

DOI: <http://dx.doi.org/10.1590/1807-1929/agriambi.v24n3p154-161>

Nutrient concentration and nutritional efficiency in ‘Gigante’ cactus pear submitted to different spacings and fertilizations

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ABSTRACT: The objective of this study was to evaluate nutrient concentration and nutritional efficiency in ‘Gigante’ cactus pear under different chemical, organic and organomineral fertilizations, planting configurations and spacings, during three production cycles. Seventy two treatments, involving two types of configuration in the plots, three spacings in the subplots and 12 types of fertilization in the sub-subplots were arranged in a split-split-plot scheme, in a randomized block design, with three repetitions. At the time of harvest of each production cycle, 40 cladode tissue samples were collected per treatment to determine dry matter mass and nutrient concentration, which were used to calculate the coefficients of biological utilization of nutrients. Organic fertilization reduces Mn concentrations in cladodes to levels below the sufficiency range. The nutritional efficiency of N, S, P, Mn and Zn is higher with organic and organomineral fertilizations and are associated with higher dry matter yields, whereas K nutritional efficiency is higher with mineral fertilization. The absence of fertilization or application of 30 Mg ha⁻¹ year⁻¹ of bovine manure is insufficient to ensure nutritional status and dry matter yield above 15 Mg ha⁻¹ in ‘Gigante’ cactus pear.

Key words: *Opuntia* sp., biological utilization coefficient, yield

Teores de nutrientes e eficiência nutricional em palma forrageira ‘Gigante’ sob diferentes adubações e espaçamentos

RESUMO: Objetivou-se com o presente trabalho avaliar durante três ciclos de produção, os teores de nutrientes e a eficiência nutricional em Palma forrageira ‘Gigante’ submetida a diferentes adubações química, orgânica e organomineral, configurações de plantio e espaçamentos. Setenta e dois tratamentos, envolvendo dois tipos de arranjos nas parcelas, três espaçamentos nas subparcelas e 12 tipos de adubação nas sub-subparcelas foram dispostos em esquema de parcelas sub-subdivididas, em delineamento experimental em blocos casualizados, com três repetições. Na época da colheita de cada ciclo produtivo, coletaram-se 40 amostras de tecidos dos cladódios por tratamento para determinação da massa de matéria seca e dos teores de nutrientes e a partir destes calcularam-se os coeficientes de utilização biológica dos nutrientes. Verificou-se que a adubação orgânica diminui os teores de Mn nos cladódios abaixo da faixa de suficiência. A eficiência nutricional de N, P, S, Mn e Zn é maior com adubação orgânica e organomineral e estão associadas às maiores produtividades de matéria seca, enquanto de K é maior com adubação mineral. A ausência de adubação ou aplicação de 30 Mg ha⁻¹ ano⁻¹ de esterco bovino é insuficiente para assegurar o estado nutricional e produtividade de matéria seca acima de 15 Mg ha⁻¹ em palma forrageira ‘Gigante’.

Palavras-chave: *Opuntia* sp., coeficiente de utilização biológica de nutrientes, produtividade

INTRODUCTION

The use of different planting densities (Silva et al., 2014), arrangement or distribution of cactus pear plants in the area (Silva et al., 2012) may alter absorption of nutrients and, consequently, the concentrations of the elements in the cladodes. Likewise, different planting spacings (Cavalcante et al., 2014), use of doses of organic fertilization (Donato et al., 2016), or mineral fertilization (Silva et al., 2012) may affect the nutrient concentrations in the cladodes and the yield of cactus pear.

Chemical analysis of the leaf tissue is important to evaluate the nutritional status of the plants, complementing soil chemical analysis and visual diagnosis, and reflects the nutrient dynamics in the soil-plant system (Donato et al., 2010). However, it requires the definition of standards and critical levels of nutrients for correct interpretation, such as sufficiency ranges (Donato et al., 2017). Interpretative patterns for the nutrient concentrations in *Opuntia ficus-indica* cladodes were defined by Blanco-Macías et al. (2010) using the Boundary-Line approach for the edaphoclimatic conditions of Mexico and by Alves (2017) through the methods of Mathematical Chance (ChM), sufficiency range and critical level (NCRIz). On the other hand, Donato et al. (2017) established the standards for the chemical attributes of the soil cultivated with 'Gigante' cactus pear by the sufficiency range and NCRIz methods.

Some factors, and especially different types of fertilization such as organic, mineral or organomineral, can influence the nutrient utilization efficiency, a subject with little information on 'Gigante' cactus pear and with difficult establishment of relationships that explain its values in different situations. This assumes greater importance when long-term contribution is considered, due to alterations in the physical, chemical and biological characteristics of the soil, in a perennial crop such as cactus pear.

Thus, the present study aimed to evaluate during three production cycles the concentrations of nutrients and nutritional efficiency in 'Gigante' cactus pear subjected to mineral, organic and organomineral fertilization, planting configurations and spacings.

MATERIAL AND METHODS

The experiment was conducted for three production cycles at the Instituto Federal de Educação, Ciência e Tecnologia da Bahia, Campus of Guanambi, BA, Brazil, in an Oxisol, with weak A horizon, medium texture and on a flat to gently undulating relief. The coordinates of the area are 14° 13' 30" S, 42° 46' 53" W and altitude of 525 m, and its climate is Aw semiarid, according to Köppen's classification, with average annual precipitation of 680.0 mm and temperature of 25.9 °C.

In the first production cycle, lasting 650 days from planting to harvesting, conducted between October 2011 and July 2013, the precipitation was 912.27 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, the precipitation was

853.96 mm. In the third cycle, lasting 330 days, between August 2014 and July 2015, the precipitation was 879.60 mm. The data were recorded in an automatic weather station installed in the experimental area.

The treatments were arranged in split plots, in a randomized block design, with three repetitions, and consisted of two planting configurations (triple and quadruple rows) in the plots; three spacings: S_1 (3.00 x 1.00 x 0.25 m); S_2 (3.00 x 1.00 x 0.16 m); and S_3 (3.00 x 1.00 x 0.125 m), in the subplots, with 24,000, 37,500 and 48,000 plants ha⁻¹ for the triple rows and 26,666, 41,666 and 53,333 plants ha⁻¹ for the quadruple rows, respectively; and 12 types of manuring (Mg ha⁻¹)/mineral fertilization/- N-P₂O₅-K₂O (kg ha⁻¹): 1) 0-000-000-000; 2) 0-300-300-300; 3) 0-300-300-600; 4) 30-000-000-000; 5) 30-150-300-300; 6) 30-150-300-600; 7) 60-000-000-000; 8) 60-000-300-300; 9) 60-000-300-600; 10) 90-000-000-000; 11) 90-000-000-300; and 12) 90-000-000-600, in sub-subplots.

Prior to planting, soil samples were collected for chemical and textural characterization: sandy clay loam texture; pH = 5.57; Organic matter = 1.13 dag kg⁻¹; P = 23.57 and K = 181.67 mg dm⁻³; Na, Ca, Mg and H+Al = 0.10, 1.93, 0.87 and 1.63 cmol_c dm⁻³, respectively; B, Zn, Fe and Mn = 0.40, 0.40, 2.03, 35.93 and 50.2 mg dm⁻³, respectively; base saturation, effective CEC and CEC at pH 7.0 = 3.40, 3.40 and 4.97 cmol_c dm⁻³, respectively; V = 67.67%; Prem = 39.10 mg L⁻¹ and EC = 0.93 dS m⁻¹.

After the preparation of the area, the furrows were opened with furrower of three and four rows regulated to 1.00 m between furrows and average depth of 0.30 m. Then, the seedlings for planting were collected and left at rest in the shade for ten days, for curing. Planting was performed with one cladode per hole, in the vertical position, with the cut part facing the soil, buried to 50% of its height.

Invasive plants were controlled with a hoe and herbicide, glyphosate at a dose of 200 mL 20L⁻¹ of water, with two applications in each rainy season, according to Silva et al. (2012; 2013) and Donato et al. (2014a,b).

The fertilizations used at planting followed the treatments with supply of 130-270-75 of N-P₂O₅-K₂O applied in the furrow. Subsequently, in the rainy seasons of the respective cycles, topdressing fertilization was performed with the remainder of the doses applied broadcast at 20 cm from the plants.

Bovine manure doses of 30, 60 and 90 Mg ha⁻¹ respectively added to the soil 130-270-75, 260-540-150 and 390-810-225 kg ha⁻¹ of N-P₂O₅-K₂O (Donato et al., 2017). The manure had OM content of 63.73 g kg⁻¹, ash content of 36.27 dag kg⁻¹, total carbon content of 29.98 dag kg⁻¹ and pH 7.42 (Brasil, 2014), moisture on dry basis at 65 °C of 16.72%, contents of macronutrients: 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); micronutrients (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 of 0.38 g cm⁻³ (Brasil, 2014).

The sources used as mineral fertilizer were: ammonium sulfate, (NH₄)₂SO₄ (20% N; 24% S), single superphosphate, Ca (H₂PO₄)₂ · 2H₂O (18% P₂O₅; 12% S; 18% Ca) and potassium chloride, KCl (58% K₂O; 45% Cl). Nitrogen and potassium were split into two applications, at the beginning and middle

of the rainy season of each cycle. P was applied at the time of planting. In all treatments, 1.5 kg ha⁻¹ of Zn and 0.5 kg ha⁻¹ of B were also applied in the three production cycles in the soil, using the sources zinc sulfate, ZnSO₄ (36% Zn) and boric acid, H₃BO₃ (17.5% B).

In the harvesting period, 40 samples of cladode tissues with approximately 25 g each were collected per treatment to determine the nutrient concentrations. The samplings considered the repetitions of each treatment and were performed in the three consecutive annual cuts (harvest). All orders of cladodes harvested (primary to quaternary) were sampled using a hole saw with 5.0 cm diameter and 4.0 cm depth, adapted to a battery drill, which was turned on above the cladode to remove a circular and uniform slice. The samples were sliced, mixed, weighed until reaching 1.0 kg of fresh weight and dried in a ventilation oven at 60 ± 0.2 °C for 120 h (Silva et al., 2012; Donato et al., 2016).

The concentrations of macronutrients [N, P, K, Ca, Mg and S (g kg⁻¹)] and micronutrients [B, Cu, Fe, Mn and Zn (mg kg⁻¹)] were determined. The analytical determinations followed Malavolta et al. (1989): N, sulfuric acid digestion with the Kjeldahl method; P, K, S, Ca, Mg, Cu, Fe, Mn, Zn and Na, nitric-perchloric digestion and B, dry digestion.

The biological utilization coefficients of all nutrients (BUC_{Nui}) were determined based on the dry matter weight and concentrations of nutrients in the cladodes of the cactus pear, according to Eqs. 1 and 2, adopted by Deus et al. (2015).

$$BUC_{Nui} = \frac{DMY}{A_{(i)}} \quad (1)$$

where:

BUC_{Nui} - biological utilization coefficient of the nutrient i, kg kg⁻¹;

DMY - dry matter yield, kg ha⁻¹; and,

A_(i) - accumulation of the nutrient i, kg ha⁻¹, given by Eq. 2:

$$A_{(i)} = CN_{(i)} \times DMY \quad (2)$$

where:

CN_(i) - content of the nutrient i, kg kg⁻¹.

The data of the evaluated characteristics were subjected to analysis of variance. Significant interactions were further analyzed and, subsequently, the means relative to fertilization were grouped by the Scott-Knott test ($p \leq 0.05$) and the means relative to configurations and spacings were compared by F and Tukey tests ($p < 0.05$), respectively.

RESULTS AND DISCUSSION

For the N, S and Mn concentrations evaluated in the cladodes of 'Gigante' cactus pear in the first cycle, there was interaction ($p \leq 0.05$) between fertilization and planting configurations, whereas for S concentrations in the second cycle there was interaction ($p \leq 0.05$) between fertilizations and spacings. The concentrations of P, K, Ca, B, Cu, Fe and Zn in the first cycle and of N, P, K, Ca, Fe, Mg and Mn in the second and third cycles were influenced by the fertilization ($p < 0.05$), regardless of the planting configurations and spacings.

In the first production cycle, for N concentrations in the cladodes of 'Gigante' cactus pear, two groups were formed by the Scott-Knott criterion ($p \leq 0.05$) between fertilizations, for both configurations. The highest N concentrations occurred under the mineral fertilizations 0-300-300-300 in the triple row and 0-300-300-300, 0-300-300-600 in the quadruple row and under organomineral fertilizations 30-150-300-300 and 30-150-300-600 of manure (Mg ha⁻¹) - N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹) in the quadruple row (Table 1). In these fertilizations, the concentrations ranged from 14.2 to 18.4 g kg⁻¹, within the sufficiency range (13.0-18.9 g kg⁻¹) proposed by Donato et al. (2017), and close to the 14.7 g kg⁻¹ found by Silva et al. (2012), with application of 200-150-100 kg ha⁻¹ of N-P₂O₅-

Table 1. Concentrations of macronutrients (N and S) and micronutrient (Mn) in cladodes of 'Gigante' cactus pear cultivated at different planting configurations and fertilizations

Cycle I - 2011/2013	Concentrations of nutrients					
	Macronutrients				Micronutrient	
	N (g kg ⁻¹)		S (g kg ⁻¹)		Mn (mg kg ⁻¹)	
	Planting configurations					
	Triple row	Quadruple row	Triple row	Quadruple row	Triple row	Quadruple row
0-000-000-000*	12.2 B a	12.7 B a	0.9 B a	0.9 C a	218.9 C a	231.6 C a
0-300-300-300	18.4 A a	16.4 A a	3.1 A a	3.9 A a	706.1 A b	889.4 A a
0-300-300-600	14.1 B a	16.3 A a	2.6 A a	3.4 A a	730.2 A b	978.2 A a
30-000-000000	11.9 B a	12.0 B a	1.3 B a	1.5 C a	239.4 C a	229.7 C a
30-150-300-300	13.2 B a	14.2 A a	3.3 A a	3.7 A a	421.0 B a	548.4 B a
30-150-300-600	13.8 B a	15.3 A a	2.9 A a	3.2 A a	484.6 B b	668.1 B a
60-000-000-000	12.1 B a	11.1 B a	1.5 B a	1.3 C a	204.6 C a	211.5 C a
60-000-300-300	14.2 B a	10.9 B a	2.6 A a	2.4 B a	234.9 C a	305.1 C a
60-000-300-600	11.9 B a	10.9 B a	2.2 B a	2.2 B a	275.2 C a	305.1 C a
90-000-000-000	13.1 B a	11.8 B a	1.4 B a	1.4 C a	182.3 C a	230.6 C a
90-000-000-300	13.6 B a	13.5 B a	1.4 B a	1.4 C a	184.8 C a	270.0 C a
90-000-000-600	12.2 B a	12.5 B a	1.3 B a	1.1 C a	212.2 C a	284.8 C a
Mean	13.3	14.9	2.0	2.2	341.1	429.3
CV (%)	16.27		19.50		28.11	
p-value	0.015		< 0.001		0.010	

* (Mg ha⁻¹) of manure - N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹); Means followed by the same letters, uppercase in the columns, for fertilization, belong to the same group by the Scott-Knott test ($p \leq 0.05$), and lowercase in the rows, for planting configurations, do not differ by F test at $p \leq 0.05$

K₂O. At the dose 0, in organic and organomineral fertilizations without addition of N the concentrations varied from 10.9 to 14.1 g kg⁻¹, interpreted as marginal or at the lower limit of the sufficient class (Donato et al., 2017), but within the sufficiency range (8.0 to 20.0 g kg⁻¹) indicated by Blanco-Macías et al. (2010), and were closer to those found by Donato et al. (2016), 11.8 to 14.3 g kg⁻¹, with organic fertilization. This is justifiable because the fertilization with N from organic source has low rates of mineralization and release of mineral N compared to the mineral source, although the contribution of N is basically the same at the highest doses, 390 kg ha⁻¹ of N for 90 Mg ha⁻¹ of manure, against 300 kg ha⁻¹ of mineral N.

For the S concentration between fertilizations, two and three groups were formed by the Scott-Knott test ($p \leq 0.05$) in the triple- and quadruple-row configurations, respectively. The highest and intermediate values observed in the mineral and organomineral fertilizations, 2.6 to 3.9 g kg⁻¹ of S, are above the sufficiency range (1.1-1.9 g kg⁻¹) conforme Donato et al. (2017) and corroborate those of Silva et al. (2012). The use of ammonium sulfate and single superphosphate justifies these results. On the other hand, lower values were found in organic fertilization, 1.1 to 1.5 g kg⁻¹, agreeing with Donato et al. (2016) and within the sufficiency range, whereas in the absence of fertilization the values were below the range. Between planting configurations, differences were observed only in mineral fertilizations for S and Mn.

The fertilizations allowed the formation of three groups by the Scott-Knott test ($p \leq 0.05$) for Mn concentration under both planting configurations. The highest and intermediate values, observed under mineral and organomineral fertilizations with N, respectively, range from 421.0 to 978.2 mg kg⁻¹ of Mn, agree with those of Silva et al. (2012) and are above the sufficiency range, 260.0-507.7 mg kg⁻¹ (Donato et al., 2017) for mineral fertilizations and within the range for organomineral fertilizations. The lowest Mn concentrations were observed under organic fertilization, organomineral fertilization without N and in the absence of fertilizer. These results agree with those of Nascimento et al. (2002), who claim that soil pH is the factor that most influences Mn availability for plants. Silva et al. (2012) found Mn concentration of 2,006.0 mg kg⁻¹, above the sufficiency range, caused by the use of ammonium sulfate as a source of N, which reduces the pH and thus increases the solubility and absorption of Mn²⁺, confirmed by the pH reduction from 5.3 before planting to 4.3 at harvest. On the other hand, Donato et al. (2016) justified the lowest Mn concentrations in the cladodes with the increment in pH from 5.4 before planting to 6.0, 6.1 and 6.2 with the additions of 30, 60 and 90 Mg ha⁻¹ year⁻¹ of manure, respectively, which corroborates with Abreu et al. (2007), who report that Mn availability in the soil is regulated by pH and organic matter concentration, among others.

In the second cycle for S concentrations, two groups were formed by the Scott-Knott test at the three spacings (Table 2). The highest values, 1.0 and 3.2 g kg⁻¹, were recorded under organomineral and mineral fertilization with N-P-K or with P-K, being above the sufficiency range (Donato et al., 2017) and agreeing with Silva et al. (2012). The use of ammonium sulfate and single superphosphate justifies these results. The lowest values were found under organic fertilization and in the

Table 2. Concentrations of sulfur (S) in cladodes of 'Gigante' cactus pear cultivated in the second production cycle under different fertilizations and spacings

Cycle II – 2013-2014	S (g kg ⁻¹)		
	Spacings		
Fertilizations	S ₁ - 3.0 × 1.0 × 0.25 m	S ₂ - 3.0 × 1.0 × 0.16 m	S ₃ - 3.0 × 1.0 × 0.125 m
0-000-000-000*	1.3 B a	1.0 B a	0.8 B a
0-300-300-300	2.6 A a	2.9 A a	3.2 A a
0-300-300-600	2.5 A a	2.8 A a	3.0 A a
30-000-000-000	1.5 B a	1.6 B a	1.4 B a
30-150-300-300	2.4 A a	2.7 A a	3.1 A a
30-150-300-600	2.3 A a	2.8 A a	2.8 A a
60-000-000-000	1.6 B a	1.5 B a	1.6 B a
60-000-300-300	2.0 A a	2.7 A a	2.5 A a
60-000-300-600	2.0 A a	2.4 A a	2.3 A a
90-000-000-000	1.4 B a	1.7 B a	1.5 B a
90-000-000-300	1.5 B a	1.4 B a	1.4 B a
90-000-000-600	1.5 B a	1.5 B a	1.6 B a
Mean	1.8	2.1	2.0
CV (%)	17.92		
p-value	< 0.001		

*(Mg ha⁻¹) of manure - N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹); Means followed by the same letters, uppercase in the columns, for fertilization, belong to the same group by the Scott-Knott test ($p \leq 0.05$), and lowercase in the rows, for planting configurations, do not differ by Tukey test at $p \leq 0.05$

absence of fertilizer, being below the sufficiency range in the latter for the spacings S₂ (3.0 x 1.0 x 0.16 m) and S₃ (3.0 x 1.0 x 0.125 m). There were no differences between the spacings for any of the fertilizations.

In the second and third production cycles for the N concentrations, there was the formation of two and three groups by the Scott-Knott test, respectively (Table 3). The highest values, 14.3 and 16.0 g kg⁻¹, for the second cycle, and 20.3 and 20.9 g kg⁻¹ for the third cycle, were recorded under mineral fertilizations with N-P-K, being within and above the sufficiency range (Donato et al., 2017), respectively, and agree with Silva et al. (2012).

In general, the lowest values occurred under organic and organomineral fertilizations and absence of fertilizer and agree with Donato et al. (2016). This is justifiable because fertilization with N from organic source has low rate of mineralization and release of mineral N compared to the mineral source, for the same contribution of N.

The P concentration in the cladodes produced in the three production cycles formed four groups by the Scott-Knott test. The highest values, 1.9 to 2.9 g kg⁻¹, above the sufficiency range (1.0 to 1.7 g kg⁻¹) suggested by Donato et al. (2017), were recorded under organomineral fertilization (30-150-300-300 of manure-N-P-K) in the first cycle, mineral fertilization (0-300-300-300/600 of N-P-K) and organomineral fertilization (30-150-300-300/600 of manure-N-P-K) in the second and third cycles, with difference when there was no addition of mineral N in the organomineral fertilization (60-000-300-300/600 of manure-N-P-K). These P values above the sufficiency range are justified by the initial P concentration in the soil, 23.57 mg dm⁻³, within the sufficiency range, 22 to 48 mg dm⁻³ (Donato et al., 2017) for medium-textured soil and mainly by the fertilizations whose lowest supplies were 300 kg ha⁻¹ of P₂O₅ for mineral fertilization and 270 kg ha⁻¹ of P₂O₅ for organic fertilization with 30 Mg ha⁻¹ of manure.

Table 3. Concentration of macronutrients and micronutrients in cladodes of 'Gigante' cactus pear subjected to mineral, organomineral and organic fertilizations in three production cycles

Cycle I - 2011/2013		Macronutrients			Micronutrients		
Fertilizations	P	K ⁺	Ca ²⁺	B ³⁺	Cu ²⁺	Fe ²⁺	Zn ²⁺
		(g kg ⁻¹)			(mg kg ⁻¹)		
0-000-000-000*	0.8 D	30.7 E	24.2 B	29.4 B	1.92 C	167.8B	37.0 C
0-300-300-300	1.7 B	31.1 E	25.7 B	57.4 A	2.85 A	218.9 A	58.4 B
0-300-300-600	1.6 B	34.9 D	25.8 B	58.4 A	2.67 A	207.1 A	54.3 B
30-000-000-000	1.2 C	33.6 D	22.7 B	65.0 A	2.51 B	174.3 C	69.8 A
30-150-300-300	2.0 A	37.6 C	28.3 A	64.5 A	2.88 A	191.7 B	62.3 B
30-150-300-600	1.8 B	40.7 B	26.4 A	64.4 A	2.93 A	238.4 A	59.5 B
60-000-000-000	1.3 C	38.0 C	25.5 B	55.1 A	2.43 B	181.9 B	72.2 A
60-000-300-300	1.8 B	40.7 B	27.5 A	54.6 A	2.51 B	241.0 A	65.5 A
60-000-300-600	1.7 B	42.6 A	28.1 A	52.6 A	2.37 B	205.9 A	61.6 B
90-000-000-000	1.2 C	40.4 B	25.0 B	54.1 A	2.48 B	189.9 B	63.4 B
90-000-000-300	1.3 C	41.2 B	23.8 B	58.7 A	2.31 B	188.6 B	68.8 A
90-000-000-600	1.1 C	44.0 A	24.5 B	55.7 A	2.15 C	212.2 A	69.6 A
Mean	1.40	37.90	25.60	55.80	2.50	201.50	61.50
CV (%)	16.95	11.28	15.29	35.91	21.49	34.67	26.01
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.03	<0.001

Cycle II - 2013-2014		Macronutrients			Micronutrients		
Fertilizations	N	P	K ⁺	Ca ²⁺	Mg ²⁺	Fe ²⁺	Mn ²⁺
			(g kg ⁻¹)			(mg kg ⁻¹)	
0-000-000-000*	12.5 B	1.0 D	27.7 D	31.7 A	9.8 B	102.9 C	489.0 B
0-300-300-300	16.0 A	2.9 A	32.3 C	31.4 A	9.7 B	220.9 A	1253.7 A
0-300-300-600	14.3 A	2.8 A	37.0 B	32.8 A	9.3 B	185.9 A	1364.3 A
30-000-000-000	12.8 B	1.5 C	37.0 B	28.2 B	12.3 A	160.9 B	268.3 C
30-150-300-300	13.1 B	2.8 A	26.5 B	29.6 B	10.3 B	206.1 A	541.5 B
30-150-300-600	13.3 B	2.6 A	36.4 B	28.6 B	10.3 B	187.7 A	591.7 B
60-000-000-000	12.0 B	1.6 C	37.1 B	27.2 C	12.4 A	155.2 B	186.9 C
60-000-300-300	12.0 B	2.4 B	37.2 B	29.4 B	12.0 A	207.8 A	216.8 C
60-000-300-600	11.4 B	2.2 B	42.2 A	29.6 B	11.9 A	205.1 A	264.5 C
90-000-000-000	12.9 B	1.5 C	41.0 A	25.3 C	11.7 A	246.0 A	149.0 C
90-000-000-300	12.5 B	1.4 C	39.4 A	22.9 D	11.5 A	217.1 A	167.2 C
90-000-000-600	12.4 B	1.5 C	40.7 A	24.2 D	11.0 A	252.1 A	180.1 C
Mean	13.0	2.0	36.2	28.4	11.0	195.5	472.7
CV (%)	15.90	17.92	10.35	14.54	24.18	37.20	40.66
p-value	<0.001	<0.001	<0.001	<0.001	0.04	<0.001	<0.001

Cycle III - 2014-2015		Macronutrients			Micronutrients		
Fertilizations	N	P	K ⁺	Ca ²⁺	Mg ²⁺	Mn ²⁺	Zn ²⁺
			(g kg ⁻¹)			(mg kg ⁻¹)	
0-000-000-000*	14.5 C	1.2 D	31.8 C	33.9 A	13.0 A	589.4 C	60.4 C
0-300-300-300	20.9 A	2.1 A	30.5 C	31.1 A	10.2 B	1984.9 A	73.4 A
0-300-300-600	20.2 A	2.0 A	36.4 B	31.1 A	9.5 B	2558.3 A	71.1 A
30-000-000-000	14.5 C	1.5 C	32.4 C	28.9 B	11.8 A	406.3 D	64.9 B
30-150-300-300	16.7 B	1.8 B	34.3 C	32.8 A	11.2 B	732.7 B	60.3 C
30-150-300-600	17.3 B	1.7 B	37.5 B	32.2 A	10.4 B	950.7 B	58.4 C
60-000-000-000	15.5 C	1.6 C	32.8 C	25.4 B	12.1 A	264.1 D	53.1 D
60-000-300-300	17.2 B	2.0 A	36.5 B	30.3 A	12.6 A	262.6 D	53.8 D
60-000-300-600	15.1 C	1.9 A	40.6 A	29.9 A	11.9 A	270.2 D	54.8 D
90-000-000-000	16.8 B	1.8 B	37.6 B	29.3 B	13.6 A	187.4 D	49.9 D
90-000-000-300	15.6 C	1.7 B	38.9 B	26.5 B	12.8 A	137.0 D	47.9 D
90-000-000-600	14.8 C	1.7 B	42.8 A	28.2 B	13.2A	154.4 D	52.5 D
Mean	16.6	1.7	36.0	29.9	11.8	708.2	58.4
CV (%)	15.00	16.30	12.80	16.52	19.37	64.45	18.52
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*(Mg ha⁻¹) of manure - N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹); Means followed by the same letter in the columns belong to the same group by the Scott - Knott test (p ≤ 0.05)

For the K concentration in the cladodes, there was the formation of five, four and three groups by the Scott-Knott test for the first, second and third cycles, respectively. The highest K concentrations were recorded under organomineral fertilizations 60-000-300-600 and 90-000-000-600 (Mg ha⁻¹) of manure - N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹) for the first and third cycles, and also 90-0000-000-000 and 90-000-000-300 (Mg ha⁻¹) of manure-N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹) in the second cycle, respectively. In these cases, the K concentrations ranged from 39.4 to 44 g kg⁻¹, remaining within the sufficiency

range (31.6-44.1 g kg⁻¹) indicated by Donato et al. (2017). Concentrations below the sufficiency range occurred in the absence of fertilization in the first and second cycles and under the organomineral fertilization 0-300-300-300 (Mg ha⁻¹) of manure-N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹) in the second cycle.

The Ca concentrations in the cladodes were higher in the first cycle under organomineral fertilization with N-P-K and P-K, in the absence of fertilization, under the mineral fertilizations in the second cycle, and in all of these in the third cycle. In these cases, the concentrations of Ca ranged from 26.4 to 33.9 g kg⁻¹, within

the sufficiency range for the majority, 23.2-32.8 g kg⁻¹ (Donato et al., 2017), and agree with Silva et al. (2012). These values are justified by the Ca supplied through single superphosphate and because the pH value of 5.7 is considered ideal. The lowest values occurred under organic fertilization with higher quantities, as found by Donato et al. (2016), but within the sufficiency range. Organic sources such as manure and sewage effluent are usually poor in Ca (Lemos et al., 2018).

The Mg concentrations in the cladodes were higher in the second production cycle under organic and organomineral fertilizations with P-K and at least 30 Mg ha⁻¹ of manure, and in the third cycle, and also in the absence of fertilization. In these cases, the values ranged from 11 to 13.6 g kg⁻¹, within the sufficiency range of 9.5-14.3 g kg⁻¹ (Donato et al., 2017), and agreed with Donato et al. (2016) and Silva et al. (2012). The lowest concentrations of Mg in the cladodes under mineral fertilization with N-P-K and organomineral fertilization with N-P-K are possibly due to the competitive inhibition with the Mg²⁺ of the NH₄⁺ and K⁺ applied. Despite this, in all cases, the concentrations of Mg²⁺ in the cladodes were within the sufficiency range.

The B concentrations in the cladodes in the first production cycle were higher in the fertilized plants, regardless of the formulation or type of fertilizer used, being statistically lower than those found in plants cultivated in the absence of fertilization. The concentrations ranged from 52.6 to 65 mg kg⁻¹, remaining far above the sufficiency range, 22.3-32.7 mg kg⁻¹ (Donato et al., 2017) and much higher than those observed by Silva et al. (2012) with mineral fertilization. In the absence of fertilization, the B concentration in the cladodes (29.4 mg kg⁻¹) was within the sufficiency range. The applications of B in the soil, in all treatments and cycles, justify the absence of concentrations of this micronutrient below the sufficiency range.

The Cu concentration in the cladodes were higher, 2.67 to 2.93 mg kg⁻¹, under the mineral and organomineral fertilizations with N-P-K, in the first production cycle. The lowest Cu concentrations occurred in the plants grown in soil without fertilization and under fertilization with 90-000-000-600 (Mg ha⁻¹ of manure-N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹)). All values were within the sufficiency range, 2.0 to 3.7 mg kg⁻¹ (Donato et al., 2017). Cu is strongly adsorbed by soil organic matter and interacts with organic compounds, forming stable complexes with carboxylic and phenolic groups (Abreu et al., 2007). This justifies the lowest values under the organic fertilizations.

The Fe concentrations in the cladodes ranged from 185.9 to 246 mg kg⁻¹ in plants subjected to mineral and organomineral fertilizations with N-P-K and P-K in the first production cycle and, besides these, under organomineral fertilizations with K and organic fertilization with 90 Mg ha⁻¹ of manure, in the second production cycle. The lowest concentration in the second cycle was observed in the absence of fertilization, but all values were above the sufficiency range, (61.1 to 126.6 mg kg⁻¹) according to Donato et al. (2017). Dubeux Júnior et al. (2010) and Silva et al. (2012) found Fe concentrations in the cladodes much lower than those of the present study.

The Mn²⁺ concentrations in the cladodes in the second and third production cycles were higher in plants that received mineral fertilization. The values ranged from 1253.7 to 2558.3 mg kg⁻¹, far above the sufficiency range (260.0-507.7 mg kg⁻¹) suggested by Donato et al. (2017), and agree with Silva et al. (2012), whereas the lowest values recorded under organic

fertilizations were below the sufficiency range. Silva et al. (2012) argue that soil pH is the factor that most influences Mn availability for plants, and the use of ammonium sulfate, as in the present study, promotes reduction of pH in the environment, which increases the solubility and consequent absorption of Mn²⁺ by plants. This justifies the higher values found under mineral fertilization, mainly with greater supply of N.

The Zn concentrations in the cladodes were higher in the first cycle under organic and organomineral fertilization with P-K and K in the first production cycle and under mineral fertilization in the third production cycle. In these cases, the concentrations ranged from 65.5 to 73.4 mg kg⁻¹, above the ideal range (34.5-57.8 mg kg⁻¹) reported by Donato et al. (2017). The applications of Zn in the soil, in all treatments and cycles, justify the adequate concentrations of this micronutrient.

The lowest dry matter yields (DMY) of 'Gigante' cactus pear were recorded in the absence of fertilization and with 30 Mg ha⁻¹ of manure in most cases (Table 4). The highest values of DMY occurred in treatments under fertilization with greater supply of nutrients, particularly under organic fertilization with 60 Mg ha⁻¹ associated with 300 or 600 kg ha⁻¹ of K₂O, 90 Mg ha⁻¹ of manure with or without supply of K, mineral fertilization with 300-300-600 kg ha⁻¹ of N-P₂O₅-K₂O, or organomineral fertilization with 30 Mg ha⁻¹ of manure and 150-300-600 kg ha⁻¹ of N-P₂O₅-K₂O. The highest increments of DMY, 35.31 and 45.25%, from the first to the second cycle and from the first to the third cycle, respectively, occurred with 90 Mg ha⁻¹ of manure with or without addition of K.

The present study tried to relate the nutritional efficiency expressed by the coefficient of biological utilization of nutrients (BUC_{Nut}) in cactus pear with mineral, organomineral and organic fertilizations and its association with DMY. According to Silva et al. (2009), the BUC_{Nut} can be influenced by edaphoclimatic, biological and management factors, which makes it difficult to establish relationships that effectively explain its values in different situations.

In the first production cycle, the macronutrients with highest variation of BUC in response to the fertilizations were S, P, K and N, with formation of four, three, three and two groups, respectively, by the Scott-Knott test. In the second cycle, K with four, S and P with three, N, Ca and Mg with two groups; and in the third production cycle, S, P, K and N with three, Ca and Mg with two groups. This denotes that S, K, P and N, in this order, were the macronutrients whose nutritional efficiency was more sensitive to the fertilizations.

In general, the highest nutritional efficiency occurred in the absence of fertilization for most nutrients. For N, S and P, the organic or organomineral fertilization with greater supply of these nutrients and with higher DMY allowed the expression of higher nutritional efficiency by the cactus pear, whereas for K, higher nutritional efficiency was shown by plants that received mineral fertilization, without association with DMY.

For the micronutrients, the BUC values with the highest variation as a function of the fertilizations were those of Mn, with the formation of four groups, and Zn, with two groups, by the Scott-Knott test in the three production cycles, followed by B with two groups in the first two cycles and Cu only in the first cycle. From these results, it can be stated that Mn, Zn and B, in this order, were the micronutrients whose nutritional efficiency was more sensitive to the fertilizations.

Table 4. Mean values of dry matter yield (DMY) and biological utilization coefficient (BUC_{Nut}) of nutrients in cladodes of 'Gigante' cactus pear subjected to mineral, organomineral and organic fertilization in three production cycles

Fertilizations	Cycle I - 2011-2013											
	Macronutrients						Micronutrients					
	DMY (Mg ha ⁻¹)	BUC_N	BUC_P	BUC_K	BUC_{Ca}	BUC_{Mg}	BUC_S	BUC_B	BUC_{Cu}	BUC_{Fe}	BUC_{Mn}	BUC_{Zn}
		(kg kg ⁻¹)										
0-000-000-000*	9.3 C	82.6 A	1293.2 A	33.4 A	43.3	123.4	1182.1 A	41635.9 A	879550.8 A	6674.5	4945.5 A	33623.5 A
0-300-300-300	16.2 A	59.8 B	583.0 C	33.0 A	41.6	131.9	291.7 D	20453.8 A	409790.8 B	5125.3	1358.7 D	20040.6 B
0-300-300-600	16.7 A	70.4 B	661.8 C	29.7 B	40.5	149.3	361.7 D	21397.4 B	512379.8 B	5147.5	1444.2 D	21489.7 B
30-000-000-000	12.4 B	86.6 A	884.2 B	30.3 B	46.0	120.5	772.3 B	18311.8 B	508072.5 B	6578.6	4632.5 A	18248.0 B
30-150-300-300	15.8 A	78.3 A	533.0 C	27.5 C	38.8	126.3	296.4 D	17514.7 B	422686.1 B	5751.8	2500.8 C	19233.0 B
30-150-300-600	15.6 A	70.6 B	579.2 C	25.2 C	39.7	124.9	338.6 D	17602.5 B	397480.7 B	4853.0	1883.9 D	19820.2 B
60-000-000-000	14.5 A	90.9 A	783.1 B	27.0 C	41.1	121.7	739.3 B	19620.1 B	496904.5 B	6004.3	5625.2 A	15684.5 B
60-000-300-300	16.6 A	86.4 A	568.9 C	25.3 C	38.4	113.6	420.5 C	19575.3 B	482733.4 B	5154.4	4038.4 B	19073.5 B
60-000-300-600	15.1 A	94.6 A	604.7 C	24.2 C	37.8	123.3	486.1 C	19795.4 B	503766.1 B	5843.9	34655.7 B	18515.3 B
90-000-000-000	14.1 A	82.4 A	835.4 B	25.4 C	42.2	106.8	741.7 B	21470.7 B	501326.2 B	6095.5	5404.8 A	17404.0 B
90-000-000-300	15.2 A	78.3 A	781.4 B	24.8 C	43.4	118.4	762.3 B	18948.0 B	544908.7 B	5671.3	4736.6 A	17475.5 B
90-000-000-600	15.0 A	82.4 A	902.7 A	23.5 C	43.3	120.4	852.8 B	21104.3 B	597549.4 B	5325.5	4517.0 A	16613.0 B
Mean	14.7	80.3	750.9	27.5	41.4	123.4	603.8	21452.5	521429.1	5685.4	3682.8	19743.4
CV (%)	30.02	24.57	25.78	17.52	23.69	27.77	35.96	40.30	70.59	34.03	35.58	39.24
p-value	<0.001	<0.001	<0.001	<0.001	0.351	0.091	<0.001	<0.001	0.021	0.086	<0.001	<0.001
Fertilizations	Cycle II - 2013-2014											
	Macronutrients						Micronutrients					
	DMY (Mg ha ⁻¹)	BUC_N	BUC_P	BUC_K	BUC_{Ca}	BUC_{Mg}	BUC_S	BUC_B	BUC_{Cu}	BUC_{Fe}	BUC_{Mn}	BUC_{Zn}
		(kg kg ⁻¹)										
0-000-000000*	7.9 C	82.3 A	1191.2 A	36.5 A	32.6 B	110.3 A	1001.5 A	41225.2 A	473150.8	12248.6	2406.3 D	26966.7 A
0-300-300-300	13.5 B	64.5 B	528.9 C	31.8 B	33.0 B	120.6 A	350.7 C	28968.6 B	424084.2	12598.5	897.6 E	19132.2 B
0-300-300-600	12.8 B	72.0 B	614.4 B	27.5 C	31.3 B	120.9 A	365.9 C	30836.9 B	369123.9	10483.4	780.2 E	18601.5 B
30-000-000-000	12.4 B	80.8 A	624.3 B	27.7 C	36.1 B	86.0 B	692.3 B	32019.2 B	469335.3	12812.0	4341.0 C	15596.2 B
30-150-300-300	15.5 A	79.0 A	549.1 C	28.3 C	35.0 B	106.3 A	381.2 C	31983.6 B	465522.7	12031.6	2101.8 D	17117.8 B
30-150-300-600	13.7 B	77.2 A	509.1 C	28.0 C	36.3 B	104.5 A	390.0 C	29576.6 B	480782.4	12394.3	1847.7 D	18193.5 B
60-000-000-000	12.9 B	85.3 A	558.9 C	27.4 C	37.6 B	84.3 B	648.9 B	33303.2 B	403100.8	11865.4	5828.1 B	16610.8 B
60-000-300-300	17.1 A	86.6 A	515.8 C	27.2 C	34.6 B	91.0 B	432.8 C	33222.4 B	470289.4	12006.0	5115.4 C	17493.4 B
60-000-300-600	17.5 A	88.9 A	514.3 C	24.1 D	34.4 B	89.0 B	475.9 C	31004.7 B	447341.2	12569.6	4155.5 C	18393.3 B
90-000-000-000	18.7 A	78.5 A	557.0 C	24.8 D	40.8 A	92.3 B	655.0 B	34445.7 B	434018.1	12398.0	7190.5 A	19976.2 B
90-000-000-300	22.0 A	83.1 A	593.5 B	25.6 D	44.9 A	94.2 B	692.3 B	31986.2 B	428899.9	11449.7	6323.2 B	19293.6 B
90-000-000-600	19.4 A	83.0 A	601.9 B	25.0 D	42.6 A	98.3 B	654.3 B	30014.6 B	444902.1	11729.2	5917.5 B	17511.0 B
Mean	15.2	80.1	608.3	27.8	36.6	99.8	560.9	32465.6	442545.9	12048.8	3908.7	18732.2
CV (%)	34.02	17.82	22.98	14.92	17.65	26.62	25.19	26.48	41.91	37.99	33.63	34.09
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.066	0.077	<0.001	<0.001
Fertilizations	Cycle III - 2014-2015											
	Macronutrients						Micronutrients					
	DMY (Mg ha ⁻¹)	BUC_N	BUC_P	BUC_K	BUC_{Ca}	BUC_{Mg}	BUC_S	BUC_B	BUC_{Cu}	BUC_{Fe}	BUC_{Mn}	BUC_{Zn}
		(kg kg ⁻¹)										
0-000-000-000*	8.2 D	71.0 A	839.7 A	32.8 A	31.3 B	78.6 B	774.2 A	46737.0	342693.0	20333.3	1995.7 D	17313.6 B
0-300-300-300	16.6 B	49.4 C	498.4 C	33.6 A	32.8 B	101.3 A	383.0 C	39975.9	310009.1	17686.2	1465.2 D	14959.6 B
0-300-300-600	21.5 A	50.4 C	523.4 C	27.8 B	33.2 B	109.1 A	328.0 C	39492.6	322147.9	15630.8	425.8 D	15389.0 B
30-000-000-000	13.1 C	70.9 A	682.1 B	31.4 A	35.3 B	87.3 B	651.8 A	37370.1	414480.3	21905.8	4212.6 C	16047.3 B
30-150-300-300	18.4 B	61.6 B	541.3 C	29.6 A	31.6 B	93.5 A	377.7 C	43677.8	414478.5	16622.1	1715.1 D	17542.1 B
30-150-300-600	20.4 A	59.0 B	577.8 C	27.0 B	31.9 B	99.6 A	367.9 C	39370.3	380210.4	16477.3	1400.7 D	18004.5 B
60-000-000-000	17.6 B	66.8 A	652.7 B	32.0 A	46.3 A	85.7 B	704.3 A	40000.6	440594.1	20247.9	5959.1 A	20605.2 A
60-000-300-300	20.5 A	59.3 B	505.0 C	27.9 B	34.0 B	82.8 B	486.8 B	42141.6	445317.9	24612.0	5545.9 B	19864.6 A
60-000-300-600	21.3 A	67.0 A	545.9 C	24.9 C	35.6 B	91.1 B	493.1 B	40060.4	383017.1	18845.2	4273.7 C	19003.9 A
90-000-000-000	21.1 A	61.5 B	570.8 C	27.0 B	35.5 B	78.6 B	656.7 A	42113.9	393026.7	21185.5	6602.6 A	20913.3 A
90-000-000-300	19.9 A	66.2 A	616.5 C	26.3 B	40.3 A	86.7 B	745.1 A	35574.3	452848.6	18852.4	7467.3 A	21772.5 A
90-000-000-600	23.3 A	70.0 A	575.5 C	23.4 C	38.0 A	77.3 B	68.5 A	35280.8	410956.6	128469.4	7080.5 A	19650.9 A
Mean	18.5	62.8	594.1	28.6	35.5	89.3	554.3	40316.3	392693.3	20072.3	4012.0	18422.2
CV (%)	27.01	17.85	21.69	16.39	833.0	21.58	26.93	26.10	42.62	93.57	48.78	23.57
p-value	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	0.128	0.166	0.219	<0.001	<0.001

*(Mg ha⁻¹) of manure - N (kg ha⁻¹) - P₂O₅ (kg ha⁻¹) - K₂O (kg ha⁻¹); Means followed by the same letter in the column belong to the same group by the Scott- Knott test (p ≤ 0.05)

Higher values of nutritional efficiency for Mn in the three cycles and for Zn in the third cycle in cactus pear were observed under the organic fertilizations that are associated with the highest DMY, whereas the lowest values were found under mineral fertilizations. The lower availability due to the adsorption of these nutrients and to the elevation of pH by the organic fertilizer (Abreu et al., 2007; Donato et al., 2016) contributed to this, as occurred in the absence of fertilization for Mn in the first cycle and for Zn in the first two cycles.

On the other hand, the higher availability of Mn due to the acidification of the soil caused by ammonium sulfate in the

mineral fertilization (Silva et al., 2012) reduced its nutritional efficiency in 'Gigante' cactus pear.

CONCLUSIONS

1. The nutritional efficiency of N, S, P, Mn and Zn in 'Gigante' cactus pear is higher with organic and organomineral fertilization and are associated with higher dry matter yields, whereas K nutritional efficiency is higher with mineral fertilization.

2. Organic fertilization reduces the Mn concentrations in the cladodes to levels below the sufficiency range.

3. The absence of fertilization or application of 30 Mg ha⁻¹ year⁻¹ of bovine manure is insufficient to ensure the nutritional status and dry matter yield above 15 Mg ha⁻¹ in 'Gigante' cactus pear.

LITERATURE CITED

- Abreu, C. A.; Lopes, A. S.; Santos, G. C. G. dos. Micronutrientes. In: Novais, R. F.; Alvarez V, V. H.; Barros, N. F. de; F. Fontes, R. L.; Cantarutti, R. B.; Neves, J. C. L. Fertilidade do solo. Viçosa: Sociedade Brasileira de Ciência do Solo, 2007. Cap. 11, p.645-736.
- Alves, J. F. T. Estabelecimento de faixas de suficiência para avaliação nutricional da palma forrageira 'Gigante'. Guanambi: Instituto Federal Baiano, 2017. 57p. Dissertação Mestrado
- Blanco-Macías, F.; Magallanes-Quintanar, R.; Valdez-Cepeda, R. D.; Vázquez-Alvarado, R.; Olivares-Sáenz, E.; Gutiérrez-Ornelas, E.; Vidales-Contreras, J. A.; Murillo-Amador, B. Nutritional reference values for *Opuntia ficus-indica* determined by means of the boundary-line approach. Journal of Plant Nutrition Soil Science, v.173, p.927-934, 2010. <https://doi.org/10.1002/jpln.200900147>
- Brasil. Ministério da Agricultura, Pecuária e Abastecimento. Manual de métodos analíticos oficiais para fertilizantes minerais, orgânicos, organominerais e corretivos. Brasília: MAPA/SDA/CGAL, 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>
- Deus, J. A. L. de; Soares, I.; Neves, J. C. L.; Medeiros, J. F. de; Miranda, F. R. de. Fertilizer recommendation system for melon based on nutritional balance. Revista Brasileira de Ciência do Solo, v.39, p.498-511, 2015. <https://doi.org/10.1590/01000683rbcs20140172>
- 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 'Gigante' 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.; Pires, A. J.; Donato, S. L. R.; 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, 2014a. <https://doi.org/10.5039/agraria.v9i1a3252>
- Donato, P. E. R.; Pires, A. J. V.; Donato, S. L. R.; Silva, J. A. da; Aquino, A. A. de. Valor nutritivo da palma forrageira 'Gigante' cultivada sob diferentes espaçamentos e doses de esterco bovino. Revista Caatinga, v.27, p.163-172, 2014b.
- 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, 2017.
- Donato, S. L. R.; Lédo, A. A.; Pereira, M. C. T.; Coelho, E. F.; Cotrim, C. E.; Coelho Filho, M. A. Estado nutricional de bananeiras tipo Prata sob diferentes sistemas de irrigação. Pesquisa Agropecuária Brasileira, v.45, p.980-988, 2010. <http://dx.doi.org/10.1590/S0100-204X2010000900007>
- Dubeux Júnior, J. C. B.; Araújo Filho, J. T.; Santos, M. V. F. dos; Lira, M. 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>
- Lemos, M. de; Ferreira Neto, M.; Medeiros, J. F. de; Dias, N. S. da; Silva, Ê. 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>
- Malavolta, E.; Vitti, G. C.; Oliveira, S. A. Avaliação do estado nutricional das plantas: Princípios e aplicações. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fósforo, 1989. 201p.
- Nascimento, C. W. A.; Fontes, R. L. F.; Neves, J. C. L. Dessorção, extração e fracionamento de manganês em Latossolos. Revista Brasileira de Ciência do Solo, v.26, p.589-597, 2002. <https://doi.org/10.1590/S0100-06832002000300003>
- Silva, A. P. da; Alvarez V., V. H.; Souza, A. P. de; Neves, J. C. L.; Novais, R. F.; Dantas, J. P. Sistema de recomendação de fertilizantes e corretivos para a cultura do abacaxi - Fertcalc-abacaxi. Revista Brasileira de Ciência do Solo, v.33, p.1269-1280, 2009. <https://doi.org/10.1590/S0100-06832009000500020>
- Silva, J. A.; 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.; Bonomo, P.; Donato, S. L. R.; Pires, A. J. V.; Silva, F. F.; Donato, P. E. R. Composição bromatológica de cladódios de palma forrageira sob diferentes espaçamentos e adubações química. Revista Brasileira de Ciências Agrárias, v.8, p.342-350, 2013. <http://dx.doi.org/10.5039/agraria.v8i2a2431>
- Silva, L. M. da; Fagundes, J. L.; Viegas, P. A. A.; Muniz, E. N.; Rangel, J. H. de A.; Backes, A. 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>