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Nutritional balance and recovery rate of macronutrients by ‘Gigante’ cactus pear under different fertilizations[1]

Balanço nutricional e taxa de recuperação de macronutrientes pela palma forrageira ‘Gigante’ sob diferentes adubações

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HIGHLIGHTS:

The export of nutrients is K > Ca > N > Mg > with P and S alternating the order with the source.
Fertilizers used are insufficient to maintain the positive nutritional balance of Ca and Mg.
Organic fertilization promotes a higher rate of K recovery by the ‘Gigante’ cactus forage.

ABSTRACT: The objective of this study was to evaluate nutrient export, nutritional balance and macronutrient recovery rate in ‘Gigante cactus pear under different fertilization doses, spacings and configurations during three production cycles. The 72 treatments were arranged in a randomized block design with three repetitions, two configurations in the plots (triple and quadruple row), three spacings in the subplots (3.00 x 1.00 x 0.25 m; 3.00 x 1.00 x 0.16 m and 3.00 x 1.00 x 0.125 m); and 12 types of fertilization in the sub-subplots (with organic, organomineral and mineral sources). Exports of nutrients are higher under fertilizers with higher nutrient supplies, regardless of source. The order of export was K > Ca > N > Mg > S > P for mineral fertilization, organic fertilization with 30 Mg ha^{-1} year^{-1} and organomineral fertilization with 30 and 60 Mg ha^{-1} year^{-1} plus NPK and PK, and it changed to K > Ca > N > Mg > P > S under organic fertilization with 60 and 90 Mg ha^{-1} year^{-1} and organomineral fertilization with 90 Mg ha^{-1} year^{-1} plus K. The nutrient balance after three production cycles was positive for N, P and S, negative for Ca and Mg in all fertilizations, and positive for K under mineral fertilization with 600 kg ha^{-1} of K_2O and organomineral fertilization with 30, 60 and 90 Mg ha^{-1} year^{-1} plus 600 kg ha^{-1} of K_2O. The highest recovery rates of K and the lowest recovery rates of N occur under organic fertilization.

Key words: *Opuntia*, organomineral fertilizers, export of nutrients

RESUMO: Objetivou-se avaliar durante três ciclos de produção a exportação de nutrientes, o balanço nutricional e a taxa de recuperação de macronutrientes pela palma forrageira‘Gigante sob doses e fontes de adubação, e arranjos de disposição de plantas na área. Os 72 tratamentos foram dispostos em esquema de parcelas sub-subdivididas em delineamento em blocos casualizados com três repetições, sendo duas configurações nas parcelas (fileira tripla e quadrupla); três espaçamentos nas subparcelas (3,00 x 1,00 x 0,25 m; 3,00 x 1,00 x 0,16 m e 3,00 x 1,00 x 0,125 m); e 12 tipos de adubação nas sub-subparcelas (com fontes orgânica, organomineral e mineral). Os maiores aportes de nutrientes proporcionam maiores exportações, independentemente da fonte. A ordem de exportação de nutrientes foi K > Ca > N > Mg > S > P para as adubações mineral, orgânica com 30 Mg ha^{-1} ano^{-1} e organomineral com 30 e 60 Mg ha^{-1} ano^{-1} adicionada de N-P-K e P-K, enquanto nas adubações orgânicas com 60 e 90 Mg ha^{-1} ano^{-1} e organomineral com 90 Mg ha^{-1} ano^{-1} mais 600 kg ha^{-1} de K_2O, a ordem de exportação altera para K > Ca > N > Mg > P > S. O balanço de nutrientes apos três ciclos foi positivo para N, P e S, como também para K nas adubações mineral com 600 kg ha^{-1} de K_2O e organomineral com 30, 60 e 90 Mg ha^{-1} ano^{-1} de esterco bovino adicionado de 600 kg ha^{-1} de K_2O. Porém, negativo para Ca e Mg em todas as adubações. As maiores taxas de recuperação de K e as menores de N ocorrem nas adubações orgânicas.

Palavras-chave: *Opuntia*, adubações organomineral, exportação de nutrientes

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Introduction

Knowledge about the nutritional requirements of cactus pear is fundamental for the sustainability of its cultivation, since the great extraction and export of nutrients during successive cycles (Silva et al., 2016a; Donato et al., 2017c) can lead to depletion of soil nutrients and result in a reduction of yield in the absence of replacement of the minerals exported by harvest (Dubeux Júnior et al., 2010).

Quantitative changes in nutrient extraction in response to fertilization reveal a high nutrient export potential in cactus pear cladodes (Dubeux Júnior et al., 2010; Silva et al., 2012). Thus, evaluating the accumulation and export of nutrients represents a relevant starting point in the definition of fertilizer doses to be used and ensure the production sustainability of soils.

In addition, planting at different spacings (Cavalcante et al., 2014), changes in population density (Silva et al., 2014; 2016b), doses of organic fertilization (Donato et al., 2016; Lemos et al., 2018) or mineral fertilization (Silva et al., 2012) may affect yield and nutrient content in cladodes, with consequences on the amount of nutrients exported (Silva et al., 2016a; Donato et al., 2017c).

Fertilization with mineral, organic or organomineral fertilizer sources, in appropriate proportions, optimizes the production of green matter, accumulation of nutrients in the cladodes and dry matter yield of cactus pear. In addition, they can determine differences in the amounts of nutrients extracted and exported by the cladodes, which becomes more important when considering several harvest cycles. Additionally, the balance of nutrient inflows and outflows in the system and the recovery rate by the plant of the applied nutrients may differ according to the sources and/or doses. The objective of this study was to evaluate for three production cycles the export, nutritional balance and apparent nutrient recovery rate by 'Gigante' cactus pear (*Opuntia ficus-indica*) cultivated with different planting configurations, spacings and fertilizations.

Material and Methods

The experiment was conducted for three production cycles at the Federal Institute of Bahia, Campus of Guanambi, BA, Brazil, located at coordinates of 14° 17' 44" S latitude, 42° 41' 39" W longitude and altitude of 545 m. The climate of the region is semi-arid hot and dry and the soil is an Oxisol. In the first production cycle, lasting 650 days between planting and harvesting, conducted between October 2011 and July 2013, precipitation was equal to 912.29 mm, corresponding to two rainy seasons, between October 2011 and February 2012 (442.67 mm) and between October 2012 and April 2013 (469.62 mm). In the second cycle, lasting 330 days between two successive harvests, from August 2013 to July 2014, precipitation was equal to 853.96 mm. In the third cycle, also lasting 330 days, between August 2014 and July 2015, precipitation was equal to 879.60 mm. Data were recorded by an automatic weather station installed in the experimental area.

The treatments were arranged in a split-split-plot scheme, in a randomized block design with three replicates, and consisted of two planting configurations in the plots (triple row and quadruple row); three spacings in the subplots: S1 (3.00 x 1.00 x 0.25 m); S2 (3.00 x 1.00 x 0.16 m); and S3 (3.00 x 1.00 x 0.125 m); 12 types of fertilization in sub-subplots composed of the following treatments: without fertilization, three organic fertilizations with bovine manure (30, 60 and 90 Mg ha^{-1} year^{-1}), two mineral fertilizations with N-P_2O_5-K_2O (300-300-300 and 300-300-600 kg ha^{-1} year^{-1}) and six organomineral fertilizations (Mg ha^{-1} year^{-1} of bovine manure - N-P_2O_5-K_2O kg ha^{-1} year^{-1} 30-150-300-300; 30-150-300-600; 60-000-300-300; 60-000-300-600; 90-000-000-300 and 90-000-000-600). Fertilization was applied in the year of planting and in the rainy seasons of the following cycles.

In the triple-row and quadruple-row configurations the areas were respectively 144.00 m² (3.00 x 48.00 m) and 192 m² (4.00 x 48.00 m) in the plots, 72.00 m² (3.00 x 24.00 m) and 96 m² (4.00 x 24.00 m) in the subplots and 6.00 m² (3.00 x 2.00 m) and 8.00 m² (4.00 x 2.00 m) in the sub-subplots.

The bovine manure doses of 30, 60 and 90 Mg ha^{-1} year^{-1} supplied to the soil, respectively, 130-270-75, 260-540-150 and 390-810-225 kg ha^{-1} year^{-1} of N-P_2O_5-K_2O. The manure used in this study showed OM content = 63.73 dag kg^{-1}, ash content = 36.27 dag kg^{-1}, total carbon = 29.98 dag kg^{-1} and pH = 7.42 (Brasil, 2014); moisture content on a dry basis at 65 °C = 16.72%; macronutrient contents: Ca, Mg, K, N and S = 1.7, 0.2, 2.5, 5.2 and 2.3 g kg^{-1} (EPA 3051/APHA 3120B), in this order, P = 4.7 g kg^{-1} (APHA 4500-PC); micronutrient contents (EPA 3051/APHA 3120B): B, Cu, Zn, Mn and Fe = 2.1, 45.2, 200.5, 391.8 and 1,932.4 mg kg^{-1}, respectively; and density = 0.38 g cm^{-3}.

The sources used as mineral fertilizer were: ammonium sulfate, $(NH_4)_2SO_4$ (20% N; 24% S), single superphosphate, $Ca(H_2PO_4)_2.2H_2O$, (18% P_2O_5; 12% S; 18% Ca), and KCl (58% K_2O; 45% Cl). N and K were split into two applications, as top-dressing, at the beginning and in the middle of the rainy season of each cycle.

Prior to planting, soil sampling was carried out for chemical and textural characterization, according to EMBRAPA (2017): sandy clayey loam texture; pH = 5.57; OM = 1.13 dag kg^{-1}; P = 23.57 and K = 181.67 (mg dm^{-3}); Na = 0.10; Ca = 1.93; Mg = 0.87 and H+Al = 1.63 (cmol$_c$ dm^{-3}); B = 0.40; Cu = 0.40; Zn = 2.03; Fe = 35.93 and Mn = 50.2 (mg dm^{-3}); SB = 3.40; Effective CEC = 3.40 and CEC at pH 7.0 = 4.97 (cmol$_c$ dm^{-3}); V = 67.67%; P-rem = 39.10 mg L^{-1} and ECse = 0.93 dS m^{-1}.

The preparation of the area, removal of seedlings and planting followed the recommendations for the crop (Silva et al., 2012; Donato et al., 2014). The collection of samples for the analysis of macronutrient contents in plant tissues was performed at the time of harvest. Within the usable plot of 2 m, cladodes from the median position of the plant were collected, in a total of 20 samples per treatment with approximately 25 g of green matter each. For this procedure, a hole saw with 5 cm diameter and 4 cm depth, adapted to a drill, was turned on over the cladodes to remove a representative circular slice, which constituted the sample. After collection, the material was sliced and dried in a forced circulation oven at 60 °C for

72 h. Subsequently, the samples were ground in a Wiley-type mill with a 1.00-mm-mesh sieve, identified, placed in plastic pots and then sent to the Soil Laboratory of the Agricultural Research Company of Minas Gerais (Epamig Norte), for the analytical procedures.

The cladodes were analyzed for the contents of the macronutrients N, P, K, S, Ca and Mg, expressed in g kg^{-1}, according to Malavolta et al. (1997): N, by sulfuric acid digestion with the Kjeldahl method; P, K, S, Ca and Mg by nitric-perchloric digestion. The dry matter content (DM) was also determined by dividing the weight of the dry sample by the weight of the fresh sample, and the value obtained was multiplied by 10 to be transformed to base g kg^{-1} of natural matter (NM) (Silva & Queiroz, 2009).

At harvest, in the three production cycles, the mother cladode and three primary cladodes were preserved. To calculate green matter yield (GMY) (Mg ha^{-1}), the cladodes of the usable plot were harvested and weighed. Dry matter yield (DMY) (Mg ha^{-1} cycle^{-1}) was calculated according to the dry matter content of the treatment multiplied by GMY. Nutrient export was calculated according to DMY and nutrient content in cladodes and expressed in kg ha^{-1} cycle^{-1} and also in kg Mg^{-1} cycle^{-1}.

As used by Silva et al. (2016a) and Donato et al. (2017b), the nutritional balance was calculated for the macronutrients (N, P, K, Ca Mg and S) in each cycle, considering the difference between the amounts of nutrients added to the soil in each fertilization treatment and the amounts exported by the collection in the cladodes, without considering the supply of nutrients through the soil. Likewise, the final balance was also calculated after three production cycles.

In addition, in each production cycle, the apparent recovery rate of nutrients by the plant (APRR) was also estimated in a similar way to the procedure performed by Maluf et al. (2015), considering the amounts of nutrients applied by organic, organomineral and mineral fertilizations and the nutrient content in the cladodes. APRR (%) = (C(i) in the treatment with fertilization - C(i) in the treatment without fertilization)×100/Q(i) applied in the treatment with fertilization), where: C(i) in the treatment with fertilization is the amount of nutrient i (kg ha^{-1}) for the treatment with fertilization; C(i) is the amount of nutrient i (kg ha^{-1}) in treatment without fertilization (0-000-000-000); Q(i) is the amount of nutrient applied (kg ha^{-1}) in the treatment with fertilization; C(i), amount of nutrient i (kg ha^{-1}), was calculated by the expression C(i) = CN(i) x DMY, in which: CN (i) is the content of nutrient i in the cladode (kg kg^{-1}) and DMY is the dry matter yield of the treatment (Mg ha^{-1}).

The data of nutrient exports in the cladodes were subjected to analysis of variance to verify the occurrence of interactions and the means of fertilization were grouped by the Scott-Knott criterion ($p \leq 0.05$).

Results and Discussion

The export of nutrients by the cladodes of 'Gigante' cactus pear in the three production cycles varied with fertilization, regardless of planting configurations and spacings. No interactions were recorded between the factors studied.

The export of N by cactus pear cladodes was lower in the absence of fertilization in the three production cycles, followed by organic fertilization with 30 Mg ha^{-1} year^{-1} of bovine manure and 60 Mg ha^{-1} year^{-1} in cycle II (Table 1). The highest exports of N were obtained with the mineral fertilization 300-300-600 kg ha^{-1} year^{-1} of N-P_2O_5-K_2O in cycles I and III, and with fertilization with organic source, except 30 and 60 Mg ha^{-1} year^{-1} of manure, mineral or organomineral in cycle II.

Mineral sources, such as the ammonium sulfate used in the present study, for being more soluble, promote higher N contents in cactus pear cladodes (Silva et al., 2012) and, consequently, greater export of nutrients (Silva et al., 2016a). In addition, the increase in N dose promoted an increase in the concentration and availability of this nutrient in the soil and, consequently, greater export of N (Donato et al., 2017b; Lopes et al., 2018).

The export of P and K by cactus pear cladodes was lower in the absence of fertilization in the three production cycles, followed by organic fertilization with 30 Mg ha^{-1} year^{-1} of manure in cycle III for P and in cycle I for K. In general, the highest doses of P and K applied to the soil resulted in higher export of this nutrient in the three production cycles.

Table 1. Exports of nitrogen (EN), phosphorus (EP), potassium (EK), sulfur (ES), calcium (ECa) and magnesium (EMg) by cladodes of 'Gigante' cactus pear subjected to mineral fertilization, organomineral fertilization and organic fertilization in three production cycles

Fertilization	Cycle I - 2011-2013						Cycle II - 2013-2014						Cycle III - 2014-2015					
	EN	EP	EK	ES	ECa	EMg	EN	EP	EK	ES	ECa	EMg	EN	EP	EK	ES	ECa	EMg
	(kg ha^{-1})																	
0-000-000-000	116 c	7 c	290 b	9 e	226 b	84 b	102 c	7 c	222 c	8 d	256 c	79 c	123 d	10 d	264 d	11 f	272 c	110 c
0-300-300-300	283 a	28 a	506 a	57 a	407 a	132a	220 a	26 a	444 b	40 a	425 a	127 b	340 b	36 b	520 c	51 c	511 b	171 c
0-300-300-600	256 a	26 a	591 a	50 b	434 a	133a	185 a	21 b	470 b	35 b	425 a	123 b	411 a	42 a	767 b	66 a	645 a	206 b
30-000-000-000	148 d	14 b	415 b	18 d	279 b	105 b	160 b	21 b	453 b	19 c	353 b	153 b	193 c	19 c	434 c	20 e	389 c	156 c
30-150-300-300	212 b	30 a	589 a	55 a	421 a	132 a	206 a	32 a	563 b	43 a	465 a	165 b	299 b	34 b	648 b	49 c	611 a	212 b
30-150-300-600	222 b	27 a	634 a	48 b	407 a	138 a	187 a	27 a	509 b	36 a	397 b	140 b	344 b	36 b	780 b	57 b	665 a	213 b
60-000-000-000	168 c	19 b	548 a	20 d	364 a	126 a	155 b	23 b	475 b	20 c	353 b	157 b	270 b	28 b	597 c	27 d	457 b	216 b
60-000-300-300	204 b	30 a	643 a	40 b	450 a	153 a	207 a	34 a	638 a	40 a	501 a	209 a	340 b	41 a	750 b	44 c	627 a	256 a
60-000-300-600	170 c	26 a	637 a	33 c	415 a	133 a	205 a	34 a	745 a	39 a	525 a	210 a	334 b	40 a	868 a	45 c	647 a	259 a
90-000-000-000	176 c	18 b	580 a	21 d	359 a	140 a	246 a	34 a	768a	29 b	473 a	219 a	328 b	37 a	805 b	33 d	632 a	298 a
90-000-000-300	208 b	20 b	613 a	22 d	358 a	131 a	217 a	30 a	677 a	25 c	393 b	194 a	304 b	32 b	760 b	27 d	518 b	251 a
90-000-000-600	186 c	17 b	651 a	18 d	366 a	137 a	252 a	33 a	801 a	30 b	473 a	222 a	332 b	41 a	1002 a	35 d	656 a	307 a
Mean	196	22	561	32	374	129	195	27	564	30	420	166	302	33	683	396	553	221
CV (%)	43.3	37.9	38.0	41.8	39	45	44	42	40	43	40	46	30	35	38	39	41	45

(Mg ha^{-1}) of manure - N (kg ha^{-1}) - P_2O_5 (kg ha^{-1}) - K_2O (kg ha^{-1}); Means followed by the same letter in the column belong to the same grouping by the Scott-Knott criterion ($p \leq 0.05$)

However, in cycle II the export of K was higher under organic or organomineral fertilization with 60 and 90 Mg ha^{-1} year^{-1} of manure and, in cycle III, organomineral fertilization with 60 and 90 Mg ha^{-1} year^{-1} of manure plus 600 kg ha^{-1} of K_2O culminated in higher export of K.

The higher doses of P added by different sources favored greater absorption of this nutrient by the plant, regardless of the source used, and corroborate the results found by Donato et al. (2017b). In relation to K, the highest values of K export were recorded in cycle III and correspond to the highest dry matter yields - DMY (Table 2). The total K added in these fertilizations corresponds respectively to 622.9 and 685.4 kg ha^{-1} and resulted in DMY of 21.1 and 23.2 Mg ha^{-1}, with exports of 868.4 and 1,002.6 kg ha^{-1} of K (Tables 1 and 2). These values of DMY and export are consistent with those found in other studies (Silva et al., 2016a; Donato et al., 2017b) and attest that the export of K varies with DMY, but is influenced to a greater extent by the dose of K added to the soil.

The export of S, Ca and Mg by cactus pear cladodes was lower in the absence of fertilization in the three production cycles, followed by organic fertilization with 30 Mg ha^{-1} year^{-1} of manure in cycles II and III for S and in cycles I and III for Ca and Mg.

Mineral fertilization and organomineral fertilization with N and P, due to the higher supply of S because of the use of ammonium sulfate and single superphosphate, and by the greater contribution of Ca due to the use of single superphosphate, a fertilizer that also contains Ca, resulted in higher export of these nutrients and corroborate those of existing research (Silva et al., 2016a; Donato et al., 2017b). The lowest values of Mg exported coincide with the absence of Mg application by mineral fertilization and in the treatment without fertilization and with the lowest dose of Mg in the soil under organic fertilization with 30 Mg ha^{-1} year^{-1} of manure, 10 kg ha^{-1} year^{-1} of Mg. It is worth pointing out that the synergistic interaction of the applied P with soil Mg and with the Mg present in organic and organomineral fertilizations with 60 and 90 Mg ha^{-1} year^{-1} of manure favors the absorption of both (Malavolta et al., 1997) and results in increased Mg exports.

The order of export of macronutrients in ‘Gigante’ cactus pear cladodes varied with the cycle and fertilizations (Table 2). In the first production cycle, the decreasing order of macronutrient export was K > Ca > N > Mg > S > P under all fertilizations and in the absence of fertilization (Table 1). However, under fertilization with mineral source with N supply, for example 000-300-300-300, 0-300-300-600, and organomineral fertilization with supply of also mineral N 30-150-300-300 and 30-150-300-600, the exported S was approximately twice the P, while under the other fertilizations the exports of S and P were close, with a slightly higher value for S. The use of ammonium sulfate containing S, as a source of inorganic N, justifies these results.

In cycles II and III, the decreasing order of export of macronutrients was Ca > K > N > Mg > S > P in the absence of fertilization, while for fertilizations with mineral source, organic source with application of 30 Mg ha^{-1} year^{-1} of manure

Table 2. Balance of macronutrients (N, P, K, Ca, Mg and S) as a function of the average export by cladodes of ‘Gigante’ cactus pear at harvest and the amounts added to the soil by organic, organomineral and mineral fertilizations expressed in (Mg ha^{-1}) of manure - N (kg ha^{-1}) - P_2O_5 (kg ha^{-1}) - K_2O (kg ha^{-1}) in three production cycles

	Fertilization											
Mg ha^{-1} of bovine manure	0	0	0	30	30	30	60	60	60	90	90	90
N (kg ha^{-1})	000	300	300	000	150	150	000	000	000	000	000	000
P_2O_5 (kg ha^{-1})	000	300	300	000	300	300	000	300	300	000	000	000
K_2O (kg ha^{-1})	000	300	600	000	300	600	000	300	600	000	300	600
Cycle I - 2011-2013												
N exported (kg ha^{-1})	116.4	282.2	259.0	148.2	212.7	226.3	168.1	204.5	170.3	176.0	208.1	186.2
N added (kg ha^{-1})*	0.0	600.0	600.0	259.8	559.8	559.8	519.7	519.7	519.7	779.5	779.5	779.5
Balance of N (kg ha^{-1})	-116.4	317.8	341.0	111.6	347.1	333.5	351.6	315.2	349.3	603.5	571.4	593.3
N exported (kg Mg^{-1})	12.5	17.7	15.3	11.9	13.4	14.5	11.5	12.3	11.2	12.4	13.7	12.4
P exported (kg ha^{-1})	7.5	28.2	26.9	14.8	30.5	27.6	19.2	30.5	26.4	18.3	20.6	17.1
P added (kg ha^{-1})*	0.0	258.0	258.0	234.8	489.3	489.3	469.7	720.6	720.6	704.5	693.9	693.9
Balance of P (kg ha^{-1})	-7.5	229.8	231.1	220.0	458.8	461.7	450.5	690.1	694.2	686.3	673.3	676.8
P exported (kg Mg^{-1})	0.8	1.8	1.6	1.2	1.9	1.8	1.3	1.8	1.7	1.3	1.4	1.1
K exported (kg ha^{-1})	290.2	504.9	587.8	415.3	589.8	634.4	548.2	673.6	637.7	580.6	613.7	651.2
K added (kg ha^{-1})*	0.0	498.0	996.0	124.9	622.9	1,120.9	249.8	747.8	1,245.8	374.8	872.8	1,370.8
Balance of K (kg ha^{-1})	-290.2	-6.9	408.2	-290.4	33.1	486.5	-298.4	74.3	608.1	-205.8	259.1	719.5
K exported (kg Mg^{-1})	31.1	31.6	34.7	33.3	37.1	40.6	37.6	40.5	42.1	41.1	40.4	43.3
Ca exported (kg ha^{-1})	226.7	412.7	428.8	279.4	421.6	407.1	364.2	450.3	415.3	359.2	358.9	365.9
Ca added(kg ha^{-1})*	0.0	600.0	600.0	84.9	684.9	684.9	169.9	769.9	769.9	254.8	254.8	254.8
Balance of Ca (kg ha^{-1})	-226.7	187.3	171.2	-194.5	263.3	277.8	-194.3	319.6	354.6	-104.4	-104.1	-111.0
Ca exported (kg Mg^{-1})	24.3	25.8	25.3	22.4	26.6	26.1	25.0	27.1	27.4	25.4	23.6	24.3
Mg exported (kg ha^{-1})	84.5	132.5	132.7	105.5	132.2	138.8	126.3	153.2	133.1	140.9	131.9	137.3
Mg added (kg ha^{-1})^{1}	0.0	0.0	0.0	10.0	10.0	10.0	20.0	20.0	20.0	30.0	30.0	30.0
Balance of Mg (kg ha^{-1})	-84.5	-132.5	-132.7	-95.5	-122.2	-128.8	-106.3	-133.2	-113.1	-110.9	-101.9	-107.4
Mg exported (kg Mg^{-1})	9.1	8.3	7.8	8.4	8.3	8.9	8.7	9.2	8.8	10.0	8.7	9.1
S exported (kg ha^{-1})	8.9	56.5	51.0	18.1	55.0	48.1	20.5	40.8	33.5	21.0	22.1	18.8
S added (kg ha^{-1})^{1}	0.0	1,120.0	1,120.0	114.9	874.9	874.9	229.9	629.9	629.9	344.8	344.8	344.8
Balance of S (kg ha^{-1})	-8.9	1,063.5	1,069.0	96.9	819.9	826.8	209.4	589.1	596.4	323.8	322.7	326.0
S exported (kg Mg^{-1})	1.0	3.5	3.0	1.4	3.5	3.1	1.4	2.4	2.2	1.5	1.5	1.2
DMY (Mg ha^{-1})	9.3	16.2	16.8	12.5	15.9	15.6	14.5	16.6	15.1	14.1	15.2	15.0

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Continuation of Table 2

Cycle II - 2013-2014												
N exported (kg ha^{-1})	102.9	228.9	180.7	161.0	206.2	187.7	155.2	207.9	205.1	246.0	217.1	252.1
N added (kg ha^{-1})	0.0	300.0	300.0	129.9	279.9	279.9	259.8	259.8	259.8	389.8	389.8	389.8
Balance of N (kg ha^{-1})	-102.9	71.1	119.3	-31.0	73.7	92.2	104.6	52.0	54.7	143.7	172.6	137.6
N exported (kg Mg^{-1})	13.0	16.4	14.5	13.0	13.3	13.7	12.0	12.2	11.7	13.2	12.7	13.0
P exported (kg ha^{-1})	7.0	27.3	21.0	21.3	32.1	27.9	23.1	34.4	34.8	34.3	30.2	33.9
P added (kg ha^{-1})	0.0	129.0	129.0	117.4	244.6	244.6	234.8	360.3	360.3	352.3	346.9	346.9
Balance of P (kg ha^{-1})	-7.0	101.7	108.0	96.2	212.6	216.8	211.8	325.9	325.5	318.0	316.8	313.0
P exported (kg Mg^{-1})	0.9	2.0	1.7	1.7	2.1	2.0	1.8	2.0	2.0	1.8	1.8	1.7
K exported (kg ha^{-1})	222.2	458.4	456.4	453.5	563.0	509.6	475.9	638.8	745.3	768.1	677.2	801.8
K added (kg ha^{-1})	0.0	249.0	498.0	62.5	311.5	560.5	124.9	373.9	622.9	185.3	436.4	685.4
Balance of K (kg ha^{-1})	-222.2	-209.4	41.6	-391.1	-251.6	50.8	-350.9	-264.9	-122.4	-582.8	-240.8	-116.4
K exported (kg Mg^{-1})	28.1	32.9	36.6	36.6	36.3	37.3	36.9	37.4	42.5	41.1	39.6	41.3
Ca exported (kg ha^{-1})	256.3	440.8	411.6	353.8	465.1	397.8	352.1	501.2	525.8	473.2	393.3	473.3
Ca added (kg ha^{-1})	0.0	300.0	300.0	42.5	342.5	342.5	84.9	384.9	384.9	127.4	127.4	127.4
Balance of Ca (kg ha^{-1})	-256.3	-140.8	-111.6	-311.4	-122.6	-55.3	-267.2	-116.2	-140.8	-345.8	-265.9	-345.9
Ca exported (kg Mg^{-1})	32.4	31.6	33.0	28.6	30.0	29.1	27.3	29.3	30.0	25.3	23.0	24.4
Mg exported (kg ha^{-1})	79.7	132.0	119.3	153.9	165.9	140.1	157.0	209.3	210.6	219.3	194.7	222.2
Mg added (kg ha^{-1})	0.0	0.0	0.0	5.0	5.0	5.0	10.0	10.0	10.0	15.0	15.0	15.0
Balance of Mg (kg ha^{-1})	-79.7	-132.0	-119.3	-148.9	-160.9	-135.1	-147.0	-199.3	-200.7	-204.3	-179.7	-207.2
Mg exported (kg Mg^{-1})	10.1	9.5	9.6	12.4	10.7	10.2	12.2	12.2	12.0	11.7	11.4	11.5
S exported (kg ha^{-1})	8.3	41.3	34.9	19.1	43.5	36.7	20.5	40.9	39.9	29.5	25.6	30.9
S added (kg ha^{-1})	0.0	560.0	560.0	57.5	437.5	437.5	114.9	314.9	314.9	172.4	172.4	172.4
Balance of S (kg ha^{-1})	-8.3	518.7	525.1	38.3	393.9	400.7	94.4	274.0	275.0	142.9	146.8	141.5
S exported (kg Mg^{-1})	1.1	3.0	2.8	1.5	2.8	2.7	1.6	2.4	2.3	1.6	1.5	1.6
DMY (Mg ha^{-1})	7.9	13.5	12.7	12.3	15.4	13.6	12.8	17.1	17.5	18.6	22.01	19.39
Cycle III - 2014-2015												
N exported (kg ha^{-1})	123.8	338.7	408.7	193.2	300.0	344.2	270.4	345.0	334.4	328.1	304.8	333.0
N added (kg ha^{-1})	0.0	300.0	300.0	129.9	279.9	279.9	259.8	259.8	259.8	389.8	389.8	389.8
Balance of N (kg ha^{-1})	-123.8	-38.7	-108.7	-63.3	-20.0	-64.3	-10.5	-85.2	-74.6	61.7	84.9	56.8
N exported (kg Mg^{-1})	15.0	20.8	19.0	14.7	16.3	16.9	15.3	16.8	15.7	15.5	15.3	14.3
P exported (kg ha^{-1})	10.3	35.3	42.8	19.5	34.2	36.1	28.4	41.3	40.3	37.1	32.5	41.6
P added (kg ha^{-1})	0.0	129.0	129.0	117.4	244.6	244.6	234.8	360.3	360.3	352.3	346.9	346.9
Balance of P (kg ha^{-1})	-10.3	93.7	86.2	97.9	210.5	208.5	206.5	319.0	320.0	315.2	314.4	305.4
P exported (kg Mg^{-1})	1.2	2.2	2.0	1.5	1.9	1.8	1.6	2.0	1.9	1.8	1.6	1.8
K exported (kg ha^{-1})	264.0	508.0	765.4	434.6	648.6	780.2	597.8	750.8	868.4	805.1	760.3	1,002.6
K added (kg ha^{-1})	0.0	249.0	498.0	62.5	311.5	560.5	124.9	373.9	622.9	185.3	436.4	685.4
Balance of K (kg ha^{-1})	-264.0	-259.0	-267.4	-372.2	-337.1	-219.7	-472.9	-376.9	-245.5	-619.8	-323.9	-317.2
K exported (kg Mg^{-1})	32.0	31.2	35.5	33.0	35.3	38.2	33.9	36.6	40.8	38.1	38.1	43.0
Ca exported (kg ha^{-1})	272.7	504.3	648.0	389.9	611.6	665.5	457.2	627.6	647.3	632.6	518.1	656.8
Ca added (kg ha^{-1})	0.0	300.0	300.0	42.5	342.5	342.5	84.9	384.9	384.9	127.4	127.4	127.4
Balance of Ca (kg ha^{-1})	-272.7	-204.3	-348.0	-347.4	-269.1	-323.0	-372.3	-242.6	-262.4	-505.2	-390.6	-529.4
Ca exported (kg Mg^{-1})	33.0	30.9	30.1	29.6	33.3	32.6	26.0	30.6	30.4	29.9	26.0	28.2
Mg exported (kg ha^{-1})	110.1	167.0	208.5	156.2	212.5	213.8	216.3	256.8	259.7	299.0	251.4	307.5
Mg added (kg ha^{-1})	0.0	0.0	0.0	5.0	5.0	5.0	10.0	10.0	10.0	15.0	15.0	15.0
Balance of Mg (kg ha^{-1})	-110.1	-167.0	-208.5	-151.2	-207.5	-208.8	-206.3	-246.8	-249.7	-284.0	-236.4	-292.5
Mg exported (kg Mg^{-1})	13.3	10.2	9.7	11.9	11.6	10.5	12.3	12.5	12.2	14.1	12.6	13.2
S exported (kg ha^{-1})	11.7	50.5	66.2	20.9	49.1	57.3	27.8	44.8	45.5	33.5	27.4	35.7
S added (kg ha^{-1})	0.0	560.0	560.0	57.5	437.5	437.5	114.9	314.9	314.9	172.4	172.4	172.4
Balance of S (kg ha^{-1})	-11.7	509.5	493.8	36.6	388.4	380.2	87.1	270.1	269.4	138.9	145.0	136.6
S exported (kg Mg^{-1})	1.4	3.1	3.1	1.6	2.7	2.8	1.6	2.2	2.1	1.6	1.4	1.5
DMY (Mg ha^{-1})	8.2	16.6	21.5	13.1	18.3	20.4	17.6	20.5	21.2	21.1	19.9	23.2

DMY - Dry matter yield; [1] The amounts of nutrients added to the soil in the first cycle correspond to the sum of the applications carried out at the time of planting and repeated in the second rainy season, before the first harvest, therefore it represents twice the nutrients supplied to the soil compared to the second and third cycles

or organomineral source with 30 Mg ha^{-1} $year^{-1}$ of manure plus N-P-K and 60 Mg ha^{-1} $year^{-1}$ plus P-K, the order of export was K > Ca > N > Mg > S > P. On the other hand, under fertilizations with organic source with doses of 60 Mg ha^{-1} $year^{-1}$ of manure and with 90 Mg ha^{-1} $year^{-1}$ of manure and organomineral source with 90 Mg ha^{-1} $year^{-1}$ plus K, the order was K > Ca > N > Mg > P > S.

The inversion in the order of P and S, in the description above, is due to the fact that the addition of organic sources to the soil reduces the adsorption capacity of P, increases the available content and promotes greater mobility in the soil profile of soluble organic forms of P. This is more evident because the driving force of this type of transport is the concentration gradient of the element between the rhizosphere and its surroundings (Novais et al., 2007).

In cycles II and III, under fertilizations with mineral source of N and organomineral source with supply of also mineral N, the behavior of S export was similar to that of the first cycle, but 150% higher than P, due to the application of ammonium sulfate (Silva et al., 2016a).

For the macronutrient balance considering the difference between the amount added to the soil and the amount exported at harvest, there is variation with the cycles, fertilizations and dry matter yield (DMY). The N balance was positive in the first cycle for all fertilizations due to the greater supply of the nutrient and lower DMY (Table 2). In the second cycle, it was negative under organic fertilization with 30 Mg ha^{-1} year^{-1} of manure and, in the third cycle, due to the higher DMY, therefore higher export for the same dose applied in the second cycle, it was positive under the fertilizations with greater supply of the nutrient, organic and organomineral with 90 Mg ha^{-1} year^{-1} of manure.

The balance of P and S was positive in the three production cycles for all fertilizations, being more efficient in cycle I due to the lower DMY and greater amount added of these nutrients, differently in cycle III due to the higher DMY and the same amounts of P and S added compared to the second cycle. Both the inorganic sources used, single superphosphate (18% of P_2O_5 and 12% of S) and ammonium sulfate (24% of S), and corral manure (1.08% of P_2O_5 and 0.23% of S) justify these results.

The balance of K was negative in the first production cycle under organic fertilization, with 30, 60 and 90 Mg ha^{-1} year^{-1} of manure (Table 2), agreeing with Donato et al. (2017c) because the manure is not enough to supply the K required by the 'Gigante' cactus pear, depending on the chosen harvest age. It was also negative under fertilization with mineral source with supply of 300 kg ha^{-1} year^{-1} of K_2O. In the second production cycle, the balance of K was positive under mineral fertilization with 600 kg ha^{-1} year^{-1} of K_2O and organomineral fertilization with 30 Mg ha^{-1} year^{-1} of manure plus 600 kg ha^{-1} of K_2O, probably because of the lower export due to the lower DMY, compared to organomineral doses with 60 and 90 Mg ha^{-1} year^{-1} of manure plus 600 kg ha^{-1} of K_2O, which led to negative balance of K despite the higher supply of K. In the third production cycle, the balance of K was negative for all fertilizations due to the high export of this nutrient in the cladodes harvested (Silva et al., 2016a; Donato et al., 2017b) promoted by the higher DMY.

In the three production cycles, the balance of Ca and Mg was negative, except in cycle I for Ca, in which fertilization with mineral source and organomineral source led to positive balance because the source used to supply P, single superphosphate, also contains Ca (18%), and also the lower DMY of cycle I, hence lower export of Ca, and the greater addition of the nutrient compared to the production cycles II and III. In these cycles, the balance of Ca was more negative in cycle III due to the higher DMY and the same dose of Ca applied.

In relation to Mg, the negative balance under all fertilizations is justifiable, because in fertilizations with mineral source Mg was not added and in fertilizations with organic or organomineral source the added Mg came from the bovine manure, a source with low content of the nutrient (20 mg kg^{-1}). However, it became more evident in cycle III due to the greater export for the same dose applied in cycle II and more subtle in cycle I due to the lower DMY and the greater addition of macronutrients. The amount of nutrients added corresponds to the sum of the applications performed at planting and repeated in the second rainy season, before the first harvest, hence representing twice the nutrients supplied to the soil compared to cycles II and III.

The final balance of nutrients after three production cycles (Table 3) was positive for N, P and S in cactus pear subjected to all fertilizations with mineral, organomineral or organic sources; however, it was negative for Ca and Mg under all fertilizations and positive for K under fertilization with mineral source with supply of 600 kg ha^{-1} year^{-1} of K_2O and organomineral source with 30, 60 and 90 Mg ha^{-1} year^{-1} of manure plus 600 kg ha^{-1} of K_2O.

Such higher export of K, Ca and Mg by the cladodes harvested, compared to the amount added, is possible due to the buffer capacity of the soil, which replaces these nutrients to the solution. Moreover, the soil does not constitute a sink for these nutrients and, therefore, the plant does not undergo competition in relation to the soil because all these elements retained in the exchange complex will recompose the nutrients absorbed from the solution, as they are absorbed by the plant. This is because the bonds of these elements with the negative charges of the soil are ionic or electrovalent, with very low adsorption energy (Novais & Mello, 2007).

Tables 2 and 3 show the need for replacement via fertilization of the exported amounts of K, Ca and Mg. In systems with organic fertilization, K supplementation is required, particularly when the DMY target to be achieved with cultivation is greater than 20 Mg ha^{-1} cycle^{-1} (Donato et al., 2017a). Another important point is the incorporation into the production systems of the recommendation of fertilization with fertilizers containing Ca and Mg, regardless of the need for liming of the area (Donato et al., 2017a), because the high export of these nutrients in cladodes can lead to depletion of soils, especially when

Table 3. Final balance of macronutrients (N, P, K, Ca, Mg and S) after three production cycles as a function of the average export by the cladodes of 'Gigante' cactus pear at harvest and the amount added to the soil by different treatments with organic, organomineral and mineral fertilizations

Fertilizations*	N	P	K	Ca	Mg	S
	(kg ha^{-1})					
0-000-000-000	-343.1	-24.8	-776.4	-755.7	-274.3	-28.9
0-300-300-300	350.2	425.2	-475.3	-157.8	-431.5	2,091.7
0-300-300-600	351.6	425.3	182.4	-288.4	-460.5	2,087.9
30-000-000-000	17.3	414.1	-1,053.7	-853.3	-395.6	171.8
30-150-300-300	400.8	881.9	-555.6	-128.4	-490.6	1,602.2
30-150-300-600	361.4	887.0	317.6	-100.5	-472.7	1,607.7
60-000-000-000	445.7	868.8	-1,122.2	-833.8	-459.6	390.9
60-000-300-300	282.0	1,335.0	-567.5	-39.2	-579.3	1,133.2
60-000-300-600	329.4	1,339.7	240.2	-48.6	-563.5	1,140.8
90-000-000-000	808.9	1,319.5	-1,408.4	-955.4	-599.2	605.6
90-000-000-300	828.9	1,304.5	-305.6	-760.6	-518.0	614.5
90-000-000-600	787.7	1,295.2	285.9	-986.3	-607.1	604.1

* - Mg ha^{-1} of manure - N (kg ha^{-1}) - P_2O_5 (kg ha^{-1}) - K_2O (kg ha^{-1})

Table 4. Apparent nutrient recovery rate (APRR) by 'Gigante' cactus pear as a function of mineral, organomineral and organic fertilizations in three production cycles

Fertilization*	Cycle I - 2011-2013						Cycle II - 2013-2014						Cycle III - 2014-2015					
	APRR																	
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
	(%)																	
0-000-000-000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0-300-300-300	27.3	1.5	29.7	32.3	-	4.3	42.6	2.9	64.7	64.6	-	5.8	74.0	3.5	64.4	77.0	-	6.8
0-300-300-600	23.6	1.4	20.5	33.8	-	3.8	26.2	2.0	32.8	50.7	-	4.9	105.3	4.8	71.7	129.0	-	10.2
30-000-000-000	12.8	0.6	73.1	68.4	305.6	8.1	46.0	2.2	264.2	233.4	1505.0	18.5	54.4	1.5	181.5	236.9	963.4	16.8
30-150-300-300	18.1	0.9	34.2	32.6	575.0	5.3	37.2	1.9	76.7	60.9	1637.3	8.0	66.8	1.8	81.7	94.6	1982.2	8.7
30-150-300-600	19.9	0.8	21.5	27.3	601.0	4.5	29.8	1.5	34.3	41.0	1272.1	6.5	83.2	1.9	61.9	110.5	2101.4	10.3
60-000-000-000	10.2	0.5	73.4	85.7	236.5	5.2	21.7	1.3	143.6	118.5	820.3	10.6	59.1	1.5	174.2	199.1	1064.2	14.1
60-000-300-300	17.9	0.6	36.0	30.1	378.8	5.2	40.8	1.4	77.0	65.6	1285.2	10.4	90.2	1.6	89.9	89.2	1510.9	10.6
60-000-300-600	10.9	0.5	19.9	26.0	266.2	3.2	39.3	1.4	57.6	69.9	1321.3	8.7	78.1	1.5	66.7	92.7	1461.8	9.9
90-000-000-000	7.7	0.3	52.3	50.3	205.6	3.4	36.5	1.5	201.1	174.4	944.7	12.2	60.5	1.5	196.4	266.7	1204.3	12.6
90-000-000-300	11.5	0.4	26.8	53.7	180.6	3.6	29.6	1.2	71.9	111.6	796.5	9.8	49.1	1.3	81.1	195.7	981.6	9.5
90-000-000-600	9.0	0.3	18.8	55.8	189.3	3.0	36.5	1.4	57.4	171.5	903.9	12.7	57.9	1.7	74.0	297.1	1341.7	13.5

* - Mg ha^{-1} of manure - N (kg ha^{-1}) - P_2O_5 (kg ha^{-1}) - K_2O (kg ha^{-1}); (-) - Recovery rates without values indicate no application of the nutrient

considering the longevity of cultivation and the achievement of high DMY targets. These measures contribute to avoiding the impoverishment of soil and maintaining their production capacity, which is more worrisome in soils of low fertility and low buffer power for these nutrients. Additionally, there is no contribution of biogeochemical nutrient cycling because cactus pear does not restore nutrients via crop remains after harvest; consequently, soil depletion becomes inevitable if the required amounts of nutrients are not added.

In general, the highest recovery rates in each cycle are associated with the lowest doses of the nutrients applied, and the lowest recovery rates, with the highest amounts added to the soil, whether by mineral, organomineral or organic sources (Table 4). For example, the higher K recovery rates in the three production cycles are associated with organic fertilization with 30, 60 and 90 Mg ha^{-1} year^{-1} of manure, precisely the fertilizations that add the lowest doses of K compared to organomineral and mineral fertilizations, while the lowest recovery rates of N and Mg are also associated with these fertilizations that promote the greatest supply.

The lowest P recovery rates in the three production cycles are associated with the greater amounts of this nutrient, either by organic fertilization with 60 and 90 Mg ha^{-1} year^{-1} of manure or organomineral fertilization with 60 Mg ha^{-1} year^{-1} of manure plus P and K or 90 Mg ha^{-1} year^{-1} of manure plus K. For Ca, the lowest recovery rates were also recorded under fertilization with greater supply of this nutrient, that is, mineral or organomineral fertilizations that used single superphosphate as source of P.

The results are consistent and contribute to the nutritional management of 'Gigante' cactus pear under cultivation conditions in the semi-arid region of Bahia, as they show that the fertilizations performed in most cactus pear plantations do not meet the requirement of the crop during the cultivation cycles.

Conclusions

1. Nutrient exports are higher under fertilizations with greater supply of nutrients, regardless of the source.

2. The order of export is K > Ca > N > Mg > S > P for mineral fertilization, organic fertilization with 30 Mg ha^{-1} year^{-1} of manure and organomineral fertilization with 30 and 60 Mg ha^{-1} year^{-1} of manure plus N-P-K and P-K. For organic fertilizations with 60 and 90 Mg ha^{-1} year^{-1} of manure and organomineral fertilization with 90 Mg ha^{-1} year^{-1} plus K, the order is K > Ca > N > Mg > P > S.

3. The balance of nutrients after three production cycles is positive for N, P and S, negative for Ca and Mg under all fertilizations, and positive for K under mineral fertilization with 600 kg ha^{-1} year^{-1} of K_2O and organomineral fertilization with 30, 60 and 90 Mg ha^{-1} year^{-1} of manure plus 600 kg ha^{-1} of K_2O.

4. The highest recovery rates of K and the lowest recovery rates of N occur under organic fertilization, which add the lowest and highest amounts of K and N to the soil compared to mineral and organomineral fertilizations.

Literature Cited

Brasil. Ministério da Agricultura, Pecuária e Abastecimento. Manual de métodos analíticos oficiais para fertilizantes minerais, orgânicos, organominerais e corretivos. Brasília: MAPA, 2014. 220p.

Cavalcante, L. A. D.; Santos, G. R. de A.; Silva, L. M. da; Fagundes, J. L.; Silva, M. A. da. Respostas de genótipos de palma forrageira a diferentes densidades de cultivo. Pesquisa Agropecuária Tropical, v.44, p.424-433, 2014. https://doi.org/10.1590/S1983-40632014000400010

Donato, P. E. R.; Donato, S. L. R.; Silva, J. A.; Londe, L.N.C.; Rodrigues, M.G.V. Implantação da lavoura de palma forrageira. Informe Agropecuário, v.38, p.21-33, 2017a.

Donato, P. E. R.; Donato, S. L. R.; Silva, J. A.; Pires, A. J. V; Raul, C. C.; Rosa, R. C. C.; Aquino, A. A. Nutrition and yield of 'Giant' cactus pear cultivated with different spacings and organic fertilizer. Revista Brasileira de Engenharia Agrícola e Ambiental, v.20, p.1083-1088, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n12p1083-1088

Donato, P. E. R.; Donato, S. L. R.; Silva, J. S.; Pires, A. J. V.; Silva Junior, A. A. Extraction/exportation of macronutrients by cladodes of 'Giant' cactus pear under different spacings and organic fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental. v.21, p.238-243, 2017b. https://doi.org/10.1590/1807-1929/agriambi.v21n4p238-243

Donato, P. E R.; Pires, A. J.; Donato, S. L.; Bonomo, P.; Silva, J. A.; Aquino, A. A. Morfometria e rendimento da palma forrageira 'Gigante' sob diferentes espaçamentos e doses de adubação orgânica. Revista Brasileira de Ciências Agrárias, v.9, p.151-158, 2014. https://doi.org/10.5039/agraria.v9i1a3252

Donato, S. L. R.; Donato, P. E. R.; Silva, J. A.; Rodrigues, M. G. V. Diagnóstico nutricional e recomendação de adubação para a palma forrageira 'Gigante'. Informe Agropecuário, v.38, p.46-58, 2017c.

Dubeux Júnior, J. C. B.; Araújo Filho, J. T.; Santos, M. V. F. dos; Lira, M. de A.; Santos, D. C. dos; Pessoa, R. A. S. Adubação mineral no crescimento e composição mineral da palma forrageira Clone IPA-20. Revista Brasileira de Ciências Agrárias, v.5, p.129-135, 2010. https://doi.org/10.5039/agraria.v5i1a591

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Manual de métodos de análise de solo. 3. ed. rev. ampl. Brasília: Embrapa Informação Tecnológica, 2017. 573p.

Lemos, M. de; Ferreira Neto, M.; Medeiros, J. F. de; Dias, N. da S.; Silva, E. F. de F. e; Lira, R. B. de. Nutritional evaluation of forage cactus fertigated with domestic sewage effluent. Revista Caatinga, v.31, p.476-486, 2018. https://doi.org/10.1590/1983-21252018v31n224rc

Lopes, M. N.; Cândido, M. J. D.; Silveira, W. M.; Maranhão, T. D.; Soares, I.; Pompeu, R. C. F. F.; Silva, R. G. da; Carneiro, M. S. de S. Accumulation and export of nutrients in cactus pear cladodes (*Opuntia ficus-indica*) under different managements in the Brazilian Semiarid. Revista Brasileira de Zootecnia, v.47, p.1-17, 2018. https://doi.org/10.1590/rbz4720170077

Malavolta, E.; Vitti, G. C.; Oliveira, S. A. Avaliação do estado nutricional das plantas. Princípios e aplicações. 2.ed. Piracicaba: Potafos, 1997. 319p.

Maluf, H. J. G. M.; Soares, E. M. B.; Silva, I. R. da; Neves, J. C. L.; Silva, M. F. de O. Disponibilidade e recuperação de nutrientes de resíduos culturais em solo com diferentes texturas. Revista Brasileira de Ciência do Solo, v.39, p.1690-1702, 2015. https://doi.org/10.1590/01000683rbcs20140658

Novais, R. F.; Mello, J. W. V. Relação solo-planta. In: Novais, R. F.; Alvarez V., V. H.; Barros, N. F.; Fontes, L. E. F.; Cantarutti, R. B.; Neves, J. C. L. (eds.). Fertilidade do solo. 1.ed. Viçosa: Sociedade Brasileira de Ciência do Solo, 2007. Cap.4. p.133-204.

Novais, R. F.; Smyth, T. J.; Nunes, F. N. P. Fósforo. In: Novais, R. F.; Alvarez V., V. H.; Barros, N. F.; Fontes, L. E. F.; Cantarutti, R. B.; Neves, J. C. L. (eds.). Fertilidade do solo. Viçosa: Sociedade Brasileira de Ciência do Solo, 2007. Cap.8. p.472-550.

Silva, D. J.; Queiroz, A. C. Análise de alimentos: Métodos químicos e biológicos. 3.ed. Viçosa: UFV, 2009. 235p.

Silva, J. A. da; Bonomo, P.; Donato, S. L. R.; Pires, A. J. V.; Rosa, R. C. C.; Donato, P. E. R. Composição mineral de palma forrageira sob diferentes espaçamentos e adubações química. Revista Brasileira de Ciências Agrárias, v.7, p.866-875, 2012. https://doi.org/10.5039/agraria.v7isa2134

Silva, J. A. da; Donato, S. L. R.; Donato, P. E. R.; Souza, E. dos S. S.; Padilha Júnior, M. C.; Silva Junior, A. A. e. Extraction/export of nutrients in *Opuntia ficus-indica* under different spacings and chemical fertilizers. Revista Brasileira de Engenharia Agrícola e Ambiental, v.20, p.236-242, 2016a. https://doi.org/10.1590/1807-1929/agriambi.v20n3p236-242

Silva, L. M. da; Fagundes, J. L.; Viegas, P. A. A.; Muniz, E. N.; Rangel, J. H. de A.; Backes, A. Produtividade da palma forrageira cultivada em diferentes densidades de plantio. Ciência Rural, v.44, p.2064-2071, 2014. https://doi.org/10.1590/0103-8478cr20131305

Silva, N. G. de M.; Santos, M. V. F. dos; Dubeux Júnior, J. C. B.; Cunha, M. V. da; Lira, M. de A.; Ferraz, I. Effects of planting density and organic fertilization doses on productive efficiency of cactus pear. Revista Caatinga, v.29, p.976-983, 2016b. https://doi.org/10.1590/1983-21252016v29n423rc