducted in a 202.80-m² greenhouse at the Prof. Ignacio Salcedo Unit at the National Institute of the Semi-Arid (INSA), located in the municipality of Campina Grande - PB, Brazil (7°16'34.9" S; 35°57'53.3" W; 542 m a.s.l.). Minimum and maximum temperatures in the greenhouse ranged between 15 and 22 °C and 37.5 and 46 °C, respectively.

The experiment was laid out in a randomized-block design with treatments arranged in a 3 × 4 factorial arrangement (soil types: chromic Luvisol [CL], Solonetz [SN] and Fluvisol [FS] × irrigation water salinity levels: 0.75, 3.0, 5.25 and 7.50 dS m^{-1}, at 25 ºC). Three replicates were used, totaling 12 treatments and 36 experimental units.

The cactus 'Orelha de Elefante Mexicana' (*Opuntia stricta* Haw) was evaluated. The clone was grown in plastic pots with a capacity of 40 L, which were arranged at a spacing of 0.8 × 0.8 m. In these pots, the cladodes were planted by burying the basal third and maintaining the planting position at 45° relative to the longitudinal axis.

The soil samples used in the production of prickly pear cactus (CL, SN and FS) were collected in three different municipalities of the state of Paraíba (Juazeirinho, Soledade and São João do Cariri) and characterized physically and chemically according to methodologies proposed by Richards (1954) and by Teixeira, Donagemma, Fontana and Teixeira (2017) (Table 1).

Based on chemical analysis of the collected soil samples, 50 g K_2O were applied per plant, at planting, for the CL soil only. For foliar application, a drip irrigation system was adopted with pressure-compensating emitters (flow of 10 L h^{-1}) spaced 0.8 m apart, which had been previously evaluated under normal operating conditions.

The saline treatments were applied 90 days after planting (DAP). The irrigation water was prepared by adding commercial NaCl (without iodine) to rainwater, whose amount was determined by multiplying the desired electrical conductivity value (dS m^{-1}) by 640, following Richards (1954). Irrigation was always carried out in the early morning, based on the water consumption of the plants in the previous irrigation, by dividing the estimated volume by the factor of 0.8, thus restoring the soil moisture to field capacity and obtaining a leaching fraction (LF) of approximately 0.2:

$$\text{VL (mL)} = [\frac{(\text{VP} - \text{VD})}{(1 - \text{LF})}] \quad \text{Eq. 1}$$

where VL: water volume to be applied in irrigation; VP: water volume applied in the previous irrigation (mL); and VD: water volume drained in the previous irrigation (mL).

Table 1
Physical, chemical and chemical-salinity characterization of the samples of soils used

Physical characterization										
Soil	Sand	Silt	Clay	Text. class	SD	PD	Porosity	Moisture (g/g)		
	--------g kg^{-1}--------				--- g/cm³ ---		%	Nat.	1 atm	15 atm
CL	607.5	232.9	159.6	Sandy loam	1.34	2.7	50.37	0.44	15.1	7.95
SN	830	71	99	Loamy sand	1.49	2.65	43.77	0.36	8.65	3.9
FS	759.3	141.8	98.9	Sandy loam	1.38	2.68	48.5	0.71	8.49	4.47

Chemical characterization												
Soil	Ca	Mg	Na	K	S	H	Al	CEC	OC	OM	N	P	pH
	------------------------cmol$_c$ kg^{-1} soil ------------------------								-------- % --------			mg kg^{-1}	H_2O 1:2.5
CL	6.53	6.1	3.19	0.18	16	1.1	0	17.1	0.42	0.72	0.04	33	6.86
SN	3.06	1.82	0.35	0.67	5.9	0	0	5.9	0.38	0.66	0.04	30.3	7.37
FS	3.4	2.22	0.12	0.58	6.32	0	0	6.32	0.45	0.78	0.05	32.2	7

Chemical characterization in terms of salinity													
Soil	ECse	Cl^-	CO_3^{-2}	HCO_3^-	SO_4^{-2}	Ca	Mg	K	Na	SP	SAR	ESP	SC
	dS m^{-1}	----------------------- meq/L -------------------------										%	
CL	7.64	85.75	0	3	Abs.	18	26.8	0.18	33.1	26.66	6.98	18.65	SS
SN	0.28	1.5	0	4.2	Abs.	1.25	0.75	0.48	2.19	23.33	2.19	5.93	Nor.
FS	0.46	2.75	0	3.1	Abs.	2.88	0.49	0.65	0.9	27	0.69	1.89	Nor.

CL: Chromic Luvisol; SN: Solonetz; FS: Fluvisol; SD: Soil density; PD: Particle density; Nat.: Natural; CEC: Cation-exchange capacity at pH 7.0; OC: Organic carbon; OM: Organic matter; ECse: Electrical conductivity in the saturation extract; SP: saturation percentage; SAR: Sodium adsorption ratio; ESP: Exchangeable sodium percentage; Abs.: Absent; Nor.: Normal; SC: Soil class; SS: Sodium saline.
Source: Irrigation and Salinity Laboratory (LIS/UFCG).

Prior to planting, a Bordeaux mixture and a 10% neutral detergent and water solution were applied to prevent fungi and cactus scale (*Diaspis echinoccati*).

Plant height (PH), plant width (PW), number of cladodes per plant (NCP) and photosynthetically active area (PAA) were measured monthly between 120 and 360 DAP. Plant height was measured using a graduated ruler from the ground to the apex of the plant. Plant width was defined as the distance between the most extreme points of the plant shoots. Number of cladodes per plant was determined by counting the sprouted cladodes in order of appearance (primary and secondary).

The photosynthetically active area was determined according to Felix et al. (2018), considering the area of the cladodes by order, which was multiplied by the number of cladodes of each generation. The areas of all orders were then added and multiplied by two, as the cladode has a flat geometry (two sides).

The cladode area was determined following the model by Silva et al. (2014), for 'Orelha de Elefante Mexicana'. One area was determined for each order of appearance. Biometric measurements were performed with a measuring tape, for the parameters of cladode length and width.

To estimate the average yield of 'Orelha de Elefante Mexicana', the following variables were analyzed at 360 DAP: fresh weight and dry matter yields in order of appearance and total.

Fresh weight was measured with a digital scale, and consisted of the weight of the total cladodes of each plant immediately after harvest. To determine the dry matter per plant, the dry weight per plant was firstly measured, followed by the dry matter content and the dry matter content.

The cladode dry weight was determined by drying, initially in a greenhouse for 48 h and later in a forced-air oven at a temperature of 65 °C for 120 h.

The dry matter content was determined following an adapted version of the methodology proposed by Rodrigues (2010), in which 1 g of the ground dry weight samples was weighed and placed in previously tared porcelain crucibles. Then, the material was dried in a forced-air oven for 16 h at a temperature of 105 °C. The samples were subsequently removed and kept in a desiccator until reaching room temperature, when they were weighed and their contents determined (Eq. 2). Once the contents were determined, the dry matter content per plant was calculated.

$$\mathrm{DM} = 100 \times \left(\frac{w_{wet} - w_{dry}}{w_{wet}}\right) \qquad \text{Eq. 2}$$

where DM: dry matter percentage; w_{wet}: weight of the sample used (1 g); and w_{dry}: weight of the sample after drying (g).

After the (destructive) assessments of yield, soil collection and analysis were carried out following the above-described methodologies, to determine the pH; electrical conductivity in the saturation extract (ECse, in dS m^{-1}); potassium, calcium, magnesium, sodium (cmolc kg^{-1}) and phosphorus (mg kg^{-1}) contents; sum of bases (SB); base saturation percentage (BS, %); cation-exchange capacity (CEC); and exchangeable sodium percentage (ESP, %) in the experimental plots per soil type.

Results were subjected to analysis of variance, by comparing the salinity levels of the irrigation water (quantitative factor) by regression analysis; and the soil types (qualitative factor) by the test of means (Tukey's) at the 5% probability level, using SISVAR statistical software version 5.2 (Ferreira, 2011).

Results and Discussion

Based on ANAVA, there was no interaction effect ($P > 0.05$) between soil and water salinity treatments for any of the studied variables. Plant height (Figure 1A) varied statistically ($P < 0.05$) at 150, 210, 240 and 270 DAP, with absolute superiority in the SN soil, but no statistical difference from the CL soil.

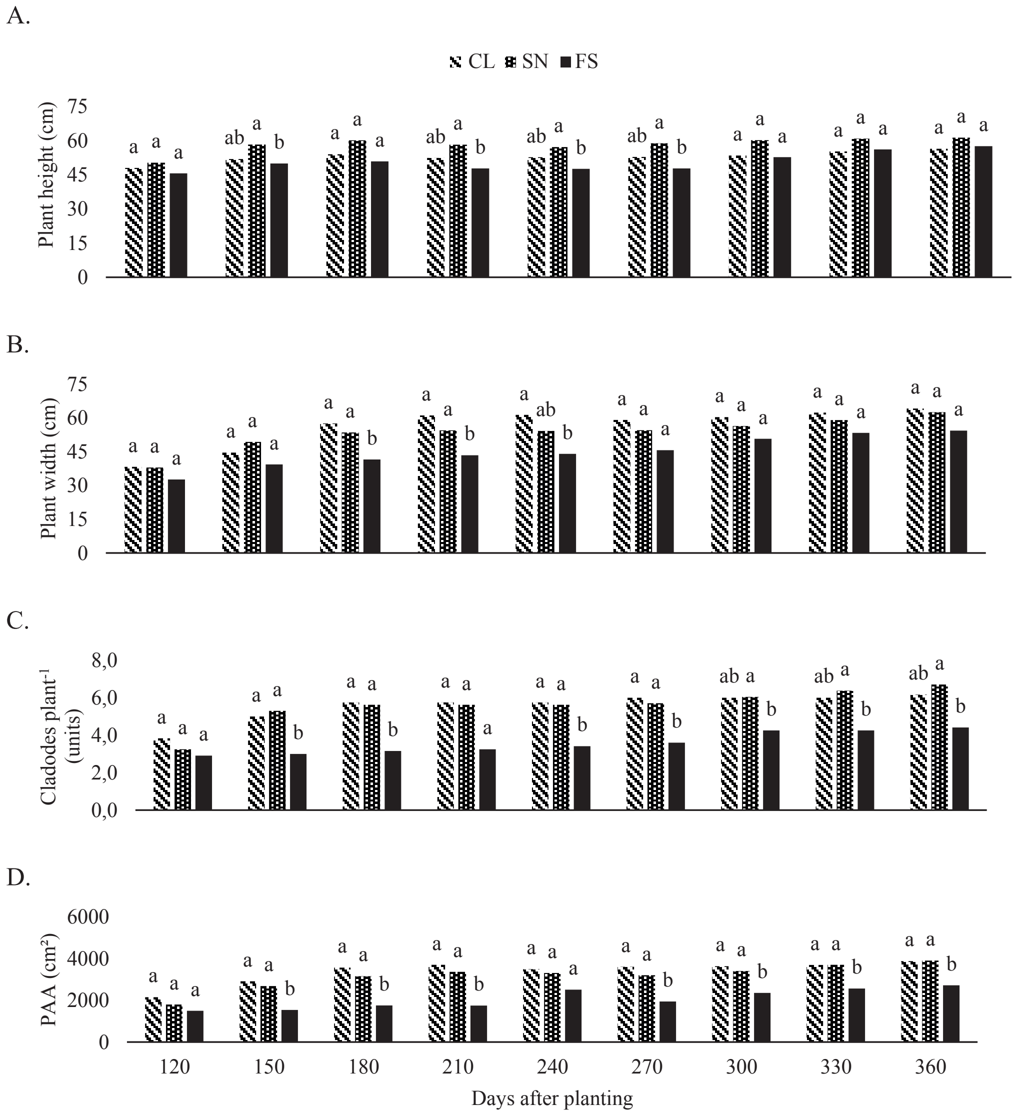

Figure 1. A. Plant height; B. plant width; C. number of cladodes per plant; and D. photosynthetically active area (PAA) from 120 to 360 days after planting according to the soil used.
Values followed by the same letters between columns, in the same period, do not differ by Tukey's test at 5% probability.

The soil types influenced PW (Figure 1B) from 180 to 240 DAP, with statistical superiority detected in the CL and SN soils. However, this differentiation did not occur in the first 150 DAP and from 270 to 360 DAP.

As expected, the tested soils significantly influenced NCP (Figure 1C), which were higher in the CL and SN than in the FS soil at 150, 180, 240 and 270 DAP. From 300 DAP onwards, the SN soil was superior to the other soils in absolute values, but did not differ from CL, which, in turn, did not differ from FS.

For PAA, the CL and SN soils were statistically superior to the FS soil from 150 DAP until the end of the growing period (Figure 1D). According to Pinheiros et al. (2014) the cladode area index (CAI) has a high and positive correlation with the number of cladodes. Thus, the fact that the FS soil provided the lowest NCP means had a negative impact on the active photosynthetic area, which is calculated based on the same parameters as CAI.

Figure 2A shows the PH means as a function of the saline levels applied. In absolute values, the highest ECiw levels (5.25 and 7.50 dS m^{-1}) provided the lowest means from 150 to 360 DAS. On the other hand, the lowest ECiw levels (0.75 and 3.00 dS m^{-1}) practically did not vary between the salinity levels in the last 60 days of the cultivation period, but always provided the highest PH means.

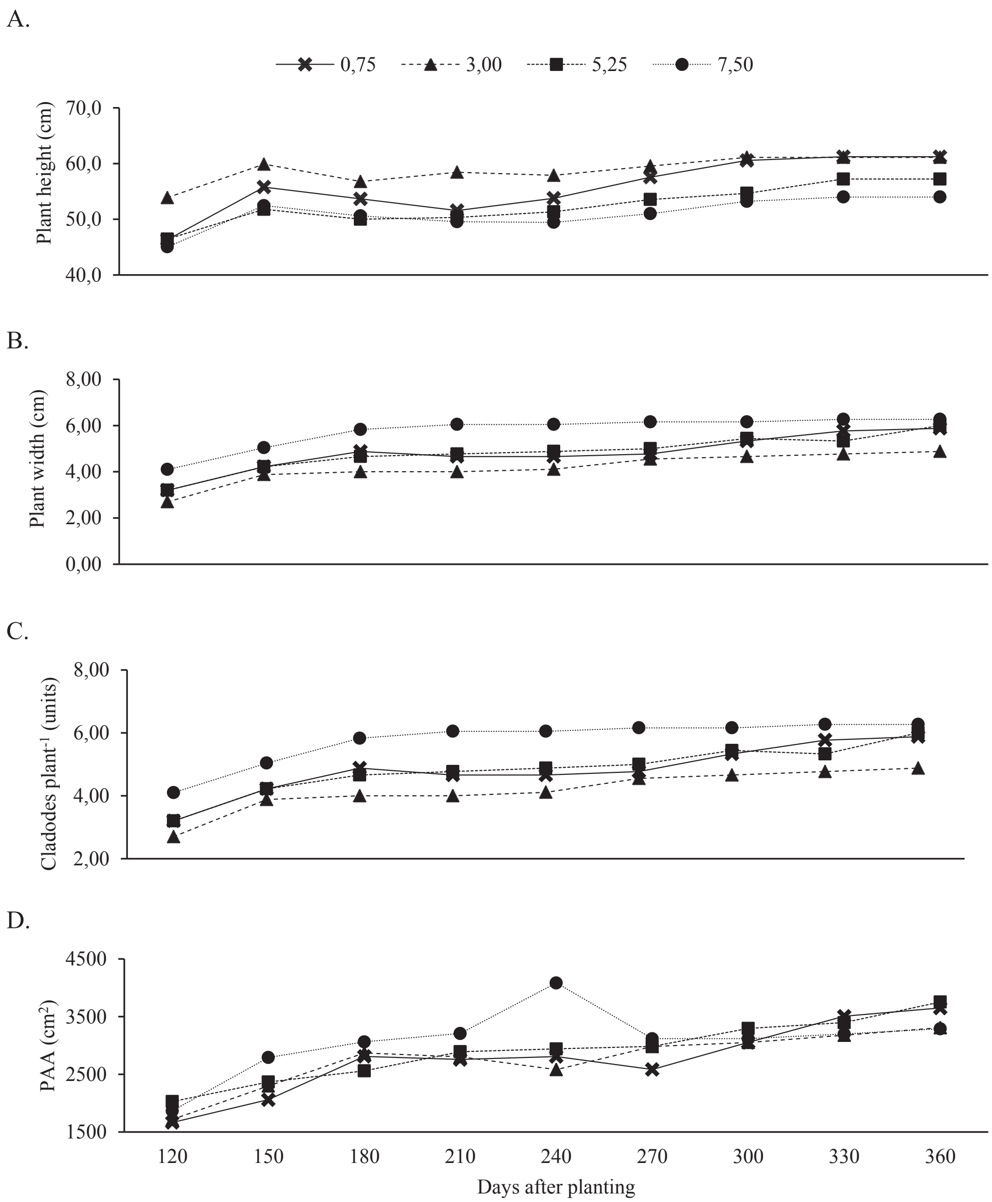

Figure 2. A. Plant height; B. plant width; C. number of cladodes per plant; and D. photosynthetically active area (PAA) from 120 to 360 days after planting according to the electrical conductivity of the irrigation water.

As illustrated in Figure 2B, the highest PW means over time were achieved using the highest ECiw level (7.5 dS m^{-1}), and the lowest with the salinity level of 3.0 dS m^{-1}, demonstrating that water salts did not influence PW in the crop linearly. Plant width decreased linearly with the increasing ECiw levels at 330 and 360 DAP (Figure 3A and 3B, respectively). Considering that variety 'Orelha de elefante mexicana' has a semi-open growth habit, that is, with a predominance of lateral growth, PW represents a factor of greater importance for the management of the crop, given the greater sensitivity to the salinity of the irrigation water.

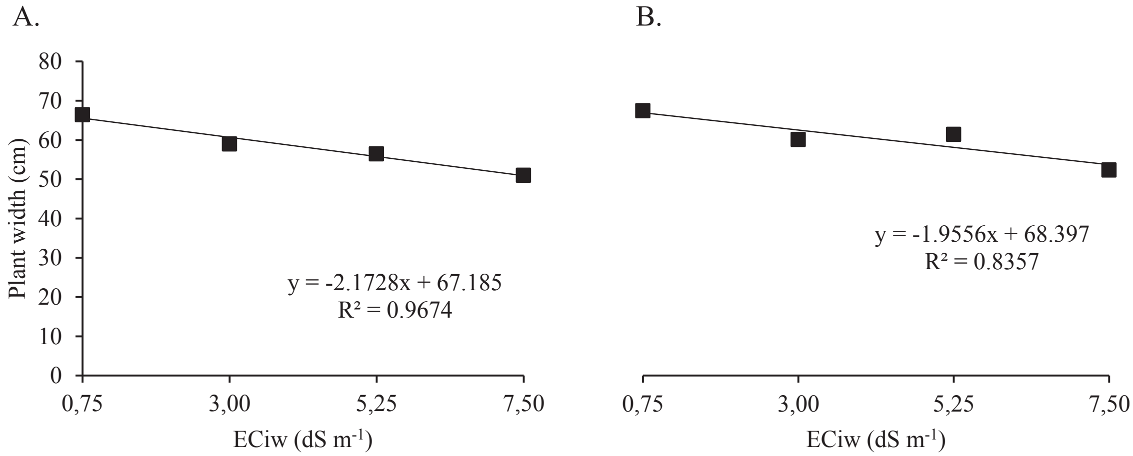

Figure 3. Plant width according to the electrical conductivity of the irrigation water used at 330 (A) and 360 days after planting (B).

If we compare the average width values of the plants grown with water containing the lowest and highest EC levels (0.75 and 7.50 dS m^{-1}, respectively), a 22.41% decrease is observed at 360 DAP. In other words, with the increasing NaCl in the irrigation water and constant application, there was a reduction of just less than 1/4 of lateral growth.

The salinity levels of the irrigation water did not significantly affect NCP (Figure 2C). Dantas (2015) applied different amounts (0, 7.5, 15 and 30 mm month^{-1}) of water with 5.25 dS m^{-1} salinity on the cactus variety 'Miúda' and also found no differences between the treatments for NCP. These results may be associated with the levels applied in these experiments, as explained by Murilo-Amador, Cortéz-Avila, Troyo-Diéguez, Nieto-Guariba and Jones (2001), who tested levels between 2 and 21 dS m^{-1} and identified, for their experimental conditions, that NCP started to be influenced from the level of 5 dS m^{-1} in *Opuntia fícus-indica.* Thus, higher salinity levels in irrigation water or a longer period of exposure to saline conditions may have an effect on NCP for 'Orelha de Elefante Mexicana'.

The different soils used influenced biomass deposition by the mother cladodes, with statistical superiority observed in the CL and SN soils (Figure 4A). The mother cladode is nothing but the seed cladode used for propagation. This structure supports the plant, originating the roots and first-generation cladodes. The greater its fresh weight, the greater the amount of organic compounds and, therefore, the better the development of the plant as a whole. The same statistical dynamics occurred for the second-generation cladodes (Figure 4C).

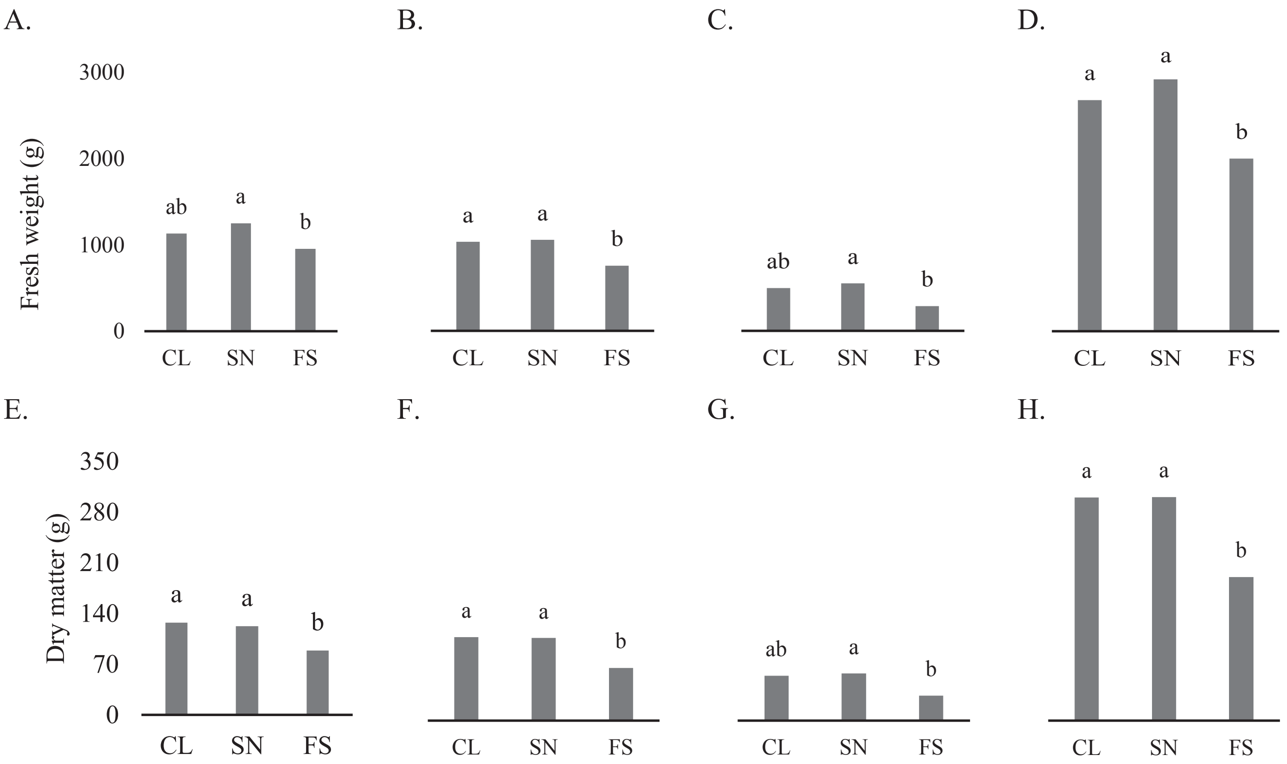

Figure 4. Fresh weight of mother (FWM; A), primary (FWP; B), secondary (FWS; C) and total (FWT; D) cladodes; and dry matter of mother (DMM; E), primary (DMP; F), secondary (DMS; G) and total (DMT; H) cladodes per plant according to the soil used.
Values followed by the same letters between columns do not differ by Tukey's test at 5% probability.

The fresh weight of primary cladodes (Figure 4B), as well as total fresh weight (Figure 4D), revealed the statistical superiority ($P < 0.05$) of the CL and SN soils over FS. Unlike other cultivated crops, the structure of the cactus plant is sectioned into cladodes and may exhibit different responses to treatments. This proposition is confirmed by Sousa (2015), who worked with organic fertilization and irrigation and found a significant effect for the primary cladodes after using chicken litter as compared with sheep manure. However, the same did not occur in the other cladode generations and in total.

The SN soil provided the highest total fresh weight mean (Figure 4D): 2.92 kg plant^{-1}. This value is greater than the 2.77 kg plant^{-1} described in control treatment by Saraiva (2017), who experimented with manure fertilizer and application of biosolids for 'Orelha de Elefante Mexicana'. It is important to note that the cultivation period in said experiment was half of that used in this experiment, that is, 180 DAP.

Considering a planting density of 20,000 plants ha^{-1}, the fresh weight yields in the CL, SN and FS soils were approximately 54, 58 and 40 Mg ha^{-1} year^{-1}, respectively. These values are below the average 131.16 t ha^{-1} year^{-1} fresh weight found in the same variety by Queiroz et al. (2015), who worked with increasing irrigation amounts in the second crop cycle.

Total fresh weight decreased linearly with the increasing saline levels in the irrigation water (Figure 5), i.e., there was a reduction in plant biomass as the saline levels of the irrigation water used in the treatments was increased.

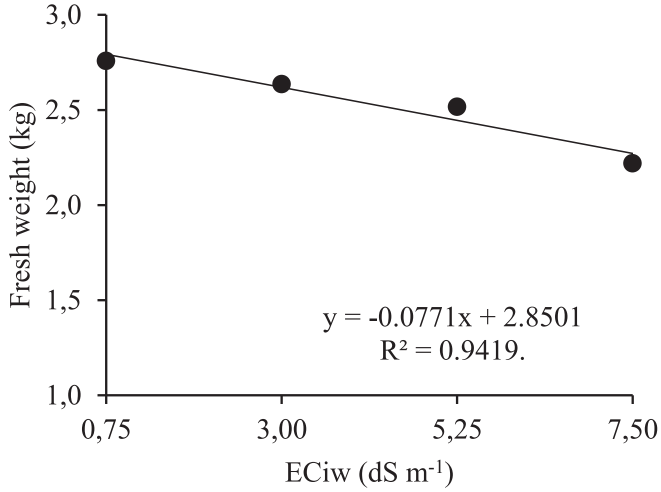

Figure 5. Total fresh weight per plant (kg) as a function of the electrical conductivity of the irrigation water (ECiw, dS m^{-1}).

On average, the cactus plants in the treatments whose EC in the irrigation water was 0.75, 3.00, 5.25 and 7.50 dS m^{-1} weighed 2.8, 2.6, 2.5 and 2.2 kg, respectively. These results reveal a 21.42% reduction when we compare the average fresh weight per plant in the treatments with the lowest and highest saline levels.

According to Meneses, Simões and Sampaio (2005), prickly pear plants have a preference for non-saline soils with high Ca and Mg contents and slightly acidic pH. Thus, the application of water with high saline levels provided a growing environment unfavorable for the cactus, resulting in lower productivity.

In terms of dry matter, the mother, primary and secondary cladode and total plant dry matter (Figures 4E, 4F, 4G and 4H, respectively) evidenced the statistical superiority of the CL and SN soils, except for the secondary cladodes (Figure 4G), for which the FS soil did not differ from the CL soil.

Queiroz (2014) obtained a maximum dry matter value of 8.18 t ha^{-1} year^{-1}, which is higher than those found in this study (extrapolated: 6.02, 6.04 and 3.88 Mg ha^{-1} yr^{-1} for the CL, SN and FS soils, respectively). It is noteworthy that the results of that author were obtained with the application of increasing amounts of non-saline water and monthly applications of

NPK (14-00-18), which probably explains the superior results. Even if we consider the lowest saline treatment (0.75 dS m^{-1}), which was close to the level used by the afore-mentioned author, dry matter yield was still below the result found by the researchers, which was 5.64 t ha^{-1}. The electrical conductivity of the irrigation water did not influence the dry matter of the prickly pear plants. These findings differed from those described by Freire et al. (2018), who applied the salinity levels of 0.3, 0.5, 1.5 and 3.6 dS m^{-1} and found a reduction of DM with the increasing salinity levels for spineless cactus (*Nopalea cochenillifera*).

The superiority of the SN and CL soils under most of the evaluated variables and periods for the growth and yield traits of prickly pear cactus may be indirectly associated with the salinity of irrigation water. The constant application of water rich in NaCl, even at the lower levels, altered the predominant characteristics of the FS soil (Table 2), making it slightly more acidic and causing a significant increase in exchangeable sodium percentage and a significant accumulation of salts in the root zone (approximately 3.3 dS m^{-1}). As such, it showed to be a less suitable soil for the production of prickly pear cactus. Unlike the FS soil, the CL soil was favored by the washing of the salts in the root zone, with an ECse increasing from 7.64 dS m^{-1} (Table 1) to 1.3 dS m^{-1} (Table 2).

Table 2
Chemical analysis of the soils at the end of the growing period (360 days after planting)

Soil	pH	ECse	P	Al^{3+}	H+Al	Ca^{2+}	Mg^{2+}	Na^+	K^+	SB	CEC	BS	AS	ESP
	(1:2.5)	dS m^{-1}	mg kg^{-1}	------------------- cmolc kg^{-1} of soil -------------------								----- % -----		
CL	6.2	1.3	52.8	0	0.9	13.5	2	3	0.3	18.8	19.7	95.3	0	16
SN	7	1.9	52.2	0	0.5	7.7	0.6	2.5	0.2	10.9	11.4	96	0	21.9
FS	6.6	3.3	79.6	0	0.5	7.9	0.8	2.4	0.2	11.3	11.8	95.5	0	20.3

CL: chromic Luvisol; SN: Solonetz; FS: Fluvisol; ECse: Electrical conductivity in the saturation extract; SB: Sum of bases; CEC: Cation-exchange capacity at pH 7.0; BS: Base saturation; AS: Aluminum saturation; ESP: Exchangeable sodium percentage.

Conclusions

The cactus pear 'Orelha de Elefante Mexicana' was able to produce under water with electrical conductivity of up to 7.5 dS m^{-1}, but with a reduction of up to 21.45% in fresh weight yield per plant. The chromic Luvisol and Solonetz soils are recommended, as they provided the best fresh weight and dry matter yields under the present experimental conditions.

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