

Research Paper

Evaluation of cactus pear clones subjected to salt stress

Evaluación de clones de nopal sometidos a estrés de salinidad

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Abstract

Cactus pear is an important source of fodder for herbivores, though its production is affected by soil salinity. This work aimed to evaluate the development of cactus pear clones subjected to salt stress as a measure of their salinity tolerance. The experimental design was a randomized block with 6 replications. Twenty genotypes of cactus pear were used from the Active Germplasm Bank, with variability in resistance to carmine cochineal [*Dactylopius opuntiae* (Cockerell)] as this insect species destroys many stands of cactus on farms. One cladode was planted per pot containing 12 kg of sandy soil. Water with a salinity of 3.6 dS/m was applied at 14-day intervals. The clones were scored at 28-day intervals for degree of damage to cladodes (1–5) and were harvested when they reached a score of 5, showing 100% damage (chlorosis and dehydration) to the whole plant. The Liso Forrageiro clone took 419 days to reach Score 5, indicating its greater tolerance to salinity. Highest dry matter yields were achieved by Orelha de Elefante Mexicana and Orelha de Elefante Africana clones with 51.5 and 50.8 g/plant, respectively, while Liso Forrageiro yielded only 36.1 g/plant, despite having similar surface area and weight of roots to these 2 clones. Further studies in the field involving these better-performing clones seem warranted to determine how the pot trial results are repeated in the field, especially in areas where carmine cochineal insect is prevalent.

Keywords: Cactus forage, *Nopalea cochenillifera*, *Opuntia ficus-indica*, root, salinity damage.

Resumen

El nopal es una fuente importante de forraje para los herbívoros, aunque su producción se ve afectada por la salinidad del suelo. Este trabajo tuvo como objetivo evaluar el desarrollo de clones de nopal sometidos a estrés salino como medida de su tolerancia a la salinidad. El diseño experimental fue en bloques al azar con 6 repeticiones. Se utilizaron veinte genotipos de nopal del Banco de Germoplasma Activo, con variabilidad en la resistencia a la cochinilla silvestre [*Dactylopius opuntiae* (Cockerell)], ya que esta especie de insecto destruye gran cantidad de plantaciones de nopal en áreas agrícolas. Se plantó un cladodio por maceta que contenía 12 kg de suelo arenoso. Se aplicó agua con una salinidad de 3.6 dS/m a intervalos de 14 días. Cada 28 días, puntajes fueron otorgados a los clones en relación al grado de daño a los cladodios (1–5) y se cosecharon cuando alcanzaron una puntuación de 5, mostrando un 100% de daño (clorosis y deshidratación) en toda la planta. El clon Liso Forrageiro tardó 419 días en alcanzar el puntaje 5, lo que indica su mayor tolerancia a la salinidad. Los clones Orelha de Elefante Mexicana y Orelha de Elefante Africana obtuvieron los mayores rendimientos de materia seca con 51.5 y 50.8 g/planta, respectivamente, mientras que Liso Forrageiro rindió solo 36.1 g/planta, a pesar de tener una superficie y peso de raíces similares a estos 2 clones. Estudios adicionales en campo que

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involucran a estos clones de mejor desempeño parece justificado, para determinar cómo se repiten los resultados obtenidos en macetas en campo, especialmente en áreas donde prevalece el insecto cochinilla silvestre.

Palabras clave: Daño por salinidad, *Nopalea cochenillifera*, Nopal forrajero, *Opuntia ficus-indica*, raíz.

Introduction

The cactus pear (*Opuntia* spp. and *Nopalea* spp.) is an important fodder in semi-arid regions due to its adaptation to rainfall irregularities. According to Fonseca et al. (2019), cactus pear is considered a xerophilic plant, so it is adapted to harsh semi-arid conditions and is an important forage resource for animal production in regions that are subject to feed shortage and long dry periods. The growth rate and low-input requirements of prickly pear cactus [*Opuntia ficus-indica* (L.) Mill.] make it an excellent forage or fodder supplement/replacement in semi-arid and arid regions (Mayer and Cushman 2019). It is regarded as a good and inexpensive source of energy, which may reduce the use of concentrate feeds and expensive fodder crops in dry areas (Rodrigues et al. 2016).

Saline water is used in agriculture in arid and semi-arid zones because potable water is scarce, especially in the dry season, but its application contributes to soil salinization (Katerji et al. 2003). To obtain economically viable and environmentally sustainable production, farmers are compelled to substitute salt-tolerant species for more sensitive crops in agricultural areas affected by salinity (Oliveira et al. 2005).

According to Inglese et al. (2017), *Opuntia* spp. are relatively tolerant of water stress, but sensitive to salinity. These authors also mention that the variation in salinity tolerance between cactus pear accessions is not well known. According to Jacobo and Chessa (2017), genetic variability in cacti must be documented if their full potential is to be exploited. Lallouche et al. (2017) completed a Biplot-based species analysis which revealed that *O. engelmannii* was the most salt-tolerant and *O. amyclaea* and *O. robusta* were the most sensitive ones. Freire et al. (2018) observed that water salinity of 3.6 dS/m and an irrigation frequency of 7 days resulted in significant damage to and reduced productivity of cactus pear cv. Miúda relative to other salinity levels and irrigation frequencies, suggesting high sensitivity of this clone to salt stress.

The carmine cochineal insect [*Dactylopius opuntiae* (Cockerell)] (Hemiptera: Dactylopiidae) has affected large areas of cactus pear in northeastern Brazil, so evaluation of cactus pear clones resistant to carmine cochineal under different environmental conditions is extremely important if cactus is to be used commercially as a fodder.

In the literature, information on the effect of salinity on the development of cactus pear clones with different levels of resistance to carmine cochineal is rare. This strengthens the need for these evaluations to improve the understanding of the morphological and productive responses of the clones to saline conditions.

The hypothesis was that cactus pear species and clones differ in sensitivity to abiotic factors, which may affect their development. Thus, the objective of this work was to evaluate the development of 20 cactus pear clones with different levels of resistance to carmine cochineal when submitted to saline stress.

Materials and Methods

The experiment was conducted in a greenhouse, with a maximum temperature of 45 °C, a minimum of 30 °C, maximum relative humidity of 85% and a minimum of 75%.

Fresh cladodes were used as planting material, weighing between 175 and 1,950 g (fresh weight). One cladode was planted in each polyethylene pot containing 12 kg of soil with a sandy texture, collected in São Bento do Una, a semi-arid region of Pernambuco, Brazil. Chemical attributes of the soil were as follows: pH – 5.80; phosphorus (Mehlich I) – 41 g/dm³; sodium – 0.03 cmolc/dm³; potassium – 0.17 cmolc/dm³; calcium (1 mol/L KCl) – 0.95 cmolc/dm³; magnesium – 0.75 cmolc/dm³; aluminum (1 mol/L KCl) – 0.10 cmolc/dm³; hydrogen + aluminum (0.5 mol/L calcium acetate) – 0.49 cmolc/dm³; and organic matter 8.52 g/kg; and physical attributes, determined by hydrometer method (error = ± 5%), were: 88% sand; 2.14% silt; and 9.86% clay with a silt:clay ratio of 0.21:1.

Twenty clones of cactus pear (Table 1) were used from the Active Germplasm Bank – BAG, with variability in their resistance to carmine cochineal. The resistance level was classified according to Vasconcelos et al. (2009), as well as previous evaluations carried out at the Germplasm Bank (Table 1).

From 35 days after planting, each pot was irrigated with saline water with an electrical conductivity (EC) of 3.6 dS/m at 14-day intervals. The criteria for irrigation frequency and salinity level of irrigation water were chosen according to Freire et al (2018). Those authors indicated that this salinity level caused the greatest damage to cactus pear.

in the shortest time (41.5 days), while Liso Forrageiro (137.4 days), F-21 (125.3 days), and Algerian (118.5 days) took the longest time ($P<0.05$) (Table 3). Damage scores had increased to 3 for Chile Fruit, Gigante, Copena V1, V-16 and F-8 in 43.3–75.4 days, while Ipa Sertânia, Ipa 90-156, F-21, Orelha de Elefante Mexicana, Orelha de Onça, Algerian and Liso Forrageiro clones took 135–172 days to do so ($P<0.05$). The same pattern continued with Chile Fruit, F-8 and Gigante reaching Score 4 in 111–121 days, while Liso Forrageiro took 265 days ($P<0.05$). The gap between clones increased with time with F-8 reaching Score 5 in 131 days and Liso Forrageiro in 419 days ($P<0.05$) (Table 2).

Electrical conductivity of drainage water from the pots increased with time with significant differences between clones throughout (Table 2). At Score 2, lowest EC levels occurred for F-24, F-8, Copena V1 and Ipa Clone 20 (31.7–33.0 dS/m) and the highest EC levels for Algerian, Liso Forrageiro, F-21, and Ipa Sertânia (62.7–69.9 dS/m) ($P<0.05$). By Score 3, EC levels had increased, with lowest values for Copena V1, Gigante and F-8 (32.8–38.3 dS/m) and the highest for Ipa Sertânia, Liso Forrageiro, Algerian, F-21, Ipa 90-111 and Redonda (69.0–75.0 dS/m) ($P<0.05$). By Score 4 values had increased further with the lowest

values for F-8 (52.7 dS/m) and highest for Ipa Sertânia, Ipa 90-156, Algerian, Liso Forrageiro, V16 and Orelha de Elefante Africana (80.8–88.9 dS/m) ($P<0.05$). Electrical conductivity of soil at harvest time varied from 66.5 dS/m for F-8 to 91.0–95.8 dS/m for Liso Forrageiro, Ipa Sertânia, Ipa 90-156, F-13, Algerian and V-16 ($P<0.05$).

There were significant differences ($P<0.05$) in DM production of cactus pear clones (Table 3).

The lowest yields were observed in F-8, F-21 and Algerian clones (19.2–28.2 g/plant), while highest yields occurred for Orelha de Elefante Africana, Ipa Clone 20, Orelha de Elefante Mexicana, Ipa 90-156 and F-13 (41.3–50.8 g/plant) ($P<0.05$).

Sodium concentration in plants ranged from 5.7 to 10.7 g/kg, being greater ($P<0.05$) for Chile Fruit, Ipa Sertânia, F-24, F-21, Orelha de Elefante Mexicana, Redonda, Algerian, Gigante and V-16 clones than for the remainder (Table 3). The lowest values occurred in Liso Forrageiro, Copena V1 and Ipa 90-156 (5.7–6.6 g/kg DM).

Similarly, there were significant differences ($P<0.05$) in chlorophyll concentrations in the various clones with values varying between 0.54 (Copena V1) and 0.82 mg/g (Liso Forrageiro).

Table 2. Total amount of water, number of days required for cactus pear clones to record damage scores of 2, 3, 4 and 5 and electrical conductivity of drainage water at these stages and electrical conductivity of soil at harvest.

Clone	Total amount of water (L/plant)	Days to reach score				EC drain (dS/m) ¹			Soil EC (dS/m) ²
		Score				Score			
		2	3	4	5	2	3	4	
F-21	19.2b	125.3a	137.5a	158.2b	227.3c	67.9a	69.7a	79.7b	81.8b
Miúda	18.1b	75.3b	117.5b	150.0c	204.0c	46.7b	62.2b	70.2b	83.3b
Ipa Sertânia	19.6b	90.8b	143.8a	200.2b	242.2c	62.7a	75.0a	82.6a	91.0a
Orelha de Onça	16.4c	69.5c	137.3a	158.3b	228.8c	42.3b	65.7b	70.0b	74.1b
Copena F1	17.0c	66.7c	122.8b	169.7b	213.5c	39.8b	44.3b	72.4b	75.2b
Copena V1	19.1b	61.7c	67.7c	140.8c	236.5c	31.7c	32.9c	66.0b	81.0b
Gigante	17.1c	57.0c	58.7c	120.7c	209.0c	36.7b	38.3c	62.3b	76.1b
Ipa Clone 20	19.2b	64.3c	114.7b	153.8b	229.7c	32.8c	63.0b	74.7b	80.6b
Redonda	17.4b	59.8c	102.3b	173.5b	232.5c	38.5b	69.0a	78.4b	80.3b
Ipa 90-156	20.6c	64.0c	144.0a	203.0b	261.3b	42.3b	62.7b	82.1a	92.7a
Ipa 90-111	19.4b	62.7c	104.2b	186.0b	259.3b	45.0b	69.6a	73.1b	83.5b
Orelha de Elefante Africana	19.9b	66.7c	109.7b	186.7b	251.0b	36.5b	60.2b	80.8a	83.1b
Orelha de Elefante Mexicana	19.1b	60.0c	135.0a	168.2b	247.6b	44.0b	54.4b	72.7b	82.2b
Algerian	20.9b	118.5a	172.0a	205.0b	297.5b	69.9a	70.3a	82.8a	91.3a
Liso Forrageiro	25.8a	137.4a	137.6a	265.2a	419.2a	69.7a	71.7a	88.9a	95.8a
Chile Fruit	15.2c	41.5d	43.3c	111.2c	175.3c	41.2b	52.8b	70.3b	75.0b
V-16	21.4b	71.7b	74.7c	206.5b	323.5b	42.4b	57.3b	83.0a	90.5a
F-13	22.0a	69.2c	113.7b	180.8b	310.8b	37.8b	56.7b	70.0b	93.0a
F-24	18.3b	61.8c	122.0b	145.3c	216.5c	31.8c	64.3b	68.2b	81.4b
F-8	14.0c	60.0c	75.4c	120.8c	130.5d	33.0c	34.9c	52.7c	66.5c
CV (%)	7.8	15.7	10.3	12.2	14.7	9.1	16.3	15.8	13.3

¹EC: Electrical conductivity in drainage on the day the score was reached. ²Soil EC: Electrical conductivity in soil. Means followed by different letters within each column differ significantly ($P<0.05$) by the Scott Knott test.

Significant differences ($P<0.05$) in length, mean diameter, surface area and dry weight of roots were recorded (Table 4). The longest roots were recorded for Miúda, Orelha de Elefante Africana, Ipa Clone 20, Orelha de Elefante Mexicana, Redonda, Gigante and Liso Forrageiro (32.76–45.89 cm), while shortest roots

occurred in Chile Fruit, F-8, Orelha de Onça, Algerian, V-16 and Copena V1 (1.60–3.26 cm) ($P<0.05$). Similarly, roots of the various clones had differing diameters with thickest roots for F-8, Miúda, Ipa Clone 20, Orelha de Elefante Mexicana, Redonda, Algerian, Gigante and Liso Forrageiro (0.619–0.939 mm), and thinnest roots

Table 3. Dry matter yield and sodium and total chlorophyll concentrations in cactus pear clones grown under saline conditions.

Clone	DM (g/plant)	Na concentration (g/kg DM)	Chlorophyll concentration (mg/g DM)
F-21	28.2 c	10.2 a	0.70 a
Miúda	34.2 b	7.6 b	0.62 b
Ipa Sertânia	39.4 b	9.1 a	0.57 b
Orelha de Onça	38.3 b	8.3 b	0.62 b
Copena F1	35.2 b	7.8 b	0.64 b
Copena V1	32.4 b	6.2 b	0.54 b
Gigante	35.3 b	10.2 a	0.65 a
Ipa Clone 20	50.6 a	8.1 b	0.73 a
Redonda	33.4 b	9.1 a	0.76 a
Ipa 90-156	45.1 a	6.6 b	0.61 b
Ipa 90-111	35.3 b	7.0 b	0.75 a
Orelha de Elefante Africana	50.8 a	7.9 b	0.79 a
Orelha de Elefante Mexicana	51.5 a	9.4 a	0.78 a
Algerian	19.2 c	10.7 a	0.59 b
Liso Forrageiro	36.1 b	5.7 b	0.82 a
Chile Fruit	33.2 b	9.0 a	0.62 b
V-16	32.2 b	9.1 a	0.72 a
F-13	41.3 a	7.4 b	0.68 a
F-24	34.1 b	10.5 a	0.55 b
F-8	25.3 c	7.9 b	0.60 b
CV (%)	6.22	5.67	7.82

Means followed by different letters within each column differ significantly ($P<0.05$) by the Scott Knott test

Table 4. Length, mean diameter, surface area and dry biomass of roots of cactus pear clones irrigated with saline solution.

Clone	Length (cm)	Mean diameter(mm)	Surface area (cm ²)	Dry weight(g/plant)
F-21	13.25 c	0.587 b	1.45 c	15.2 b
Miúda	39.73 a	0.736 a	3.04 a	15.4 b
Ipa Sertânia	14.72 b	0.372 b	1.30 c	10.3 b
Orelha de Onça	3.26 d	0.297 c	0.89 c	5.1 c
Copena F1	15.89 b	0.589 b	2.12 b	12.8 b
Copena V1	3.00 d	0.229 c	1.02 c	3.1 c
Gigante	43.78 a	0.743 a	3.92 a	29.5 a
IPA Clone 20	38.72 a	0.879 a	2.03 b	22.3 a
Redonda	32.76 a	0.715 a	4.10 a	33.7 a
IPA 90-156	17.89 b	0.249 c	1.23 c	14.7 b
IPA 90-111	26.54 b	0.329 c	1.46 c	15.6 b
Orelha de Elefante Africana	32.91 a	0.515 b	3.42 a	16.1 b
Orelha de Elefante Mexicana	42.09 a	0.829 a	3.15 a	20.2 a
Algerian	1.99 d	0.619 a	2.12 b	3.0 c
Liso Forrageiro	45.89 a	0.939 a	3.51 a	34.7 a
Chile Fruit/1317	2.97 d	0.362 b	0.99 c	5.2 c
V-16	1.60 d	0.216 c	1.03 c	3.2 c
F-13	25.33 b	0.479 b	2.43 b	19.1 b
F-24	18.24 b	0.426 b	1.36 c	13.1 b
F-8	1.96 d	0.682 a	0.76 c	3.1 c
CV (%)	47.1	33.3	52.37	13.12

Means without a common letter within each column differ significantly ($P<0.05$) by the Scott Knott test.

for Ipa 90-156, Ipa 90-111, Orelha de Onça, V-16 and Copena V1 (0.216–0.297 mm) ($P < 0.05$). Consequently, surface area of roots varied widely among the clones with greatest areas for Miúda, Orelha de Elefante Africana, Redonda, Gigante and Liso Forrageiro (3.04–4.10 cm²) and smallest areas for F-8, Orelha de Onça, Chile Fruit, V-16 and Copena V1 (0.76–1.03 cm²) (Table 4; $P < 0.05$).

The greatest values for root biomass were reached by Liso Forrageiro, Gigante, Redonda, Orelha de Elefante Mexicana and IPA Clone 20 (20.2–34.7 g/plant), while lowest yields were for Chile Fruit, F-8, Orelha de Onça, Algerian, V-16 and Copena V1 (3.0–5.2 g/plant) ($P < 0.05$).

Discussion

This study has shown that cactus pear clones display marked variation in adaptation to salinity under greenhouse conditions, indicating that there are options for selecting more productive clones to grow on saline soils.

The amount of water supplied to the cactus pear clones directly influenced the accumulation of Na in the soil and the EC of the soil saturation extract (Table 2). Consequently, chlorosis and wilting symptoms appeared in the clones at different ages due to the accumulation of Na in the soil or inside the plants, making the water or nutrients required unavailable.

While Liso Forrageiro took far longer than other species to reach Score 5 for harvest, this clone has low resistance to carmine cochineal, which is an undesirable characteristic for cactus pear in areas where this insect pest occurs. In addition, this clone was not as productive as some other clones studied.

The clone that reached Score 5 most quickly was F-8 which did so in 130 days (Table 2), possibly indicating lower tolerance to saline stress. The soil, in which this clone was grown, had lower EC (66.5 dS/m) at harvest, probably influenced by the smaller amount of water received. Freire et al. (2018) observed that irrigating cv. Miúda every 7 days with saline water (3.6 dS/m) resulted in an increase in soil EC and a high percentage of damage to cladodes, suggesting high sensitivity of this clone to salt stress.

Franco-Salazar and Veliz (2008) demonstrated that *O. ficus-indica* could survive 10 weeks of treatment with 100 mM NaCl, but the shoot showed symptoms of chlorosis and dehydration at harvest. In our study, most clones had barely reached Score 2 after 70 days of irrigation with saline water. Values for soil EC we recorded are considered high because, according to Bor et al. (2003), most plants can develop when the EC of soil is less than 8 dS/m, while some species grow only in soils with EC \leq 3 dS/m. Osmotic or ionic stress occurs above this value,

causing the plants to die. According to Dias et al. (2016), good quality water for irrigation should have EC < 0.75 dS/m, while plant growth generally is not affected below 2.0 dS/m, although differences can be found between species and cultivars. EC values in soil at the end of the study were much higher than these levels.

Accumulation of soluble salts in the root zone in saline environments causes a decrease in cellular expansion, thus reducing the overall development of the plant (Khalid and Silva 2010). Franco-Salazar and Véliz (2008) observed that, when NaCl concentration in the root medium is increased, there is a reduction in the formation of new organs, which causes negative effects in the development of *Opuntia* spp. According to Munns and Tester (2008), the survival of plants subjected to saline stress depends on the ability to restrict ion absorption. It is probable that the Liso Forrageiro clone used tolerance mechanisms to survive for 419 days in a saline environment.

The highest dry matter yields observed in Ipa 90-156, Orelha de Elefante Africana, Ipa Clone 20, F-13 and Orelha de Elefante Mexicana clones (Table 3) may result from the storage of ions in large vacuoles of the cactus pear as well as the accumulation of organic solutes in these vacuoles (Fonseca et al. 2019). Although they were harvested after a shorter growing period than Liso Forrageiro, they showed greater production, and are considered to possess some resistance to carmine cochineal (low, high, low, high and high, respectively).

Amador et al. (2001) observed a productivity of 46 g DM/plant for the Copena V1 clone after 147 days of growth in salinity of 2 dS/m, which was considered low productivity, even though the clone is cultivated and considered adapted to the conditions of the region of Mexico, where mean soil salinity is 2–5 dS/m. Fonseca et al. (2019) irrigated Gigante with saline (3.6 dS/m) water and 33% reference evapotranspiration every 3 days and it grew, increasing in height, number of cladodes, cladode area index, green mass and DM yield. The tolerance of crops to salinity is generally displayed as phytomass production, plant growth, plant number/unit area and ability to survive in saline environments (Dias et al. 2016).

The low yields for F-8, F-21 and Algerian clones (Table 3) indicated that these clones did not grow well in saline soils. Gajender et al. (2014) observed that *O. ficus-indica* was moderately tolerant of salinity (52 mM NaCl), but sensitive to pH, with negligible growth at pH 9.8. Liso Forrageiro was the last clone to be harvested and contained 5.7 g Na/kg DM (Table 3). Thus, it is probable that Na exclusion and/or ion absorption restriction are more efficient in this clone than in the others, indicating its greater adaptation to salt stress, since the soil of this clone presented greater EC. According to Lastiri-Hernández et

al. (2018), due to transpiration Na^+ is deposited and accumulates in leaves rather than in roots. In perennial species, Na^+ accumulation in leaves results mainly from their longer lifespan and thus longer duration of transpiration. Silva et al. (2014) observed that Orelha de Elefante Mexicana presented greater water use efficiency, followed by IPA Sertânia. Miúda was the least efficient clone for the Brazilian semi-arid region. Orelha de Elefante Mexicana and Miúda presented greater Na use efficiency.

In a study assessing *Nopalea cochenillifera*, Freire et al. (2018) observed that increasing the salinity level of irrigation water increased Na concentration in the cactus, and there was a significant interaction between irrigation frequency and irrigation water salinity. Amador et al. (2001) observed that Na concentration in shoot DM of Copena F1 increased from 0.51 to 1.51% when grown for 21 weeks in a greenhouse and salinity level of irrigation water was increased from 2 to 21 dS/m. At the salinity level of 5 dS/m, Na concentration in shoots was 0.62%. Schuch and Kelly (2008) irrigated species of cacti (*Echinocactus grusonii*, *Carnegiea gigantea*, *Fouquieria splendens* and *Agave parryi* var. *truncata*) for 5 months and observed that Na concentration in plants varied from 15.52 to 18.30 g/kg DM, as the EC of the irrigation water rose from 0.6 to 15 dS/m.

Franco-Salazar and Veliz (2008) grew *O. ficus-indica* hydroponically for 10 weeks with concentrations of 0, 50 and 150 mM NaCl and showed that chlorophyll concentration ranged from 0.5 to 1.0 mg/g fresh tissue weight. As salinity increased, titratable acidity in apical cladodes also increased, while no significant effect was detected for either the number of apical or basal cladodes or for chlorophyll concentration in either type of cladodes, suggesting some kind of osmotic adjustment or osmoprotection.

The significant differences in lengths of roots in the various cacti (Table 4) may indicate differences in tolerance to salinity of the various clones. Amador et al. (2001) showed that the length of roots of *O. ficus-indica* cv. Copena V1 was 10 cm when grown for 21 weeks and irrigated with saline water, while roots of the Control plants were 21.7 cm long. Corresponding DM yields of plants were 2.7 and 13 g/plant, respectively. In that study, the salinity of water applied increased gradually from 2 to 21 dS/m, and the authors concluded that inhibition of root growth in treated plants was due to Na toxicity and that the clone under study was not tolerant of salinity.

In cultivating *O. ficus-indica* and *O. robusta* in South Africa, Snyman (2004) found that root growth decreased significantly under water stress. According to the author, cactus pear roots do not develop well in saline environments since they produce little dry mass and tend

to die under dry or ionic stress. Working with *O. ficus-indica* in hydroponic culture with different concentrations of NaCl, Franco-Salazar and Veliz (2007) observed that increased salinity reduced growth of both shoots and roots.

As expected, the largest surface areas of roots occurred in clones with greater root length and larger mean root diameter (Table 4); mean diameter and root surface area are directly related to nutrient uptake. The genotype Liso Forrageiro was harvested at the oldest age and presented the largest mean diameter and largest root surface area but surprisingly did not produce the highest DM yield.

Since highest yields occurred for Orelha de Elefante Africana, Ipa Clone 20, Orelha de Elefante Mexicana, Ipa 90-156 and F-13, it would seem that these clones would be the most promising candidates for further study to identify most appropriate cacti for growing as a source of fodder. As 3 of the clones (Africana, Mexicana and F-13) are regarded as highly resistant to carmine cochineal insect, while Clone 20 and Ipa 90-156 are only lowly resistant, further evaluations should be carried out in the field where these insects are prevalent.

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