

**Productivity and nutrient supply in 'Gigante'
cactus pear with regulated deficit irrigation
using wastewater**

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ABSTRACT

Aims: To evaluate productivity and nutrient supply in 'Gigante' cactus pear with regulated deficit irrigation (RDI) using wastewater, compared to RDI using common water and fertilization with bovine manure.

Study design: Treatments: no fertilization and no irrigation (T1); no fertilization and RDI with wastewater (0.6 L plant⁻¹ week⁻¹) (T2); no fertilization and RDI with wastewater (1.2 L plant⁻¹ week⁻¹, applied once a week) (T3); no fertilization and RDI with wastewater (1.2 L plant⁻¹ week⁻¹, divided into two applications per week) (T4); with organic fertilization (60 Mg ha⁻¹ of bovine manure) and RDI with common water (1.2 L plant⁻¹ week⁻¹) (T5); and with organic fertilization (60 Mg ha⁻¹ of bovine manure) and no irrigation (T6). The treatments were arranged in a randomized complete block design, with five replicates.

Place and Duration of Study: The experiment was carried out between October 2015 and August 2017 at Instituto Federal Baiano, Guanambi Campus, Brazil.

Methodology: Productivity of green and dry matter, amount of macro and micronutrients applied in the soil by wastewater and by organic fertilizer, macro and micronutrient contents present in the cladodes tissues, and macro and micronutrient contents in the soil were evaluated. The wastewater used was collected in the stabilization pond of the campus.

Results: Green matter yield was significantly higher in irrigated treatments. Regarding dry matter, its value was higher in T5 and it did not differ statistically in the others.

Conclusions: RDI, using common water, provided a yield of green matter 2.47 times higher than in non-irrigated treatment with the same fertilization; in the absence of organic fertilization, RDI, using wastewater, provided a yield of green matter 1.96 times higher than in non-irrigated treatment; in the absence of irrigation, organic fertilization does not provide a yield higher than in non-fertilized treatment; and the contribution of N, K, Cu, Zn and Mn only by the wastewater is not enough to sustain the crop's productivity in the long term.

Keywords: Fertigation, domestic sewage, Opuntia ficus, water use efficiency.

1. INTRODUCTION

In Brazil, the semi-arid region covers 60% of the Northeast region. The climate is characterized by low and irregular precipitations and high evapotranspiration. These characteristics constitute stress factors, both for livestock and for agriculture, making forage production scarce during prolonged periods of drought, which last up to 9 months.

23 An alternative to this region is the production of 'Gigante' cactus pear (*Opuntia ficus-indica*
24 *Mill*). This crop has high water use efficiency, high productivity, high digestibility, besides
25 storing large amounts of water in its tissues, which is strategic water reserve for the herds.

26 The Cactus pear is native to Mexico, and belongs to the cactus family. In Brazil, it is mainly
27 cultivated in the Northeast region. The most cultivated varieties are the 'Redonda', the
28 'Gigante' and the 'Miúda' (TORRES, 2009).

29 When choosing the appropriate cultivar, one has to take into account some characteristics,
30 such as: growth habit, productivity, resistance to pests and diseases, palatability,
31 environmental adaptability and management (SILVA et al., 2017).

32 The cactus pear is considered a xerophilous plant, that is, it is adapted to adverse
33 conditions, such as high temperatures and water scarcity; therefore, this plant is suitable for
34 cultivation in semiarid regions, although its development and growth vary with the fluctuation
35 in weather conditions (LEMOS, 2016).

36 This crop has the characteristic of closing the stomata during the day and opening them at
37 night for CO₂ fixation, resulting in water saving. However, despite this crop being adapted to
38 adverse conditions, such as high evapotranspiration rate and water deficit, plants lose vigor
39 and may die over the dry season due to excessive water loss, requiring water
40 supplementation during this period to maintain productivity.

41 Management strategies in cactus pear production tend to increase productivity. Coupled with
42 these strategies, one alternative to ensure this productivity throughout the year is to use
43 irrigation to supply, in whole or in part, the crop water demand. However, since water
44 resources in this region are limiting, alternatives for using this resource more efficiently are
45 necessary. The use of domestic sewage to irrigate crops is an option when conventional
46 water resources are scarce or nonexistent. It is an increasingly common practice in
47 agriculture as it has several advantages such as availability throughout the year and nutrient
48 supply for crops.

49 Thus, this work aims to evaluate the productivity and the nutrient supply in the 'Gigante'
50 cactus pear with regulated deficit irrigation (RDI) using wastewater, without any fertilization,
51 compared to other strategies: RDI using common water and fertilization with bovine manure;
52 no irrigation with fertilization with bovine manure; and no irrigation neither fertilization.

53

54 **2. MATERIAL AND METHODS**

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56 The experiment was installed at the Federal Institute of Education, Science and Technology
57 Baiano, Guanambi Campus, Guanambi, Bahia, Brazil, Latitude 14° 13' 30" S and Longitude
58 42° 46' 53" W. The predominant climate is the semiarid, with mean annual rainfall of 663.69
59 mm, annual average ET rate of 1961,6 mm and a mean temperature of 26 °C. The soil was
60 classified as a typical dystrophic yellow red Latosol, A weak, medium texture.

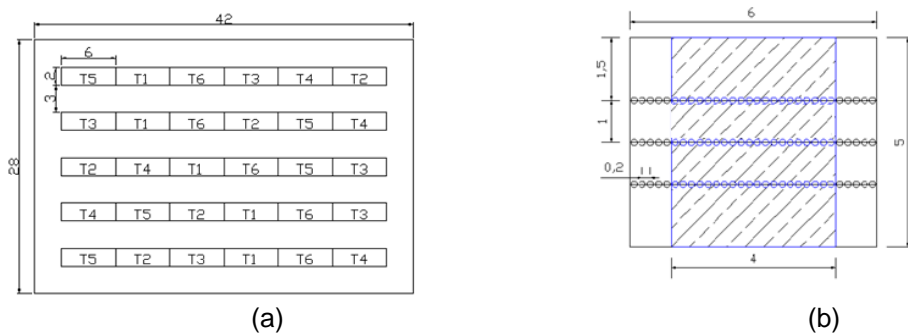
61 The productivity and nutrient supply in 'Gigante' cactus pear with RDI using wastewater
62 (*Opuntia ficus-indica Mill*) were evaluated. The experiment was designed in randomized
63 blocks with six treatments and five replicates. The treatments were:

64 • T1: no fertilization and no irrigation;

65 • T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹ week⁻¹);

- 66 • T3: no fertilization and RDI with wastewater ($1.2 \text{ L plant}^{-1} \text{ week}^{-1}$, applied once a week);
- 67 • T4: no fertilization and RDI with wastewater ($1.2 \text{ L plant}^{-1} \text{ week}^{-1}$, divided into two
- 68 applications of 0.6 L plant^{-1} per week);
- 69 • T5: with organic fertilization (60 Mg ha^{-1} of bovine manure, applied before planting) and
- 70 RDI with common water ($1.2 \text{ L plant}^{-1} \text{ week}^{-1}$); and
- 71 • T6: with organic fertilization (60 Mg ha^{-1} of bovine manure applied before planting) and no
- 72 irrigation.

73
 74 The experimental plot consisted of three 6-m-long rows of plants spaced 1 m apart (30
 75 plants per row, spaced 0.2 m apart), with 30 m^2 area (6 m x 5 m - including a 3-m-wide
 76 path), with a stand of 30,000 plants ha^{-1} . In the blocks, the treatments succeeded each
 77 other without additional spacing, so only the plants within the 4-m-long central row of each
 78 plot (20 plants per row, 60 plants in total) were evaluated. The remaining plants were border.
 79 Thus each block was 36 m long and 2 m wide, spaced apart by a 3-m-wide path. On the
 80 outer sides, there was also a 3-m-wide path surrounding the experimental area. Figure 1
 81 illustrates the randomized block design used (a) and details of the experimental plot, with the
 82 evaluation plot hatched in blue (b).



83
 84 **Fig. 1. Scheme of the experimental design in randomized blocks (a) and detail of the**
 85 **experimental plot, with the useful area hatched in blue (b).**
 86

87 The area was subsoiled, plowed, harrowed and then furrowed with a distance of one meter
 88 between furrows. Bovine manure was applied only in the planting furrow of the plots of the
 89 T5 and T6 treatments (60 Mg ha^{-1}). Mature cladodes with accumulation of reserves were
 90 selected in another cactus pear plantation of the campus, and after harvest, they remained
 91 in the shade for 15 days to cure, and then were planted. The cladodes were planted with the
 92 longest portion buried about 50% in the soil for better fixation at a distance of one meter
 93 between the rows of planting and the cladodes spaced 20 cm apart. Invasive plants were
 94 mechanically controlled during the experiment. Planting was completed at the end of
 95 October 2015.

96 The wastewater used in the experiment was collected in the stabilization pond of the
 97 campus, which receives domestic sewage collected from campus buildings, and was stored
 98 for 24 hours in a water tank (5000 L) before using it for irrigation, so that the larger particles
 99 could settle on the bottom of the tank, reducing clogging problems.

100 The common water was collected in a tubular well installed on campus and stored in a water
 101 tank (500 L). Both irrigations, with common and wastewater, were performed by a drip

102 irrigation system consisting of submersible pump, disk filter and emitters with nominal flow
 103 equal to 1.5 L h^{-1} , at a pressure of 150 kPa, spaced apart on the lateral line by 0.5 m. This
 104 spacing allowed forming a 0.5-m-wide wet band along the planting line. This wet band
 105 represents 30% of wet area.

106 Irrigation began at 04-18-2016, after the end of the rainy season, and lasted until 08-21-
 107 2017. In the treatment T2, the irrigation time was equal to 1.0 h, once a week; in treatments
 108 T3 and T5, it was equal to 2.0 h, once a week; in the treatment T4, it was equal to 1.0 h,
 109 twice a week. These times, combined with the flow of the emitters and the planting stand,
 110 resulted in an average weekly volume per plant equal to 0.6 L in T2; and 1.2 L in treatments
 111 T3, T4 and T5.

112 Five evaluations were performed to determine the amount of nutrients present in the
 113 wastewater. Evaluations were made every four months, from April 2016 until August 2017.
 114 The average macro and micronutrient contents present in wastewater and bovine manure
 115 are presented in Table 1. From the manure characteristics, it was calculated how much the
 116 manure contributed in terms of nutrients to 5 and 6 treatments.

117 **Table 1. Macro and micronutrients levels present in wastewater (WW) and bovine**
 118 **manure (BM)**

Macronutrients	WW	BM	Micronutrients	WW	BM
	mg L ⁻¹	mg Kg ⁻¹		mg L ⁻¹	mg Kg ⁻¹
N	7.98	5200	Cu	0.006	45.2
P	4.7	4700	Fe	4.6	1932.4
K	65.6	2500	Mn	0.002	391.8
S	-	2300	Zn	0.002	200.5
Ca	200	1700			
Mg	30	200			

119
 120 At each evaluation of the wastewater, the irrigation system was also evaluated, analyzing
 121 the mean weekly water depth (Dm) and the uniformity of water distribution (DU), at each
 122 irrigated treatments. The calculation of Dm took into account the mean flow rates (Fm)
 123 multiplied by the irrigation time of each treatment and divided by the wet area of the emitter.

124 The total volume of wastewater applied in each treatment was obtained multiplying Fm by
 125 weekly irrigation time and amount of irrigated weeks. This volume multiplied by the
 126 wastewater nutrient contents results in the contribution of nutrients for the plants in 2, 3 and
 127 4 treatment.

128 Precipitation and reference evapotranspiration (ET_o) data, obtained from an automatic
 129 meteorological station installed at campus, and Dm were used to do the Crop Water Balance
 130 (CWB), according to the method proposed by Thornthwaite and Mather (1955), for the whole
 131 experimental period, to determine the water deficit of the crop in all treatments.

132 For determination of productivity, all 60 plants of the evaluation unit of each plot were
 133 harvested and weighed. The productivity (Kg ha⁻¹) was determined multiplying the total mass
 134 of each evaluation unit (Kg evaluation unit⁻¹) by 10,000 m² ha⁻¹ and dividing by 20 m²
 135 evaluation unit⁻¹, in other words, multiplying the total mass of each plot by 500. Sample of
 136 six plants were collected randomly from each useful plot to determine the nutrient contents.

137 The data were subjected to analysis of variance, adopting 5% as a critical level of
138 significance. The averages were grouped by the Skott-Knott criterion, at 5% significance.
139 Statistical analysis was performed using the statistical program "Sisvar" (FERREIRA, 2014).

140 3. RESULTS AND DISCUSSION

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142 The average flow rates of the drippers, the Distribution Uniformity and the mean weekly
143 water depth applied per irrigated treatment after five evaluations of the irrigation system are
144 shown in Table 2.

145

146 **Table 2. Mean flow rates of the drippers (Fm), Distribution Uniformity (DU) and mean**
147 **weekly water depth (Dm) applied per irrigated treatment**

Treatment	Fm (L h ⁻¹)	DU (%)	Dm (mm)
T2	1.495	95	5.98
T3	1.441	94	11.53
T4	1.443	94	11.53
T5	1.470	93	11.76

148 *T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹ week⁻¹); T3: no fertilization and RDI with*
149 *wastewater (1.2 L plant⁻¹ week⁻¹); T4: no fertilization and RDI with wastewater (0.6 L planta⁻¹, two*
150 *applications per week); T5: with bovine manure (60 Mg ha⁻¹) and RDI with common water (1.2 L plant⁻¹*
151 *week⁻¹).*

152

153 The Table 2 shows that the uniformity of water distribution, with DU ranging from 93 to 95%,
154 can be considered as excellent in all treatments, according to the evaluation criterion
155 proposed by Mantovani (2001) (Excellent: DU>84%). It was observed that the use of
156 wastewater during the whole experiment did not negatively affect the uniformity of water
157 distribution neither the average flow of the emitters, which was close to the nominal flow
158 reported by the manufacturer (1.5 L h⁻¹) in all treatments.

159 From Dm applied in all irrigated days, to obtain the total irrigation (I) in the irrigated
160 treatments, the Crop Water Balance (CWB) was set up. For this, the coefficient of culture
161 (Kc) was considered equal to 0.5, according to Consoli, Inglese and Inglese (2013). The
162 Total soil water storage capacity (TWSC) was equal to 50.4 mm, calculated on the basis of
163 the Field Capacity (FC = 15%), the Permanent Wilting Point (PWP = 6%), soil global density
164 (Dg = 1.4) and in the Depth of the Root System (Z = 40 cm).

165 Table 3 summarizes the CWBs in all treatments for the period from the third week of January
166 2016, the last period in which the soil was in field capacity (TWSC equal to 50.4 mm) in all
167 treatments, until the fourth week of August 2017, when the last irrigation in the crop was
168 carried out; and Table 4 shows the averages of dry matter and green matter yields (kg ha⁻¹),
169 as well as of the dry matter content in each treatment. The mean values of the green matter
170 yield of cactus pear crop differed significantly from each other (P=.05) as a function of
171 irrigation and organic fertilization. In the non-irrigated treatments, the yields were significantly
172 lower than in the remaining treatments (P=.05).

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177 **Table 3. Summary of the Crop Water Balance (CWB) in all treatments, from the third**
 178 **week of January 2016 until the fourth week of August 2017**

Treat ment	ET _o (mm)	K _c	ET _{pc} (mm)	P (mm)	I+P-ET _{pc} (mm)	ET _c (mm)	DEF (mm)	EXC (mm)	I (mm)	ET _c / ET _{pc}
T1	3433.30	0.50	1716.65	923.52	-793.13	455.65	-1261.01	567.75	0.00	0.27
T2	3433.30	0.50	1716.65	923.52	-923.52	769.80	-946.85	586.60	382.72	0.45
T3	3433.30	0.50	1716.65	923.52	-55.00	1146.37	-570.28	613.01	738.13	0.67
T4	3433.30	0.50	1716.65	923.52	-55.00	1146.37	-570.28	613.01	738.13	0.67
T5	3433.30	0.50	1716.65	923.52	-40.49	1110.00	-606.66	614.19	752.64	0.65
T6	3433.30	0.50	1716.65	923.52	-793.13	455.65	-1261.01	567.75	0.00	0.27

179 *T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹ week⁻¹);*
 180 *T3: no fertilization and RDI with wastewater (1.2 L plant⁻¹ week⁻¹); T4: no fertilization and RDI with*
 181 *wastewater (0.6 L plant⁻¹, two applications per week); T5: with organic fertilization (60 Mg ha⁻¹) and RDI*
 182 *with common water (1.2 L plant⁻¹ week⁻¹); T6: no irrigation and with organic fertilization (60 Mg ha⁻¹).*
 183 *ET_o: reference evapotranspiration; K_c: crop coefficient; ET_{pc}: potential crop evapotranspiration; P:*
 184 *rainfall; ET_c: real crop evapotranspiration; DEF: deficit; EXC: excess; I: irrigation; ET_c/ ET_{pc}: relative*
 185 *crop evapotranspiration.*

186 **Table 4. Average yields of green matter (GM) and dry matter (DM), in kg ha⁻¹, and dry**
 187 **matter content (DM content), in %, of ‘Gigante’ pear crop in each treatment.**

Treatment	Yield (Kg ha ⁻¹)		DM content (%)
	GM	DM	
T1	91,350 A	11,049 A	11.98 B
T2	179,000 B	13,818 A	7.77 A
T3	186,550 B	13,173 A	6.98 A
T4	171,450 B	12,238 A	7.13 A
T5	258,700 C	16,821 B	6.75 A
T6	104,850 A	11,378 A	10.92 B

188 *Means followed by the same letter do not differ significantly from each other (P=0.05), by the Scott-Knott*
 189 *test. T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹*
 190 *week⁻¹); T3: no fertilization and RDI with wastewater (1.2 L plant⁻¹ week⁻¹); T4: no fertilization and RDI*
 191 *with wastewater (0.6 L plant⁻¹, two applications per week); T5: with organic fertilization (60 Mg ha⁻¹)*
 192 *and RDI with common water (1.2 L plant⁻¹ week⁻¹); T6: no irrigation and with organic fertilization (60 Mg*
 193 *ha⁻¹).*

194
 195 Table 3 shows that even the crop with a low water demand (K_c=0.5), in the non-irrigated
 196 treatments (T1 and T6), the water deficit was equal to $73\% \left(\left(1 - \frac{ET_c}{ET_{pc}} \right) 100 \right)$. This means that
 197 the culture has failed to transpire a potential amount that is almost three times greater than
 198 what it had actually transpired. If we take into account a production function relating real
 199 yield and potential yield $\left(1 - \frac{Y_r}{Y_p} \right)$ proportional to the transpiration, the crop lost approximately
 200 three-quarters of its productive potential.

201 On the other hand, the treatment with organic fertilization and water supplementation with
 202 common water (1.2 L week⁻¹ plant⁻¹) (T5) had the highest productivity (Table 4). Looking
 203 again at Table 3, it can be seen that the water deficit in this treatment (T5) was equal to
 204 35%, that is, the crop had not transpired just over a third of its potential evapotranspiration.
 205 This higher evapotranspiration in T5 treatment, associated with organic fertilization, allowed
 206 plants of T5 treatment to reach higher productivity than plants of the other treatments.

207 By comparing only T5 and T6, which had the same fertilization, the ET_c of the former was
 208 2.44 times that of the latter and the green matter yield was 2.47 times greater. A near linear
 209 relationship between relative ET_c and relative productivity demonstrates the beneficial effect
 210 of irrigation on productivity, even with only 1.2 L week⁻¹ plant⁻¹. In other words, the regulated

211 deficit irrigation - RDI (deficit equal to 35%), using common water (T5), provided a green
212 matter yield 2.47 times higher than in non-irrigated treatment (T6 - water deficit equal to
213 73%), with the same fertilization.

214 In Table 4, regarding green matter yield, there was no statistical difference between
215 treatments with irrigation with wastewater (T2, T3 and T4). These treatments had a mean
216 higher than the mean of non-irrigated treatments, either with or without organic fertilization,
217 namely T6 and T1, respectively, which did not differ between them either.

218 Two things can be inferred from these results: 1) even without organic fertilization, regulated
219 deficit irrigation - RDI with wastewater was fundamental for increasing crop productivity; and,
220 2) in the absence of irrigation, fertilization with 60 Mg ha⁻¹, performed in T6, did not
221 contribute to increasing productivity compared to T1, probably due to the intense water
222 deficit of the crop (73%) in both treatments, which impaired the mineralization of organic
223 matter in T6 and the consequent absorption of nutrients by plants.

224 Padilha Júnior et al. (2016), testing doses of organic fertilization in non-irrigated cactus pear,
225 concluded that the production of green matter without fertilization or with only 60 Mg ha⁻¹
226 year⁻¹ of manure, in two annual applications, did not provide a statistical difference in
227 productivity of 'Gigante' pear crop.

228 Even in the treatment T2, with application of only 0.6 L week⁻¹ plant⁻¹, which reduced the
229 water deficit to 55%, the applied wastewater was fundamental in increasing the productivity
230 of green matter, even without organic fertilization. Comparing only T2 and T1, the ET_c of the
231 former was 1.69 times higher than the latter and the productivity was 1.96 times higher. This
232 relationship is even better than that linear relationship occurred when comparing T5 with T6.
233 In other words, the regulated deficit irrigation - RDI (deficit equal to 55%), using wastewater
234 (T2), provided a yield of green matter 1.96 times higher than in the non-irrigated treatment –
235 T1 (water deficit equal to 73%). Considering that, in both treatments there was no organic
236 fertilization; here we have the beneficial effect on productivity, not only of irrigation, but also
237 of the nutrients contained in the wastewater, even with only 0.6 L week⁻¹ plant⁻¹. This amount
238 of water reduced the deficit from 73% to 55%, which is still considered high for most crops.
239 This also demonstrates high water use efficiency in 'Gigante' cactus pear crop.

240 Fonseca (2017), cultivating 'Gigante' cactus pear crop irrigated with different saline water
241 depths and different irrigation intervals, reported a maximum yield of 218.20 Mg ha⁻¹ by
242 irrigating with 100% of ET_o daily. This productivity is lower than what was recorded in T5
243 treatment, in which there was a water deficit of 35%, but with application of 60 Mg ha⁻¹ of
244 manure. It is worth noting that 100% of the ET_o is equivalent to 200% of the ET_c of the crop,
245 which may have impaired crop productivity, especially for saline water.

246 Regarding dry matter yield, there was no statistical difference, considering a 5% significance
247 level, between the non-irrigated treatments (T1 and T6) and those irrigated with wastewater
248 (T3, T4 and T5). The treatment irrigated and fertilized (T5) was superior to all others.
249 However, numerically, the difference between treatments T3 and T1 (statistically equal) is
250 very close to the difference between T5 and T3 (T5 is statistically greater than T3). As the
251 dry matter contents in the non-irrigated treatments were higher than in the irrigated
252 treatments, the dry matter yield was statistically identical in most treatments, despite the
253 great difference in yield of green matter. Irrigation maintained plant turgidity rather than
254 increasing accumulation of dry matter.

255 Table 5 shows the values of the contributions of macro- and micronutrients in soil in
256 treatments that received irrigation with wastewater (T2, T3 and T4) and in treatments that

257 received organic fertilization with 60 Mg ha⁻¹ of bovine manure (T5 and T6). In the
 258 treatments with wastewater, the total volume of water applied per area (L ha⁻¹) during the
 259 experiment was multiplied by the mean contents (mg L⁻¹) of each nutrient in the wastewater,
 260 shown in Table 1, and the results were converted in Kg ha⁻¹.

261 **Table 5: Amount of macro and micronutrients applied to the soil via wastewater (T2,**
 262 **T3 and T4) and via fertilization with bovine manure with 60 Mg ha⁻¹ (T5 and T6)**

Treatment	K	Ca	P	Mg	Fe	Cu	Zn	Mn	N
(Kg ha ⁻¹)									
T2	100.2	234.0	5.5	35.1	5.4	0.007	0.002	0.002	9.3
T3	189.6	443.0	10.4	66.4	10.2	0.013	0.004	0.004	17.7
T4	189.6	443.0	10.4	66.4	10.2	0.013	0.004	0.004	17.7
T5	150.0	102.0	282.0	12.0	115.9	2.712	12.030	23.508	312.0
T6	150.0	102.0	282.0	12.0	115.9	2.712	12.030	23.508	312.0

263 *T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹ week⁻¹); T3: no fertilization and RDI with*
 264 *wastewater (1.2 L plant⁻¹ week⁻¹); T4: no fertilization and RDI with wastewater (0.6 L plant⁻¹,*
 265 *two applications per week); T5: with organic fertilization (60 Mg ha⁻¹) and RDI with common water (1.2 L*
 266 *plant⁻¹ week⁻¹); T6: no irrigation and with organic fertilization (60 Mg ha⁻¹).*

267
 268 Treatment T5 had the highest productivity, even though the same amount of water was
 269 applied to treatments T3 and T4. This is possibly explained by the greater amount of
 270 nutrients applied through fertilization with manure (60 Mg ha⁻¹) than with wastewater. As can
 271 be seen in Table 5, only in relation to K, Ca and Mg, the contributions were higher in the
 272 treatments with wastewater than with manure, but in the same order of magnitude. As for all
 273 other nutrients, fertilizer intake with manure was much higher than with wastewater for P, N
 274 and all micronutrients.

275 The macronutrient and micronutrient contents present in the tissues of cladodes of cactus
 276 pear were evaluated to quantify nutrient extraction/exportation. Table 6 shows the
 277 macronutrient contents in cladodes and Table 7, the amount extracted by the crop in each
 278 treatment.

279 **Table 6. Macronutrient contents in the tissues of cladodes of ‘Gigante’ cactus pear**
 280 **cultivated under different fertilizations and irrigations**

Treatment	Macronutrients (dag kg ⁻¹)					
	N	P	K	S	Ca	Mg
T1	0.974 A	0.068 A	4.098B	0.172 B	4.338 A	1.260 A
T2	0.948 A	0.108 B	3.682 A	0.120 A	3.752 A	0.982 A
T3	1.014 A	0.080A	3.634 A	0.140 A	3.744 A	1.006 A
T4	0.904 A	0.074 A	3.170 A	0.116 A	3.140 A	1.070 A
T5	1.306 B	0.118 B	4.320B	0.194 B	3.616 A	1.144 A
T6	1.430 B	0.110B	4.380 B	0.234 B	3.796 A	1.032 A
Mean	1.096	0.093	3.881	0.158	3.731	1.082
CV (%)	11.21	26.17	12.93	24.06	13.08	17.80

281 *Means followed by the same letter do not differ significantly from each other (P=0.05), by the Scott-Knott*
 282 *test. T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹*
 283 *week⁻¹); T3: no fertilization and RDI with wastewater (1.2 L plant⁻¹ week⁻¹); T4: no fertilization and RDI*
 284 *with wastewater (0.6 L plant⁻¹, two applications per week); T5: with organic fertilization (60 Mg ha⁻¹)*
 285 *and RDI with common water (1.2 L plant⁻¹ week⁻¹); T6: no irrigation and with organic fertilization (60 Mg*
 286 *ha⁻¹).*

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290 **Table 7. Extraction of macronutrients by ‘Gigante’ cactus pear cultivated under**
 291 **different fertilizations and irrigations**

Treatment	Macronutrients (kg ha ⁻¹)					
	N	P	K	S	Ca	Mg
T1	107.2 A	7.3 A	452.2 A	19.0 A	475.6 A	140.6 A
T2	130.8 A	16.4 B	498.5 A	16.9 A	515.8 A	134.9 A
T3	137.1 A	10.7 A	486.3 A	15.4 A	495.2 A	133.5 A
T4	110.2 A	9.1 A	389.7 A	14.2 A	382.9 A	130.7 A
T5	228.7 B	20.4 B	745.8 B	33.7 B	623.3 A	195.8 B
T6	158.4 A	12.9 A	505.0 A	26.8 B	433.3 A	117.9 A
Mean	145.4	12.8	512.9	21.0	487.7	142.3
CV (%)	29.09	51.21	26.42	35.24	25.69	27.62

292 *Means followed by the same letter do not differ significantly from each other (P=.05), by the Scott-Knott*
 293 *test. T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹*
 294 *week⁻¹); T3: no fertilization and RDI with wastewater (1.2 L plant⁻¹ week⁻¹); T4: no fertilization and RDI*
 295 *with wastewater (0.6 L plant⁻¹, two applications per week); T5: with organic fertilization (60 Mg ha⁻¹)*
 296 *and RDI with common water (1.2 L plant⁻¹ week⁻¹); T6: no irrigation and with organic fertilization (60 Mg*
 297 *ha⁻¹).*
 298

299 For most of the macronutrients, except Ca and Mg, the contents were higher in the fertilized
 300 treatments. This is due to the much greater contribution made through organic fertilization
 301 than via wastewater. In relation to Ca and Mg, as the contributions were similar, the levels
 302 did not differ statistically, even in relation to T1, which received no contribution. According to
 303 Silva et al. (2012), N acts by reducing the absorption of Ca and Mg. Considering the large
 304 contribution of N in T5 and T6, this may explain that the Ca and Mg contents in the cladodes
 305 of the plants of these treatments are similar to those of the T1 treatment, in spite of the Ca
 306 and Mg contribution made in T5 and T6.

307 The average amount of macronutrients extracted/exported in descending order were K, Ca,
 308 N, Mg, S and P (Table 7). Similar results were found by Donato et al. (2016) using different
 309 spacing and fertilizer rates. The authors found differences only for extraction/export of P,
 310 which is possibly due to organic fertilization. According to Donato et al., (2017), to ensure the
 311 cactus pear productivity over time, it is necessary to replenish the extracted/exported
 312 nutrients, mainly K, Ca and Mg.

313 The treatment with the highest productivity of green matter also had the largest
 314 extraction/export of nutrients, evidencing the need of nutritional supplementation to ensure
 315 productivity in the coming years. Considering the extraction of N in treatments irrigated with
 316 wastewater, much higher than the contribution of this nutrient by the wastewater (Table 5), it
 317 appears that only the nutrient contribution by the wastewater is not enough to sustain the
 318 crop's productivity in the long term, so supplementation with another source of this nutrient is
 319 needed.

320 The N levels, according to Table 6, in the tissues of cladodes of cactus pear, with a mean of
 321 1.096 dag kg⁻¹, varied significantly (P=.05) with organic fertilization. The highest values were
 322 observed in the treatments with organic fertilization. According to Donato et al. (2016), the
 323 addition of bovine manure leads to a higher extraction of this nutrient by plants.

324 The P levels in the cladodes, according to Table 6, varied significantly (P=.05) and were
 325 higher in the treatments with organic fertilization and in the treatment with irrigation with 0.6
 326 L week⁻¹ of wastewater. According to Silva et al. (2012), the cactus pear responds little to the
 327 addition of this nutrient, which justifies the similarity of the contents in these treatments.

328 Although the contents of K, according to Table 6, varied significantly ($P=0.05$) across
 329 treatments, when the amount extracted by the crop was observed, only the T5 treatment
 330 differs from and is superior to the other treatments. This is due to the higher productivity in
 331 the treatment T5. However, there was also no significant difference for the non-fertilized and
 332 non-irrigated treatment (T1). Perhaps the absorption of K also underwent the same
 333 interference of the N with respect to Ca and Mg. Silva et al. (2012) mention this competitive
 334 inhibition in the presence of high concentrations of K, Ca, Mg and N in the soil solution.

335 In all treatments, the extraction of K was superior to the input, either by the wastewater, or
 336 by the bovine manure. Therefore, it will be necessary to replace K with other sources of K to
 337 sustain the crop's productivity in the long term.

338 As for the extraction of S, according to Table 6, the fertilized treatments were also superior
 339 to the others due to the great contribution of this element through the organic fertilization.
 340 These results are equivalent to those found by Silva et al. (2016) when applying S indirectly
 341 through fertilization with NPK sources, and S extractions were higher in the fertilized
 342 treatments.

343 Table 8 shows the micronutrient contents in cladodes and the Table 9 shows the extraction
 344 of these nutrients by the crop.

345 **Table 8. Micronutrient contents in the tissues of cladodes of cactus pear cultivated**
 346 **under different fertilization and irrigation**

Treatment	Macronutrients (mg kg ⁻¹)				
	B	Cu	Fe	Mn	Zn
T1	30.120 A	2.112 A	110.110 A	339.266 A	34.140 A
T2	24.938 A	3.198 A	188.674 A	362.820 A	37.730 A
T3	29.934 A	2.132 A	89.190 A	464.602 B	37.044 A
T4	28.642 A	2.810 A	157.886 A	519.890 B	39.788 A
T5	28.958 A	4.572 A	218.998 A	358.678 A	45.428 A
T6	26.662 A	2.486 A	235.388 A	256.328 A	43.126 A
Mean	28.209	2.885	166.707	383.597	39.543
CV (%)	17.72	51.63	68.42	30.29	23.54

347 *Means followed by the same letter do not differ significantly from each other ($P=0.05$), by the Scott-Knott*
 348 *test. T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant⁻¹*
 349 *week⁻¹); T3: no fertilization and RDI with wastewater (1.2 L plant⁻¹ week⁻¹); T4: no fertilization and RDI*
 350 *with wastewater (0.6 L plant⁻¹, two applications per week); T5: with organic fertilization (60 Mg ha⁻¹)*
 351 *and RDI with common water (1.2 L plant⁻¹ week⁻¹); T6: no irrigation and with organic fertilization (60 Mg*
 352 *ha⁻¹).*

353

354 **Table 9. Extraction of micronutrients by 'Gigante' cactus pear cultivated under**
 355 **different fertilizations and irrigations**

Treatment	Micronutrients (kg ha ⁻¹)				
	B	Cu	Fe	Mn	Zn
T1	0.328 A	0.023 A	1.135 A	3.71 A	0.382 A
T2	0.329 A	0.053 A	2.459 A	4.70 A	0.498 A
T3	0.405 A	0.031 A	1.234 A	6.19 B	0.490 A
T4	0.349 A	0.034 A	2.090 A	6.25 B	0.491 A
T5	0.504 A	0.079 A	3.985 A	6.20 B	0.790 B
T6	0.309 A	0.028 A	2.399 A	3.00 A	0.483 A
Mean	0.371	0.041	2.217	5.01	0.546
CV (%)	29.06	74.78	67.36	34.69	48.95

356 Means followed by the same letter do not differ significantly from each other ($P=0.05$), by the Scott-Knott
 357 test. T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1}
 358 week^{-1}); T3: no fertilization and RDI with wastewater ($1.2 \text{ L plant}^{-1} \text{ week}^{-1}$); T4: no fertilization and RDI
 359 with wastewater (0.6 L plant^{-1} , two applications per week); T5: with organic fertilization (60 Mg ha^{-1})
 360 and RDI with common water ($1.2 \text{ L plant}^{-1} \text{ week}^{-1}$); T6: no irrigation and with organic fertilization (60 Mg
 361 ha^{-1}).

362
 363 It can be seen in Tables 8 and 9 that there was no statistical difference at 5% level of
 364 significance across treatments for most micronutrients, except for Mn for both contents and
 365 micronutrient extraction, and for Zn, only for extraction.

366 Table 10 shows soil pH in all treatments.

367 **Table 10. Soil pH values**

Treatment	pH
T1	6.180 A
T2	6.040 A
T3	5.980 A
T4	5.860 A
T5	6.040 A
T6	6.200 A
Mean	6.050
CV (%)	3.93

368 Means followed by the same letter do not differ significantly from each other ($P=0.05$), by the Scott-Knott
 369 test. T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1}
 370 week^{-1}); T3: no fertilization and RDI with wastewater ($1.2 \text{ L plant}^{-1} \text{ week}^{-1}$); T4: no fertilization and RDI
 371 with wastewater (0.6 L plant^{-1} , two applications per week); T5: with organic fertilization (60 Mg ha^{-1})
 372 and RDI with common water ($1.2 \text{ L plant}^{-1} \text{ week}^{-1}$); T6: no irrigation and with organic fertilization (60 Mg
 373 ha^{-1}).

374
 375 Although the Mn contribution was often higher in organic fertilizer treatments (T5 and T6)
 376 than in the others, higher Mn contents were observed in plants of the treatments T3 and T4.
 377 Regarding the extraction of Mn, in addition to these two treatments, the treatment T5 was
 378 also superior to T1, T2 and T6, and statistically equal to T3 and T4. The availability of Mn is
 379 directly related to soil pH. The rise in pH decreases the soil concentration of this nutrient
 380 (SILVA et al., 2012). Soil pH did not differ significantly in the treatments (Table 10), but the
 381 treatments T3 and T4 were where the lowest pH values were observed and the only ones
 382 below 6.0. Minimal changes in pH values influence the absorption of this nutrient.

383 Similarly, extraction of Cu, Zn and Mn by the crop was higher than the contribution made by
 384 the wastewater in the treatments T2, T3 and T4. Therefore, it is necessary to supply these
 385 micronutrients with other sources to maintain the crop's productivity in the long term.

386 4. CONCLUSIONS

387
 388 The regulated deficit irrigation - RDI (deficit equal to 35%), using common water, provided a
 389 yield of green matter 2.47 times higher than in non-irrigated treatment with the same
 390 fertilization.

391 In the absence of organic fertilization, the regulated deficit irrigation - RDI (deficit equal to
 392 55%), using wastewater, provided a yield of green matter 1.96 times higher than in non-
 393 irrigated treatment.

394 In the absence of irrigation, organic fertilization does not provided a yield higher than in non-
395 fertilized treatment.

396 The contribution of N, K, Cu, Zn and Mn only by the wastewater is not enough to sustain the
397 crop's productivity in the long term, requiring some supplementation with another source of
398 these nutrients.

399 The absence of an irrigated treatment using common water and without fertilization did not
400 allow measuring the nutrient effects contained in the wastewater for the crop. In future
401 research, this and other treatments with irrigation using wastewater plus fertilizer could be
402 added.

403 **COMPETING INTERESTS**

404

405 Authors have declared that no competing interests exist.

406

407

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