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Forage Cactus Pear Cultivars Irrigated with Wastewater in a Semi-Arid Region

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Abstract: The reuse of wastewater from domestic sewage can contribute to forage production in regions with limited water availability. The aim was to study the agronomic performance of Gigante, Miúda, and Orelha de Elefante Mexicana cactus pear cultivars irrigated with treated sewage water; contents of macro- and micronutrients in plant tissues; export of nutrients and productivity. The study was conducted in an area near the domestic sewage treatment plant in the municipality of Guanambi, Bahia, Brazil. The experimental design was completely randomized blocks, with six replications. A drip irrigation system was used, with a flow rate of 1.6 L h^{-1} and a watering interval of three days, applying 33% of the reference evapotranspiration. The physical/chemical characteristics of the soil, dry matter content, nutritional content of the forage cactus pear, productivity, and soil quality were evaluated. Without soil correction or application of mineral or organic fertilizers, only with the application of wastewater, the forage cactus pear plants developed within expected standards. The 'Orelha de Elefante Mexicana' and the 'Gigante' show greater green mass productivity and irrigation water productivity for green mass when compared to the 'Miúda'. The highest dry matter productivity is expressed by the Orelha de Elefante Mexicana cultivar. The decreasing order of macronutrient export by the forage cactus pear is K, Ca, N, Mg, S, and P, and Mn, Fe, Zn, B, and Cu for micronutrients. Irrigation with treated wastewater, using 33% of the reference evapotranspiration, maintains K contents within a sufficient range; however, for the other nutrients, it is insufficient for the forage cactus pear plants.

Keywords: *Opuntia*; semiarid; wastewater reuse; irrigation water productivity

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1. Introduction

Forage cactus pear has crassulacean acid metabolism (CAM), which allows it to adapt to drought. Thus, it is a strategic plant for arid and semi-arid regions of the world, which are characterized by high temperatures, excess radiation, and water scarcity (low precipitation with irregular rainfall), which affects food availability for animals. With the long periods of drought in the semi-arid region, the use of forage cactus pear is of great importance for livestock farming. However, despite being tolerant to water deficit, the plant improves its production rates when irrigated.

Irrigation with reused water in agriculture has been the subject of research for several crops. Regarding the use of wastewater from treated sewage effluent, it was the subject of study on chemical changes in the soil [1], the impacts on soil fertility [2], in cowpea [3], in soil microbial activity and growth of castor beans [4], in the growth and production of peppers [5], in the growth of tree species in the caatinga [6], among others. These studies have very interesting results, such as that described by [3], which demonstrated that, in the absence of mineral fertilization, soils irrigated with wastewater from treated domestic sewage can meet the nutritional needs of cowpea.

Irrigation of forage pear, in recent years, has been widely studied, in 'Miúda' [7], 'Gigante' [8,9], 'Gigante' and 'Miúda' [10], and 'Orelha de Elefante Mexicana' [11,12]. In all these studies, the authors obtained profitable productivity using lower depths than the region's evapotranspirometric demand.

Studies related to the use of treated wastewater from domestic sewage in cactus pear cultivation are still incipient in the literature. However, studies in this line show interesting results. The study in [13] found that the use of treated sewage wastewater and the preservation of second-order cladodes during harvest contributed to gains in production and in morphogenic and bromatological characteristics of the forage cactus pear 'Orelha de Elefante Mexicana' and 'Doce Miúda', with a production of 237.58 t ha^{-1}, greater than the values found using raw water.

When evaluating the supply of nutrients to 'Gigante' forage cactus pear irrigated with wastewater, compared to water from clean sources and plots fertilized with cattle manure, ref. [14] found that, when it comes to irrigation with wastewater, plants that did not receive fertilization with cattle manure maintained similar averages to those that did receive it.

Given the above, it can be assumed that the use of treated sewage wastewater contributes to gains in quality and production in forage cactus pear, an important factor, in addition to the preservation and reuse of water. Thus, the objective of this work was to study the agronomic performance; to evaluate the contents of macro- and micronutrients in plant tissues; and to determine the export of nutrients and the productivity of three cultivars of forage cactus pear (Gigante, Miúda, and Orelha de Elefante Mexicana), irrigated with treated sewage water, and the impacts on soil quality.

2. Materials and Methods

2.1. Experiment Location

The experiment was carried out on private property close to the Sewage Treatment Station (STE), with geographic coordinates equal to 14°14′10″ S and 42°47′46″ W, in the municipality of Guanambi, Bahia, Brazil.

The planting of cactus pear cultivars took place at the end of August 2021. Before the implementation of the reuse unit (RU), the soil in the area was sampled at depths of 0–0.10, 0.10–0.20, and 0.20–0.40 m, collecting 20 samples per layer, walking in a zigzag pattern, to determine physical (soil density, sand, silt, and clay contents, and total porosity), water (water retained at 0.1, 6, 10, 30, 50, and 100 kPa), and chemical characteristics (pH, SOM, P, K, Na, Ca, Mg, Al, H+Al, SB, t, T, V, m, B, Cu, Fe, Mn, Zn, P-rem, electrical conductivity of the saturated paste extract—EC and sodium adsorption ratio—SAR), according to methods proposed by EMBRAPA [15]. To evaluate the effect of wastewater application, 4 soil samples per experimental plot were collected in the center of the double row of cactus pear plants, at a depth of 0–0.20 m. This depth was adopted for sampling the chemical properties of the soil after application of wastewater because most of the plant's root system is there [16]. However, to evaluate the soil at harvest, samples were collected at depths of 0.0–0.20 m and 0.20–0.40 m.

2.2. Soil Conditions When Installing the Experiment

Soil analyses before planting showed contents of 74.67%, 13.33%, and 12% of sand, silt, and clay, respectively, which characterizes it as sandy loam, with a specific mass of 1.51 g cm^{-3} and total porosity of 43%. The average chemical composition of the soil in the experimental area, at a depth of 0 to 0.20 m, is presented in Table 1. Soil moisture at retention tensions of 0.10, 6, 10, 30, 50, and 100 kPa was 0.35, 0.26, 0.23, 0.18, 0.15, and 0.12 m^3 m^{-3}, respectively, for the 0.0–0.20 m soil layer.

Table 1. Chemical analysis of the soil in the experimental area, in the 0.0–0.20 m depth layer, before planting the forage cactus pear and the legume cultivars.

Attributes	Values
pH [(1)]	6.02
SOM [(2)] (dag kg^{-1})	0.68
P [(3)] (mg dm^{-3})	5.90
K [(3)] (mg dm^{-3})	151.33
Na [(3)] ($cmol_c$ dm^{-3})	0.20
Ca [(4)] ($cmol_c$ dm^{-3})	0.98
Mg [(4)] ($cmol_c dm^{-3}$)	0.38
Al [(4)] ($cmol_c$ dm^{-3})	0.08
H + Al [(5)] (cmolc dm^{-3})	1.43
SB ($cmol_c$ dm^{-3})	1.98
t ($cmol_c$ dm^{-3})	2.07
T ($cmol_c$ dm^{-3})	3.40
V (%)	57.33
m	5.00
B [(6)] (mg dm^{-3})	0.10
Cu [(3)] (mg dm^{-3})	0.10
Fe [(3)] (mg dm^{-3})	183.87
Mn [(3)] (mg dm^{-3})	19.22
Zn [(3)] (mg dm^{-3})	0.77
P-rem [(7)] (mg L^{-3})	39.13
EC (dS m^{-1})	0.50

Note: [(1)] pH in water; [(2)] colorimetry; [(3)] extractant Mehlich-1; [(4)] extraction with KCl 1 mol L^{-1}; [(5)] pH SMP; [(6)] extractant $CaCl_2$; [(7)] P equilibrium of the solution. SB: sum of bases; t: effective cation exchange capacity; T: cation exchange capacity at pH 7; V: base saturation; P-rem: remaining P; CE: electrical conductivity. dag kg^{-1} = %; mg dm^{-3} = ppm; $cmol_c$ dm^{-3} = 0.01 meg cm^{-3}.

For forage cactus pear, in the semi-arid region of Bahia, Brazil, the soil has medium acidity, which is sufficient [17]. The contents of organic matter, P, Ca, and Mg are very low; the K content is average (sufficient); potential acidity is medium (sufficient); the base sum, total CEC, and effective CEC are very low; base saturation is low; the P-rem content is very low; and the EC is average (sufficient). Regarding micronutrients, there is a low content of Zn available; high contents of available Mn and Fe; and very low contents of available Cu and B [18]. According to [19], soil electrical conductivity does not present a risk for reducing potential crop productivity.

No correction or fertilization of the soil was carried out, with the purpose of evaluating only the effect of wastewater on the growth and production of forage cactus pear cultivars.

2.3. Wastewater Quality

Some chemical attributes of the wastewater evaluated at the beginning of the experiment are presented in Table 2. The water is classified as having low risk of salinization, C1S2, by the new nomogram [20], and the corrected SAR was also calculated, according to the same authors. The water has an average concentration of sodium; however, as the soil has a sandy loam texture, the sodification problem can be minimized.

Table 2. Chemical analysis of wastewater used for irrigation in the forage cactus pear.

Attributes	Values
pH	6.80
EC at 25 °C (dS m^{-1})	0.712
Ca (meq L^{-1})	1.28
Mg (meq L^{-1})	0.48
K (meq L^{-1})	0.71
Na (meq L^{-1})	5.00

Table 2. *Cont.*

Attributes	Values
Carbonate (meq L^{-1})	0.00
Bicarbonate (meq L^{-1})	6.70
Chloride (meq L^{-1})	5.60
SARco ($mmol_c$ $L^{-1})^{0.5}$	6.54

Note: According to the Ü.S. Salinity Laboratory Staff.

2.4. Forage Cactus Pear Planting

The forage cactus pear cultivars Gigante (*Opuntia ficus-indica* Mill), Orelha de Elefante Mexicana (*Opuntia stricta* (Haw.) Haw), and Miúda (*Nopalea cochenillifera* Salm Dyck) were planted in an area of 10,000 m^2. The cactus pear seeds were acquired in the experimental area in the Agriculture Sector of the Instituto Federal Baiano, at the Campus Guanambi, Bahia, Brazil, with uniform cladodes, collected from the same hierarchical position in the parent plants. They were left to dehydrate for a period of approximately 30 days, for later planting.

The forage cactus pears were planted on 2 September 2021, in randomized blocks, with six replications, in double rows, burying a third of the cladode, with the cut part facing the soil. The spacing was 3.00 × 0.75 × 0.25 m for cultivation in double rows, resulting in a planting density of 21,334 plants per hectare. Between the double rows of forage cactus pear cultivars, a line of legumes was planted: pigeonpea (*Cajanus cajan*), moringa (*Moringa oleifera*), and jack bean (*Canavalia ensiformis*). Probably, due to the distance of 1.5 m from the legume row to the forage cactus pear row, there was no effect of the legumes on the variables analyzed for the forage cactus pear. However, in this study, only the results of forage cactus pear will be presented.

2.5. Irrigation System and Its Management

The plants were drip-irrigated, using self-compensating 'in line' emitters with a flow rate of 1.6 L h^{-1}, spaced 0.5 m apart in a continuous wet strip in the center of the double row of cactus pear and for each row of legumes. Irrigation was carried out based on reference evapotranspiration (ETo), considering 33% of ETo, with an irrigation shift of three days. ETo was calculated according to the modified Penman–Monteith model [21], with data on climatic elements obtained from the INMET meteorological station located in the municipality of Guanambi, Bahia, Brazil. When INMET data were unavailable, ETo was obtained from the meteorological station located at IF Baiano, in Ceraíma, Guanambi, Bahia, Brazil.

The use of the 33% ETo base is due to the history of irrigation with brackish water on the 'Gigante' forage cactus pear in the region, according to [8,9].

For irrigation management, the criterion of a continuous wet strip and application efficiency of 90% was used. The double row of cactus pear plants and their shaded width were considered to obtain the percentage of wetted area, plus the shaded area, to obtain the location coefficient (Kl) using the formula proposed by Keller 1978 [22,23]. After each rain event, soil moisture was assessed before restarting irrigation.

Changes in the values of climate elements (maximum and minimum temperature, wind speed, relative air humidity, cumulative rainfall, and cumulative gross irrigation depth during the experimental period) are presented in Figure 1. A rainy period can be observed, occurring between 60 and 130 days after the beginning of planting, in which the accumulated amount reached 605 mm.

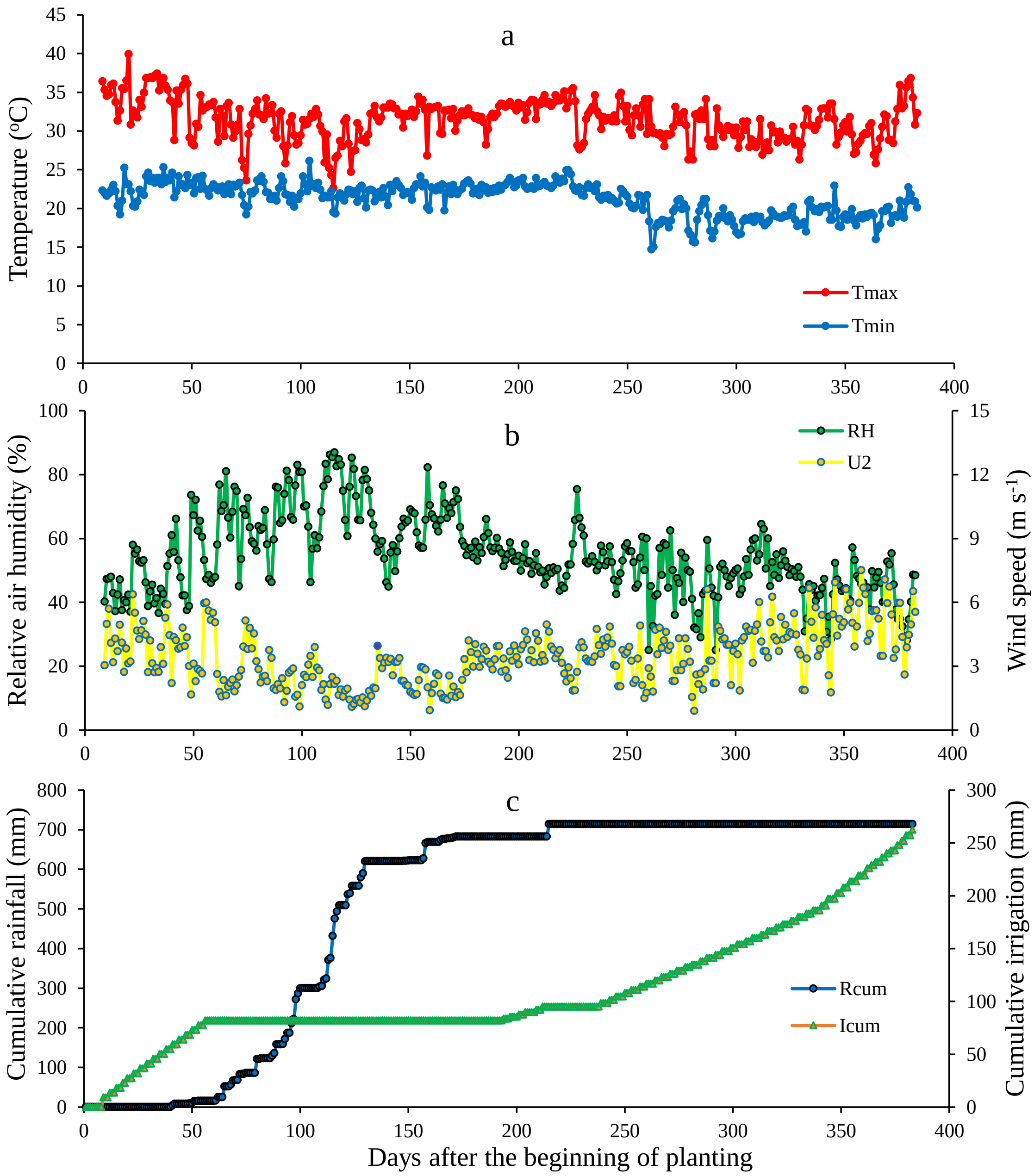

Figure 1. Average maximum temperature—Tmax and minimum temperature—Tmin (**a**), wind speed—U2 and relative air humidity—RH (**b**), cumulative rain—Rcum and cumulative irrigation—Icum (**c**) during the experimental period.

2.6. Analyzed Variables

2.6.1. Morphological Variables of Forage Cactus Pear Cultivars

Plant height, number of cladodes, plant diameter, cladode area, and cladode area index were measured in the forage cactus pear cultivars 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana' throughout the cycle. These characteristics were evaluated through monthly measurements, using a measuring tape, during the plants' development phase. One plant was selected within the subplot and identified with string. After the first evaluation, at 67 days after planting (DAP), there was a pause in the evaluations, due to intense rains, and they restarted at 167 DAP. Assessments were carried out at 67, 169, 200, 231, 261, 292, and 322 days after planting.

The forage cactus pear cladode area index was estimated by multiplying the cladode area by 2 (considering both sides of the cladode), and multiplying by the number of cladodes per plant, obtaining the total area of cladodes (m^2) and dividing by the area occupied by the plant in the soil (m^2). The cladode area was determined according to the method described by [24], as in Equation (1).

$$ACL = LCL \times WCL \times 0.693 \quad (1)$$

where:

ACL = cladode area, in m^2;
LCL = cladode length, in m;
WCL = cladode width, in m;
0.693 = correction factor due to the elliptical shape of the cladode.

2.6.2. Chemical Analysis of the Soil

The following chemical attributes were determined: pH, SOM, P, K, Na, Ca, Mg, Al, H+Al, SB, t, T, V, m, B, Cu, Fe, Mn, Zn, P-rem, and electrical conductivity of the saturated paste extract—EC. Soil sampling and chemical analysis were carried out 40 days after wastewater application, considering irrigation after a rainy period, which coincides with 233 days after the start of planting, and at the time of harvest, which coincides with 384 days after the beginning of planting.

2.6.3. Green Mass and Dry Matter Productivity of Forage Cactus Pear

The cactus pears were harvested between 21 September 2022 and 7 October 2022. All cladodes were harvested, leaving only the mother cladode. To determine the dry matter content, central portions of 4 harvested cladode samples per experimental plot were removed. These were weighed, cut into smaller sizes, exposed to the sun to dehydrate, and then placed in an oven at 60 °C for three days and at 100 °C for two days, until constant mass. The dry matter contents were obtained by dividing the dry masses by the green masses of the samples from each cactus pear. With the dry matter contents and green mass productivities, dry matter productivities were estimated.

2.6.4. Nutrient Contents and Exports in the Cladodes

The dried plant tissue samples were placed in paper envelopes, identified, and sent to the Laboratory Labras Análises Ambientais e Agrícolas, in Monte Carmelo, Minas Gerais, Brazil, for chemical determinations. The contents of N, P, K, Ca, Mg, and S were determined in g kg^{-1}, and the contents of B, Cu, Fe, Mn, and Zn in mg kg^{-1}. N was determined by Sulfuric Digestion; P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn were determined by Nitro Perchloric Digestion; and B was determined by Dry Digestion/Reference: Assessment of the Nutritional Status of Plants—Principles and Applications—2nd Edition (Potafos).

With the data on dry matter productivity and macro- and micronutrient contents in plant tissue, nutrient exports (kg ha^{-1}) by forage cactus pear cultivars were obtained, as described by [25].

2.7. Data Analysis

Data from the collected variables were subjected to normality and homogeneity tests. Once these assumptions were met, analysis of variance was carried out. When significant, the means of the evaluated variables were compared by the Tukey test, at a 5% content of significance.

3. Results

3.1. Morphological Variables of Forage Cactus Pear Cultivars

Plant height (Figure 2a) showed quadratic growth for 'Gigante' and 'Miúda' and linear growth for 'Orelha de Elefante Mexicana'. At 67 days after planting (DAP), plant height was 0.50, 0.40, and 0.45 m, while at 322 DAP, these values were 0.62, 0.60, and 0.59 m for the 'Gigante', the 'Miúda', and the 'Orelha de Elefante Mexicana', respectively.

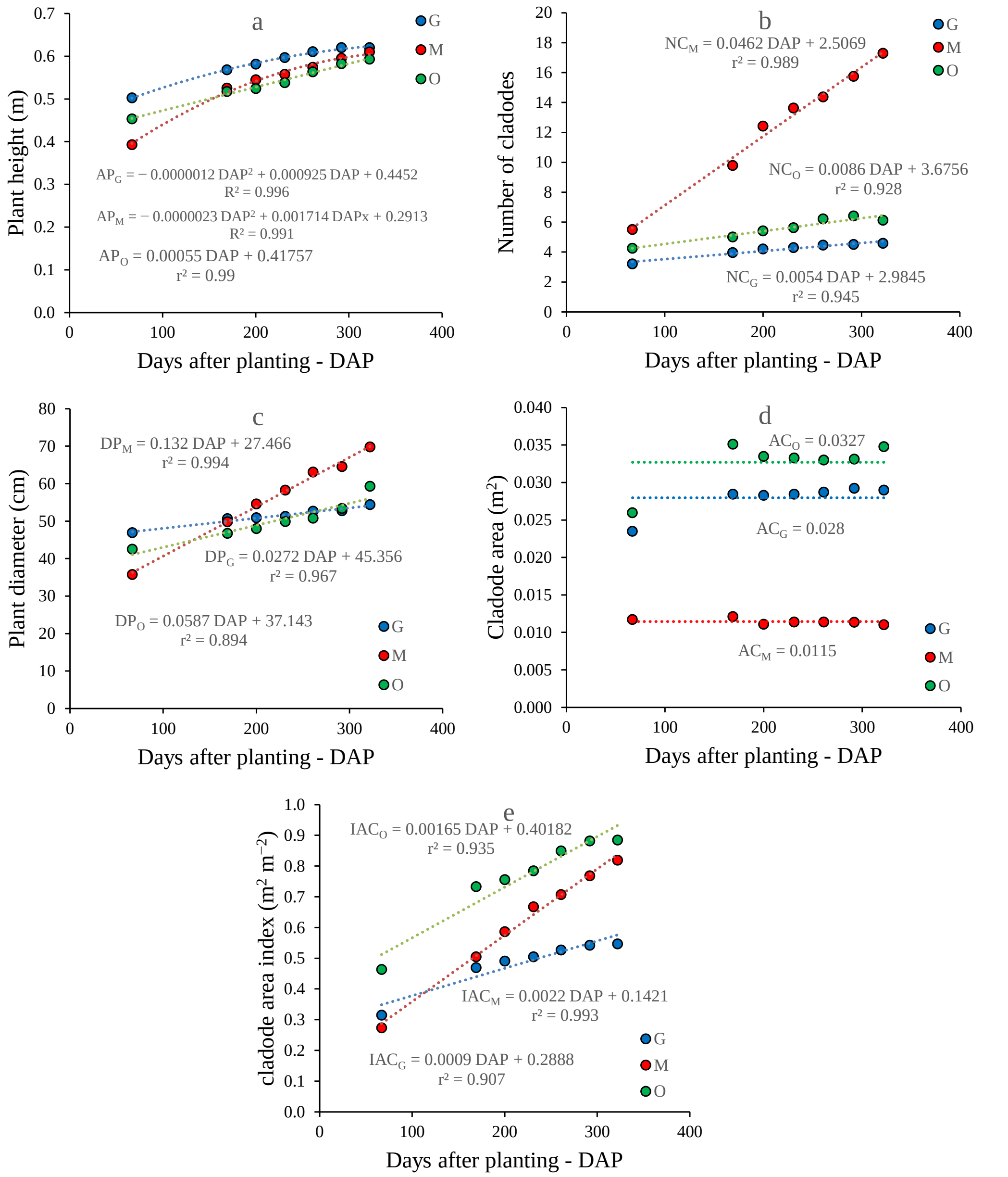

Figure 2. Means of plant height (**a**), number of cladodes (**b**), plant diameter (**c**), cladode area (**d**), and cladode area index (**e**), as a function of days after planting, for forage cactus pear cultivars Gigante (G), Miúda (M), and Orelha de Elefante Mexicana (O).

The number of cladodes showed linear growth for the three cultivars throughout the cycle. At 67 DAP, the number of cladodes was 3.30, 5.60, and 4.20, and at 322 DAP, these values were 4.40, 17.40, and 6.40 m, for 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', respectively.

The diameter of the plant showed linear growth for the three cultivars throughout the cycle, being that, at 67 DAP, it was 47, 36, and 41 cm, and at 322 DAP, the values were 54, 70, and 56 cm for 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', respectively.

The cladode area was different between the three cultivars and did not vary throughout the cycle (Figure 2d). The average cladode area was 0.028, 0.011, and 0.033 m^2 for 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', respectively.

The cladode area index (IAC) showed linear growth for the three cultivars throughout the cycle, and at 67 DAP, it was 0.35, 0.29, and 0.51 $m^2\ m^{-2}$, and at 322 DAP, the values were 0.58, 0.85, and 0.93 $m^2\ m^{-2}$ for 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', respectively.

3.2. Soil Chemical Analysis at the Beginning of Wastewater Application

Table 3 shows the averages for pH, SOM, P, K, Na, Ca, Mg, Al, H+Al, SB, t, T, V, m, B, Cu, Fe, Mn, Zn, P-rem, and EC in soils planted with the forage cactus pear cultivars Gigante, 'Miúda', and 'Orelha de Elefante Mexicana', after 40 days of wastewater application, which coincides with 233 DAP. These analyses are compared to the condition of non-interference with the application of wastewater, that is, immediately after the rainy season. From the analysis of these data, it appears that only the P values in the soil were different between the cultivars, with the highest contents recorded in the soil cultivated with 'Gigante'.

Table 3. Chemical analysis of the soil in the experimental area, in the 0.0–0.20 m depth layer, after the rainy season and after 40 days of application of wastewater at 33% ETo for three forage cactus pear cultivars.

Attributes	After Rain	Forage Cactus Pear		
		'Gigante'	**'Miúda'**	**'O. Elefante'**
pH [(1)]	5.30	5.67 ± 0.31	5.50 ± 0.17	5.73 ± 0.24
SOM [(2)] (dag kg^{-1})	0.15	0.33 ± 0.24	0.15 ± 0.05	0.30 ± 0.21
P [(3)] (mg dm^{-3})	6.45	13.10 a ± 4.11	7.77 b ± 2.50	8.18 b ± 1.06
K [(3)] (mg dm^{-3})	135.50	162.00 ± 19.6	145.5 ± 20.2	160.83 ± 25.66
Na [(3)] ($cmol_c$ dm^{-3})	0.20	0.25 ± 0.05	0.22 ± 0.04	0.25 ± 0.05
Ca [(4)] ($cmol_c$ dm^{-3})	0.70	0.88 ± 0.41	0.62 ± 0.18	1.00 ± 0.42
Mg [(4)] ($cmol_c dm^{-3}$)	0.35	0.43 ± 0.15	0.37 ± 0.10	0.47 ± 0.16
Al [(4)] ($cmol_c$ dm^{-3})	0.25	0.05 ± 0.05	0.02 ± 0.04	0.05 ± 0.12
H + Al [(5)] (cmolc dm^{-3})	1.30	1.50 ± 0.20	1.45 ± 0.20	1.47 ± 0.10
SB ($cmol_c$ dm^{-3})	1.60	1.97 ± 0.59	1.57 ± 0.33	2.13 ± 0.66
t ($cmol_c$ dm^{-3})	1.85	2.02 ± 0.55	1.58 ± 0.34	2.18 ± 0.62
T ($cmol_c$ dm^{-3})	2.90	3.47 ± 0.56	3.00 ± 0.40	3.58 ± 0.71
V (%)	55.00	55.83 ± 9.47	52.33 ± 5.13	58.83 ± 5.91
m (%)	13.50	3.33 ± 3.78	0.83 ± 2.04	2.67 ± 6.63
B [(6)] (mg dm^{-3})	0.10	0.17 ± 0.05	0.17 ± 0.05	0.10 ± 0.00
Cu [(3)] (mg dm^{-3})	0.10	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00
Fe [(3)] (mg dm^{-3})	199.70	186.20 ± 80.17	192.08 ± 41.27	165.42 ± 47.58
Mn [(3)] (mg dm^{-3})	11.85	15.08 ± 8.89	13.32 ± 5.73	18.27 ± 8.22
Zn [(3)] (mg dm^{-3})	0.50	2.97 ± 5.75	2.25 ± 4.04	0.85 ± 0.12
P-rem [(7)] (mg L^{-3})	38.75	36.02 ± 2.85	35.58 ± 3.68	38.13 ± 1.60
EC (dS m^{-1})	0.65	0.62 ± 0.08	0.60 ± 0.06	0.62 ± 0.10

Note: [(1)] pH in water; [(2)] colorimetry; [(3)] extractant Mehlich-1; [(4)] extraction with KCl 1 mol L^{-1}; [(5)] pH SMP; [(6)] extractant $CaCl_2$; [(7)] P equilibrium of the solution. SB: sum of bases; t: effective cation exchange capacity; T: cation exchange capacity at pH 7; V: base saturation; P-rem: remaining P; CE: electrical conductivity. dag kg^{-1} = %; mg dm^{-3} = ppm; $cmol_c$ dm^{-3} = 0.01 meq cm^{-3}. Different letters in the line values for forage cactus pear cultivars indicate a difference at a 5% content of significance using the Tukey test.

3.3. Chemical Analysis of Soil during Forage Cactus Pear Harvest

Soil pH values at depths of 0.0–0.20 and 0.20 to 0.40 m, depending on the three forage cactus pear cultivars, are presented in Table 4.

Table 4. Soil pH means at depths of 0.0–0.20 and 0.20 to 0.40 m under three forage cactus pear cultivars.

Depth (m)	Forage Cactus Pear		
	'Gigante'	**'Miúda'**	**'O. Mexicana'**
0.0–0.20	5.30 B a ± 0.21	5.47 AB a ± 0.15	5.58 A a ± 0.26
0.20–0.40	5.40 A a ± 0.23	5.23 A b ± 0.10	5.37 A b ± 0.23

Note: Means followed by different uppercase letters in the rows and different lowercase letters in the columns differ at a 5% content of significance by the Tukey test.

The pH values were greater in the soil cultivated with 'Orelha de Elefante Mexicana' compared to 'Gigante', in the 0.0–0.20 m layer, and greater in the 0.0–0.20 m layer compared to 0.20–0.40 m under 'Miúda' and 'Orelha de Elefante Mexicana'.

Table 5 shows the average pH, SOM, P, K, Na, Ca, Mg, Al, H+Al, SB, t, T, V, m, B, Cu, Fe, Mn, Zn, P-rem, and EC of the soil, in the 0 to 0.40 m layer, under application of wastewater, as a function of the forage cactus pear cultivars 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', by harvest time of these cultivars, which coincides with 384 DAP. These analyses are compared to the condition of non-interference with the application of wastewater, that is, immediately after the rainy season. The cultivar means, when there was a significant effect, are indicated by different letters, referring to the Tukey test at 5% significance. There were differences only for Ca, SB, t, and T, and the soil under the cultivar Orelha de Elefante Mexicana presented greater values compared to 'Miúda'.

Table 5. Chemical analysis of the soil in the experimental area, from 0 to 0.40 m, after the rainy season and at harvest, after application of wastewater at 33% ETo, for three forage cactus pear cultivars.

Attributes	After Rain	Forage Cactus Pear		
		'Gigante'	'Miúda'	'O. Elefante'
pH [(1)]	5.33	5.35 ± 0.22	5.35 ± 0.17	5.48 ± 0.26
SOM [(2)] (dag kg^{-1})	0.23	0.39 ± 0.25	0.43 ± 0.32	0.46 ± 0.27
P [(3)] (mg dm^{-3})	7.53	7.98 ± 6.66	7.47 ± 6.36	6.44 ± 5.02
K [(3)] (mg dm^{-3})	124.00	96.92 ± 21.06	96.75 ± 16.27	108.00 ± 30.34
Na [(3)] ($cmol_c$ dm^{-3})	0.20	0.30 ± 0.04	0.31 ± 0.08	0.33 ± 0.09
Ca [(4)] ($cmol_c$ dm^{-3})	0.63	0.97 ab ± 0.37	0.73 b ± 0.21	1.12 a ± 0.43
Mg [(4)] ($cmol_c dm^{-3}$)	0.33	0.36 ± 0.16	0.33 ± 0.13	0.42 ± 0.17
Al [(4)] ($cmol_c$ dm^{-3})	0.33	0.37 ± 0.36	0.47 ± 0.26	0.29 ± 0.32
H + Al [(5)] ($cmol_c$ dm^{-3})	1.30	1.37 ± 0.25	1.33 ± 0.26	1.39 ± 0.36
SB ($cmol_c$ dm^{-3})	1.50	1.86 ab ± 0.51	1.62 b ± 0.44	2.15 a ± 0.60
t ($cmol_c$ dm^{-3})	1.83	2.23 ab ± 0.49	2.08 b ± 0.41	2.44 a ± 0.54
T ($cmol_c dm^{-3}$)	2.80	3.23 ab ± 0.55	2.96 b ± 0.56	3.55 a ± 0.75
V (%)	53.33	56.83 ± 8.94	54.08 ± 7.43	60.08 ± 7.48
m (%)	18.33	16.08 ± 14.68	22.83 ± 12.66	12.17 ± 12.61
B [(6)] (mg dm^{-3})	0.10	0.20 ± 0.06	0.19 ± 0.09	0.18 ± 0.06
Cu [(3)] (mg dm^{-3})	0.10	0.10 ± 0.00	0.10 ± 00	0.10 ± 0.00
Fe [(3)] (mg dm^{-3})	184.70	116.73 ± 46.76	117.93 ± 18.41	109.68 ± 23.84
Mn [(3)] (mg dm^{-3})	9.63	9.31 ± 7.90	9.30 ± 7.75	10.53 ± 6.50
Zn [(3)] (mg dm^{-3})	0.43	0.74 ± 0.21	0.64 ± 0.30	0.62 ± 0.24
P-rem [(7)] (mg L^{-3})	38.27	37.03 ± 4.68	37.44 ± 5.44	36.80 ± 6.12
EC (dS m^{-1})	0.57	1.00 ± 0.46	0.96 ± 0.45	0.97 ± 0.24

Note: [(1)] pH in water; [(2)] colorimetry; [(3)] extractant Mehlich-1; [(4)] extraction with KCl 1 mol L^{-1}; [(5)] pH SMP; [(6)] extractant $CaCl_2$; [(7)] P equilibrium of the solution. SB: sum of bases; t: effective cation exchange capacity; T: cation exchange capacity at pH 7; V: base saturation; P-rem: remaining P; CE: electrical conductivity. dag kg^{-1} = %; mg dm^{-3} = ppm; $cmol_c$ dm^{-3} = 0.01 meq cm^{-3}. Different letters in the line values for forage cactus pear cultivars indicate a difference at a 5% content of significance using the Tukey test.

The averages of pH, SOM, P, K, Na, Ca, Mg, Al, H+Al, SB, t, T, V, m, B, Cu, Fe, Mn, Zn, P-rem, and EC in the soil for the layers from 0 to 0.20 and from 0.20 to 0.40 m, regardless of the cactus pear cultivars, are presented in Table 6. Differences were identified at harvest time, where the values of SOM, P, Na, SB, V, Mn, Zn, P-rem, and CE were greater in the 0.0–0.20 m layer compared to the 0.20–0.40 m layer. On the other hand, the attributes that reflect soil acidity, given by exchangeable acidity (Al), total acidity (H+Al), Al saturation (m), and effective CEC (t), were greater in the 0.20–0.40 m layer.

Table 6. Chemical analysis of the soil in the experimental area at depths of 0.0–0.20 and 0.20–0.40 m at harvest of forage cactus pear under application of wastewater at 33% of ETo.

Attributes	After Rain		Harvest	
	Depth (m)			
	0–0.20	0.20–0.40	0–0.20	0.20–0.40
pH [(1)]	5.30	5.40	5.45 ± 0.23	5.33 ± 0.20
SOM [(2)] (dag kg^{-1})	0.15	0.40	0.67 a ± 0.15	0.18 b ± 0.09
P [(3)] (mg dm^{-3})	6.45	9.70	12.07 a ± 4.84	2.53 b ± 0.67
K [(3)] (mg dm^{-3})	135.50	101.00	107.39 ± 15.93	93.72 ± 27.57
Na [(3)] ($cmol_c$ dm^{-3})	0.20	0.20	0.35 a ± 0 07	0.27 b ± 0.05
Ca [(4)] ($cmol_c$ dm^{-3})	0.70	0.50	0.94 ± 0 29	0.94 ± 0.45
Mg [(4)] ($cmol_c dm^{-3}$)	0.35	0.30	0.39 ± 0.13	0.34 ± 0.18
Al [(4)] ($cmol_c$ dm^{-3})	0.25	0.50	0.19 b ± 0.15	0.56 a ± 0.33
H + Al [(5)] ($cmol_c$ dm^{-3})	1.30	1.30	1.26 b ± 0.21	1.46 a ± 0.33
SB ($cmol_c$ dm^{-3})	1.60	1.30	1.96 a ± 0.46	1.79 b ± 0.63
t ($cmol_c$ dm^{-3})	1.85	1.80	2.14 b ± 0.41	2.36 a ± 0.55
T ($cmol_c dm^{-3}$)	2.90	2.60	3.22 ± 0.60	3.27 ± 0.72
V (%)	55.00	50.00	60.17 a ± 5.31	53.83 b ± 9.33
m (%)	13.50	28.00	9.39 b ± 7.22	24.67 a ± 14.54
B [(6)] (mg dm^{-3})	0.10	0.10	0.18 ± 0.09	0.19 ± 0.05
Cu [(3)] (mg dm^{-3})	0.10	0.10	0.10 ± 0.00	0.10 ± 0.00
Fe [(3)] (mg dm^{-3})	199.70	154.70	120.37 ± 32.52	109.18 ± 30.11
Mn [(3)] (mg dm^{-3})	11.85	5.20	13.81 a ± 7.77	5.62 b ± 3.38
Zn [(3)] (mg dm^{-3})	0.50	0.30	0.79 a ± 0.21	0.54 b ± 0.22
P-rem [(7)] (mg L^{-3})	38.75	37.30	40.69 a ± 3.60	33.48 b ± 4.15
CE (dS m^{-1})	0.65	0.40	1.24 a ± 0.36	0.71 b ± 0.16

Note: [(1)] pH in water; [(2)] colorimetry; [(3)] extractant Mehlich-1; [(4)] extraction with KCl 1 mol L^{-1}; [(5)] pH SMP; [(6)] extractant $CaCl_2$; [(7)] P equilibrium of the solution. SB: sum of bases; t: effective cation exchange capacity; T: cation exchange capacity at pH 7; V: base saturation; P-rem: remaining P; CE: electrical conductivity. dag kg^{-1} = %; mg dm^{-3} = ppm; $cmol_c$ dm^{-3} = 0.01 meq cm^{-3}. Different letters in the line values for forage cactus pear cultivars indicate a difference at a 5% content of significance using the Tukey test.

3.4. Chemical Analysis of Plant Tissues from the Forage Cactus Pear Cultivars

The average contents of macronutrients N, P, K, Ca, Mg, and S, in g kg^{-1}, and of micronutrients B, Cu, Fe, Mn, and Zn, in mg kg^{-1}, in plant tissue, when harvesting forage cactus pear cultivars Gigante, Miúda, and Orelha de Elefante Mexicana, under irrigation with wastewater at 33% ETo, are presented in Table 7.

Table 7. Macro- and micronutrient contents in the cladodes of the forage cactus pear cultivars Gigante, Miúda, and Orelha de Elefante Mexicana (OEM).

Attributes	Forage Cactus Pear		
	'Gigante'	'Miúda'	'OEM'
N (g kg^{-1})	11.08 ± 1.87	11.82 ± 2.08	9.37 ± 1.52
P (g kg^{-1})	0.73 ± 0.15	0.60 ± 0.28	0.45 ± 0.19
K (g kg^{-1})	36.33 ± 15.27	40.95 ± 4.88	36.07 ± 4.00
Ca (g kg^{-1})	14.48 ± 1.58	11.87 ± 2.71	15.02 ± 2.26
Mg (g kg^{-1})	6.20 ab ± 0.52	5.45 b ± 0.98	6.97 a ± 0.53
S (g kg^{-1})	1.03 a ± 0.14	1.07 a ± 0.32	0.73 b ± 0.18
B (mg kg^{-1})	17.17 a ± 1.17	10.83 b ± 2.40	16.33 a ± 3.72
Cu (mg kg^{-1})	1.00 ± 0.00	1.00 ± 0.00	1.50 ± 1.22
Fe (mg kg^{-1})	71.83 ± 21.59	81.83 ± 35.15	72.17 ± 59.08

Table 7. *Cont.*

Attributes	Forage Cactus Pear		
	'Gigante'	'Miúda'	'OEM'
Mn (mg kg^{-1})	124.83 ± 47.88	85.00 ± 41.14	79.67 ± 31.85
Zn (mg kg^{-1})	21.33 a ± 7.34	14.33 ab ± 4.41	12.17 b ± 2.32

Note: N: (LQ:0.69 g kg^{-1})—Sulfuric Digestion; P: (LQ: 0.019 kg^{-1}). K: (LQ: 0.3 9 kg^{-1}), Ca: (LQ: 0.19 kg^{-1}), Mg: (LQ: 0.019 kg^{-1}), S: (LQ: 0.049 kg^{-1}), Cu: (LQ: 2 mg kg^{-1}), Fe: (LQ: 2 mg kg^{-1}), Mn: (LQ: 3 mg kg^{-1}), Zn: (LO: 0.6 mg kg^{-1}), digestion with mixture of nitric and perchloric acids. Determination by ICP-AES. B: (LQ: 0.04 mg kg^{-1})—dry digestion. Reference: Assessment of the Nutritional Status of Plants—principles and applications—2nd Edition (Potafos). Different letters in the line values for forage cactus pear cultivars indicate a difference at a 5% content of significance using the Tukey test.

According to the analysis of variance, there was an effect of cactus pear cultivars on the contents of Mg, S, B, and Zn. The Orelha de Elefante Mexicana cultivar has a greater Mg content when compared to 'Miúda'. Lower S contents were registered in 'Orelha de Elefante Mexicana' and lower B in 'Miúda', while greater Zn contents were found in 'Gigante' when compared to 'Orelha de Elefante Mexicana'.

3.5. Nutrient Export by the Forage Cactus Pear Cultivars

Observing the analysis of variance, there was an effect of forage cactus pear cultivars on the export of macronutrients Ca and Mg and micronutrient B (Table 8). 'Orelha de Elefante Mexicana' presents greater export of Ca and Mg when compared to 'Gigante' and 'Miúda'. The highest export of B is presented by 'Gigante' and 'Orelha de Elefante Mexicana' and the lowest by 'Miúda'.

Table 8. Export of macro- and micronutrients by forage cactus pear cultivars Gigante, Miúda, and Orelha de Elefante Mexicana (OEM).

Nutrient	Export by Forage Cactus Pear (kg ha^{-1})		
	'Gigante'	'Miúda'	'OEM'
N	34.22 ± 6.58	32.38 ± 8.06	39.65 ± 6.90
P	2.28 ± 0.52	1.66 ± 0.82	1.88 ± 0.64
K	111.48 ± 48.41	111.77 ± 19.31	154.53 ± 35.23
Ca	44.72 b ± 5.78	32.75 b ± 9.20	63.96 a ± 14.46
Mg	19.13 b ± 1.99	15.07 b ± 3.99	29.70 a ± 5.03
S	3.24 ± 0.70	2.94 ± 0.98	3.09 ± 0.68
B	0.053 a ± 0.01	0.030 b ± 0.01	0.069 a ± 0.01
Cu	0.0031 ± 0.00	0.0027 ± 0.00	0.0063 ± 0.00
Fe	0.22 ± 0.05	0.22 ± 0.10	0.29 ± 0.18
Mn	0.39 ± 0.16	0.23 ± 0.11	0.34 ± 0.15
Zn	0.067 ± 0.03	0.038 ± 0.01	0.053 ± 0.02

Note: Different letters in the line values for forage cactus pear cultivars indicate a difference at a 5% content of significance using the Tukey test.

Regardless of the forage cactus pear cultivar, the export order is K > Ca > N > Mg > S > P for macronutrients and Mn > Fe > Zn > B > Cu for micronutrients.

3.6. Productivity and Water Use Efficiency of Forage Cactus Pear Cultivars

Throughout the cycle of cactus pear cultivars (385 days), 265.85 mm of wastewater was applied. Green mass productivity and water-to-dry matter productivity for green mass were greater in the cultivars Gigante and Orelha de Elefante Mexicana when compared to Miúda (Table 9). However, dry matter productivity and water-to-dry matter productivity were greater in the Orelha de Elefante Mexicana cultivar.

Table 9. Green mass and dry matter productivity and irrigation water productivity (IWP) in forage cactus pear cultivars Gigante, Miúda, and Orelha de Elefante Mexicana (OEM) irrigated with wastewater.

Variables	Cactus Pear Cultivars		
	'Gigante'	'Miúda'	'OEM'
Green mass productivity (t ha^{-1})	42.93 a ± 18.60	34.44 b ± 7.22	44.58 a ± 21.53
Dry matter productivity (t ha^{-1})	3.10 b ± 1.34	2.73 b ± 0.57	4.27 a ± 0.99
IWP for green mass (kg ha^{-1} mm^{-1})	161.46 a ± 38.78	129.56 b ± 15.06	167.68 a ± 21.53
IWP for dry matter (kg ha^{-1} mm^{-1})	11.67 b ± 2.80	10.25 b ± 1.19	16.07 a ± 2.06

Note: Means followed by equal letters in the line do not differ significantly by Tukey's test at a 5% content of significance.

Water use efficiencies followed the same trend as productivity, since the irrigation condition was the same.

4. Discussion

4.1. Morphological Variables of the Forage Cactus Pear Cultivars

The plant heights of 0.62, 0.60, and 0.59 m for 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', respectively, at 322 DAP, are within the expectations and corroborate the architectural characteristic of each cultivar. These plant height values were greater than those found by [26]. These authors, working with forage cactus pear cultivars in the municipality of Serra Talhada (PE, Brazil), with three intervals (7, 14, and 28 days) of application of a 7.5 mm fixed irrigation depth, found that, after nine months, the plant height was 47.5 and 46.9 cm for 'Miúda' and 'Orelha de Elefante Mexicana', respectively. The values were also close to those found by [27], who, when evaluating the effect of spacing and mineral fertilization on the growth and production of forage cactus pear, found that, without any fertilization, the plant height varied from 60.77 cm to 64.06 cm, for the average evaluations from 90 to 390 days after planting. However, regardless of fertilization and planting configuration, the estimated plant height at 322 DAP by [27] is 69 cm.

The number of cladodes of 4.40, 17.40, and 6.40 m for 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', respectively, found in the present study at 322 DAP, is greater than 13, 9 for 'Miúda' and less than 13.5 for Orelha de Elefante Mexicana found by [26], while for 'Gigante', the number of cladodes was smaller than that found by [28]. According to these authors, the number of cladodes for the forage cactus pear 'Gigante', in a population of 20,000 plants per hectare, is estimated at 11.9 cladodes and, regardless of planting density, with a depth of 33% of the ETo with brackish water, the number of cladodes was 10.60. However, when comparing with the results of cladode numbers of 6.04 to 6.59, found by [27], the values are much closer.

The cladode area indices (CAIs) of 0.58, 0.85, and 0.93 m^2 m^{-2} for 'Gigante', 'Miúda', and 'Orelha de Elefante Mexicana', respectively, at 322 DAP, are low when compared to other studies. The study in [28] found a CAI of 1.62 m^2 m^{-2}, reaching 3.53 m^2 m^{-2} under a depth of 33% ETo with brackish water. The study in [27] found that, without any fertilization, the CAI varied from 0.59 to 0.65 for the average evaluations from 90 to 390 days after planting and that, regardless of the fertilization and planting configuration, the CAI estimate at 322 DAP per [27] is 0.99 m^2 m^{-2}.

The cladode area was smaller in 'Miúda'; however, as it had a greater number of cladodes, it presented a larger CAI than 'Gigante'. This, in turn, presented a smaller number of cladodes and a smaller cladode area than the cladode area of the 'Orelha de Elefante Mexicana'. Although 'Miúda' had a larger plant diameter (Figure 2c), this did not contribute to an increase in CAI, since this variable does not consider the plant area.

By comparing the growth results of the present study with those found in the literature, it can be concluded that it is possible to achieve normal development of forage cactus pear irrigated with wastewater. However, by not adding chemical or organic fertilizers, it would be advisable to analyze larger volumes of wastewater replacement to meet the nutritional requirements of the forage cactus pear, or nutritional supplementation with fertilization.

4.2. Soil Chemical Analysis at the Beginning of Wastewater Application

According to [17], after 40 days of wastewater application, the pH of the soil under the forage cactus pear 'Miúda' was classified as low, and medium under the 'Gigante' and 'Orelha de Elefante Mexicana'. Despite changes in the organic matter content, it remained in the very low class. There was an increase in the P content in the soil under 'Gigante', going from very low to the low content class. The K content did not change, remaining medium. Ca and Mg contents remained very low. Potential acidity went from low to medium (sufficient) in the soil under the three cultivars. The sum of bases, despite a slight increase, remained very low. The effective soil CEC under 'Miúda' increased for medium class, while under the others, it remained very low, and the soil CEC at pH 7.0 remained very low under the three cultivars. Base saturation remained low under all conditions. P-rem remained very low in the soil under the three cultivars.

As for micronutrients in the soil, according to [18], the Zn content, which immediately after the rainy season was classified as low, became medium in the soil under 'Orelha de Elefante Mexicana' and high for 'Gigante' and 'Miúda'. Despite this, the average Zn concentration in the soil under the cactus pear cultivars did not differ statistically. The Mn content, which was classified as good, varied to high in the soil, while Fe remained in the same classification, as very high in the soil. The Cu content did not change, being considered very low in the soil. Regarding B, it remained in the classification of very low in the soil under 'Orelha de Elefante Mexicana' and low in the soil under 'Gigante' and under 'Miúda'.

There were no changes in the electrical conductivity of the soil. This behavior was expected, since the electrical conductivity of the water presented values of, at most, 0.90 ds m^{-1}. An irrigation depth of 33% of ETo, over a period of 40 days, would not be enough to cause significant changes in the soil with a 0.62 dS m^{-1} value, being unable to cause impacts on the cultivars used.

4.3. Chemical Analysis of Soil during Forage Cactus Pear Harvesting

A higher pH value was observed in the surface layer of the soil under the forage cactus pear 'Orelha de Elefante Mexicana'. However, even with these statistical differences, as [17], the pH of the soil at a depth of 0.20–0.40 m under 'Miúda' was very low, and low in other conditions, in which there were no changes.

According to [17], when harvesting forage cactus pear under wastewater application, the soil pH under the three forage cactus pear cultivars was classified as low. Despite changes in organic matter content, it continued to be classified as very low. The P content in the soil in the three cultivars was very low, which indicates extraction, since after 40 days of application of wastewater, there was a low content of this nutrient in the soil under 'Gigante' cactus pear. The K content in the soil under 'Gigante' and 'Miúda' went from medium to low. In 'Orelha de Elefante Mexicana', it remained at an average rating. The Ca and Mg contents remained very low, although the Ca content in the soil under 'Orelha de Elefante Mexicana' presented a greater concentration when compared to the soil under 'Miúda'. Potential acidity, which was considered average in the soil under the three cultivars after 40 days of wastewater application, reduced to low. The sum of bases, despite having a greater value in the soil under 'Orelha de Elefante Mexicana' compared to 'Miúda', remained very low. The effective CEC in the soil under 'Orelha de Elefante Mexicana' was greater than that in the soil beneath 'Miúda'. However, it remained very low, and the same was observed for soil CEC at pH 7.0, which remained very low under all three cultivars.

Base saturation remained low under all conditions. The P-rem remained very low in the soil under the three cultivars and EC reached values considered very high.

Regarding micronutrients in soil, according to [18], Zn, which shortly after the rainy season had very low contents, began to show contents considered as low. Mn, despite rising in classification when evaluated after 40 days of application of wastewater, at harvest showed the same classification, with a good content in the soil; Fe remained in the same classification as very high in the soil. There were no changes for Cu, which was considered very low in the soil. Regarding B, which had a very low classification in the soil, it became low during the forage cactus pear harvest period.

Regarding the electrical conductivity of the soil, there was an increase when compared to the EC value immediately after the rainy season. However, it did not exceed 1.0 dS m^{-1}. As the harvest was carried out before the rainy season, with the advent of rain, salts are leached, and the electrical conductivity of the soil is reduced. In [29], a study with brackish water with an EC of 3.6 dS m^{-1}, it was found that the electrical conductivity of the soil reached 4.63 dS m^{-1} with 33% of ETo and irrigation frequency of three days, at the end of the second cycle of production. However, after the rain, soil salinity presented an average value of 0.52 dS m^{-1}. This is lower than that presented by the initial soil (0.7 dS m^{-1}), which indicates that, after the rainy period, the soil returned to its initial salinity conditions.

From the results of the soil analysis (Table 6), it can be seen that, regardless of the cultivar, there were changes in the chemical composition of the soil under the forage cactus pear irrigated with 33% of ETo with wastewater. There was an increase in organic matter and P content in the layer from 0.0 to 0.20 m, while in the layer from 0.20 to 0.40 m, those variables decreased. The root system of the forage palm is concentrated up to 0.40 m deep, and the application of this irrigation depth caused a moistening front of less than 0.30 m. Therefore, it is expected that the nutrients available in wastewater will be more concentrated in the surface layer and that roots below 0.20 m will also begin to extract nutrients from the soil in this layer.

The sodium concentration in the surface layer of the soil increased and the exchangeable and potential acidity showed a slight increase in the 0.20–0.40 m layer. The Ca content and the sum of bases increased in both layers, but in the superficial layer, the sum of bases was greater than in the 0.20–0.40 m layer. Effective and potential CECs increased. The effective CEC was greater in the 0.20–0.40 m layer after wastewater application. P-rem increased slightly in the 0–0.20 m layer and decreased in the 0.20–0.40 m layer. Regarding Mn and Zn, there was a slight increase in their concentrations in both layers. However, right after the rainy season, the surface layer already showed greater concentration. As for B, there was a slight increase in layers. There were no changes in the concentration of Cu; the concentration of exchangeable Fe decreased and there was an increase in the electrical conductivity of the soil, which was greater in the surface layer.

4.4. Chemical Analysis of Plant Tissues from the Forage Cactus Pear Cultivars

The N, P, B, and Cu contents found in plant tissues of forage cactus pear cultivars in this study are similar to those found in 'Gigante' forage cactus pear in the literature. However, the average values of K and Fe found in this study are much higher than those found in the current literature. On the other hand, the contents of S, Ca, Mg, Mn, and Zn found in this study were much lower than those found by the aforementioned authors, which is related to the employed fertilization.

Comparing the macronutrient contents in tissues of forage cactus pear cladodes with the sufficiency ranges established by [30] for the forage cactus pear 'Gigante' fertilized with different contents of cattle manure in two production cycles, the N and P contents are in the marginal range for 'Gigante' and 'Miúda' and deficient for 'Orelha de Elefante Mexicana'; the K content is considered sufficient in the three cultivars; Ca contents are in the deficient range and S in the marginal range for the three cultivars. Regarding micronutrients, according to [31], the B content is in the marginal range for 'Gigante' and deficient for 'Miúda' and 'Orelha de Elefante Mexicana'; Cu and Mn contents are in the deficient range; the Fe concentration is in the sufficient range; and the Zn content is marginal for 'Gigante' and deficient for 'Miúda' and 'Orelha de Elefante Mexicana'. It can be seen that irrigation with treated wastewater using 33% of the reference evapotranspiration maintains K contents within the sufficient range for the crop.

4.5. Nutrient Export by the Forage Cactus Pear Cultivars

Macronutrient export differs in part from the results found by [25], which verified greater extraction of P compared to S. The order of export of macro- and micronutrients by the forage cactus pear cultivar is related to the nutrient supply and the fertilizer source.

4.6. Productivity of Crop and Irrigation Water in the Forage Cactus Pear Cultivars

The dry matter contents of the forage cactus pear cultivars range from 7.23% for 'Gigante' to 9.58% for 'Orelha de Elefante Mexicana', while for 'Miúda', this value was 7.92%. These values are higher than that found by [9], which, for the cultivar 'Gigante', in the first year of cultivation and irrigated with 33% of ETo with a three-day irrigation shift, was 6.31%. The higher dry matter content values found in the present study may be related to a lower emission of new cladodes, as after the cold period, no new cladodes were emitted. Thus, those that were sampled were more lignified, contributing to increasing the dry matter content.

The productivity of 'Gigante' was similar to that of 'Orelha de Elefante Mexicana', both being superior to the productivity of the 'Miúda'. These productivity values, compared to productivities of forage cactus pear under irrigation conditions in the first year of cultivation, are low. The study in [32] found higher productivity of 'Orelha de Elefante Mexicana' than 'Miúda', at 163 and 118 Mg ha^{-1}, respectively. However, it is worth highlighting that, in the present study, the plants were intercropped, which decreased plant population. Furthermore, there was a period of heavy rain between December 2021 and January 2022, which probably caused stress due to excess water and influenced plant development. There was also a cold period between May and July 2022, in which plants decreased cladode emission. Another point that deserves to be highlighted is that no fertilization or correction of soil fertility was carried out, simply the application of wastewater.

Considering dry matter productivity, 'Orelha de Elefante Mexicana' showed the greater values. Even though the green mass productivity of 'Gigante' did not differ from that of 'Orelha de Elefante Mexicana', the dry matter productivity of 'Gigante' was lower and similar to the 'Miúda' productivity. Such results can be explained by the higher dry matter content found in 'Orelha de Elefante Mexicana' and the lower content in 'Gigante'.

The study in [9] found productivities of 'Gigante' forage cactus pear of 96.19 t ha^{-1} and 6.07 t ha^{-1} of green mass and dry matter, respectively, irrigated with brackish water in the first year of harvest, using 33% of ETo. It is worth mentioning that the plant population in the present study was half when compared to that in [9], and no fertilization was employed, simply the application of wastewater.

5. Conclusions

The use of wastewater at 33% ETo provides increases in the morphometric characteristics of the forage cactus pear associated with its varietal architectures, with emphasis on plant height in 'Gigante', number of cladodes and plant diameter in 'Miúda', and area and cladode area index in 'Orelha de Elefante Mexicana'.

In general, the soil cultivated with forage cactus pear 'Orelha de Elefante Mexicana' shows a greater tendency towards alkalinization.

There is a greater increase in fertility expressed by organic matter, base saturation, and P, Mn, and Zn contents, an increase in salinity expressed by electrical conductivity and alkalinity by Na in the surface layer of the soil, while in the subsurface layer, there is an increase in the values of the attributes that express acidity.

Irrigation with treated wastewater maintains K contents within the sufficiency range for forage cactus pear.

The cultivation of forage cactus pear exports more macronutrients K, Ca, N, Mg, S, and P and micronutrients Mn, Fe, Zn, B, and Cu, in that order, from the cultivated area.

The cultivars Gigante and Orelha de Elefante Mexicana have higher productivity of green mass and irrigation water productivity for green mass, but 'Orelha de Elefante Mexicana' stands out in dry matter productivity.

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