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Effect of mixed organic and inorganic fertilizers on growth, leaf macronutrient contents and yield of pitaya (*Hylocereus undatus*) under field conditions

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Abstract

This study aimed to evaluate the effect of organic and inorganic fertilizers on the pitaya's *Hylocereus undatus* performance under field conditions. The experimental design used was Completely Randomized Block Design (CRBD). Five treatments consisting of the four different fertilizer dosages were included in this study, namely T1 (00-120-320-120); T2 (04-080-160-080); T3 (06-060-100-060); T4 (08-000-000-000) and T5 (Control: 00-000-000-000) of bovine manure (kg pit^{-1}), urea (g pit^{-1}), super simple (g pit^{-1}) and potassium chloride (g pit^{-1}), respectively. Parameters such as height, number, length, width, area, and volume of the cladodes were assessed at 20 and 320 days after planting. The number of fruits produced and mineral composition (N, K, Ca, Mg, P, and S) of *H. undatus* plants were also assessed. The results on morphometric characteristics of the cladodes, macronutrient composition and fruit yield have been recorded with higher values in treatments 3 and 4. However, according to the principal component analysis performed, treatment 3 was the one that correlated with the evaluated characteristics. The results have clearly indicated the importance of combination of adequate dose of mineral and organic fertilizer for better vegetative performance and yield of pitaya crop.

Keywords: Dragon fruit; fertilization; management; manure; plant nutrition.

Efeito da combinação de fertilizantes orgânicos e inorgânicos no crescimento, conteúdo de macronutrientes nas folhas e rendimento de pitaya (*Hylocereus undatus*) em condições de campo

Resumo

Este estudo teve por objetivo avaliar o efeito de fertilizantes orgânicos e inorgânicos sobre o desempenho da pitaya *Hylocereus undatus* em condições de campo. O delineamento experimental utilizado foi Delineamento em Blocos Completamente Casualizados (DBC). Foram incluídos neste estudo cinco tratamentos constituídos por quatro diferentes dosagens de fertilizantes, nomeadamente T1 (00-120-320-120); T2 (04-080-160-080); T3 (06-060-100-060); T4 (08-000-000-000) e T5 (Controle: 00-000-000-000) de esterco bovino (kg cova^{-1}), ureia (g cova^{-1}), super simples (g cova^{-1}) e cloreto de potássio (g cova^{-1}), respectivamente. Parâmetros como altura, número, comprimento, largura, área e volume dos cladódios foram avaliados aos 20 e 320 dias após o plantio. O número de frutos produzidos e a composição mineral (N, K, Ca, Mg, P, e S) das plantas *H. undatus* foram também avaliados. Os resultados sobre as características morfométricas dos cladódios, composição de macronutrientes e rendimento de frutos foram registados com valores mais elevados nos tratamentos 3 e 4. No entanto, de acordo com a análise dos componentes principais (PCA) realizada, o tratamento 3 foi o que mais se correlacionou com as características avaliadas. Os resultados indicaram claramente a importância da combinação de doses adequadas

de fertilizante mineral e orgânico para um melhor desempenho vegetativo e rendimento da cultura da pitaya.
Palavras-chave: Fruta-do-dragão; fertilização; manejo; esterco; nutrição vegetal.

Introduction

Fruit growing is one of the main agricultural activities developed in Brazil and, recently, it has stood out both in the production of fresh fruit, juices, and other processed products (BRASIL, 2021). The fruit production area in Brazil is around 2.5 million hectares and accounts for approximately 6 million direct jobs, by which is equivalent to 27% of the jobs generated by national agriculture (IEA, 2021). Currently, Brazil is the third largest fruit producer in the world and its production was estimated at 41 million tons in 2019 (IEA, 2021). Most of the fruit produced in the country is destined for domestic consumption, however, recently exports have increased. For example, in 2020, Brazil exported about 1 million tons of fruit, a turnover of about $875 million, by which represented growth over the previous year (ABRAFRUTAS, 2021).

Along with the advancement of agriculture in Brazil, the exotic fruits market has also been boosted and has been increasing recently (WATANABE; OLIVEIRA, 2014; PITAYA DO BRASIL, 2021; HFBRASIL, 2021). Thus, pitaya, popularly known as Dragon fruit, has drawn much attention from consumers because of its sensory characteristics, nutritional and exotic aspects (Silva *et al.*, 2017). However, the interest of fruit growers is the high commercial value of pitaya fruits, therefore, considered a promising alternative for developing Brazilian fruit production (CORDEIRO *et al.*, 2015; SILVA *et al.*, 2018; PITAYA DO BRASIL, 2021).

Currently, the pitaya fruit occupies an important niche in the world exotic fruit market (CATUXO; COSTA, 2019). It is considered the most cactaceous fruit cultivated worldwide (MIZRAHI *et al.*, 1997; MIZRAHI, 2014; NUNES *et al.*, 2014). In Brazil, the pitaya cultivation is relatively new and there are few cultivated areas with this crop, which leads to the need to import most of the fruit sold in the country. The pitaya commercialization in Brazil began in 2005, but the supply of this product has been constantly growing (PROHORT, 2021). The São Paulo state has stood out for both cultivation and volume commercialization, followed by the Santa Catarina and Minas Gerais states (PROHORT, 2021).

The pitaya plants, in general, are considered drought resistant, not demanding in terms of soil quality and subsist in limited natural conditions. Thus, it can adapt to different environmental conditions and can be found in tropical, subtropical, and dry climates (NUNES *et al.*, 2014). This plant tends to have a superficial root system to quickly absorb the available nutrients, even in small quantities in soils of low fertility (LE BELLEC *et al.*, 2006).

The red pitaya (*Hylocereus undatus* (Haw.) Britton & Rose), is a plant belonging to the family Cactaceae and its basic description is characterized by being a climbing, rupicolous plant, with cladodes-like branches triangular, averaging a little more than 20 cm in length and 5 to 7 cm in diameter, with ribs measuring 2 to 3 cm in height, green, sharp edges, and contains aureoles with small spines (DONADIO, 2009). Although it is a rustic fruit that easily adapts to various regions and soil types, it performs better in soil conditions with higher fertility or when it is fertilized (ORTIZ-HERNANDEZ, 2000; LE BELLEC *et al.*, 2006). Nitrogen, for example, is required for the vegetative growth of plants and stimulates the emission of roots and sprouts (LUDERS, 2004). Potassium is related to carbohydrate translocation and the regulation of the opening and closing of stomata (MARENCO; LOPES, 2011; DUARTE, 2013) and phosphorus is necessary for fruit formation (MARENCO; LOPES, 2011).

The most studies related to the pitaya nutrition are aimed at evaluating the isolated effects of nutrients on the performance of this plant (CAVALCANTE *et al.*, 2011; ALMEIDA *et al.*, 2014; MOREIRA *et al.*, 2016; CAJAZEIRA *et al.*, 2018). However, still few studies evaluate the combined effects of nutrients or different forms of fertilization (mineral and organic) on the pitaya crop (CAVALCANTE *et al.*, 2011; GONÇALVES *et al.*, 2019). In this sense, this study evaluated the effect of mineral fertilization and organic matter in different formulations on the vegetative and reproductive development of white-fleshed red pitaya *H. undatus*.

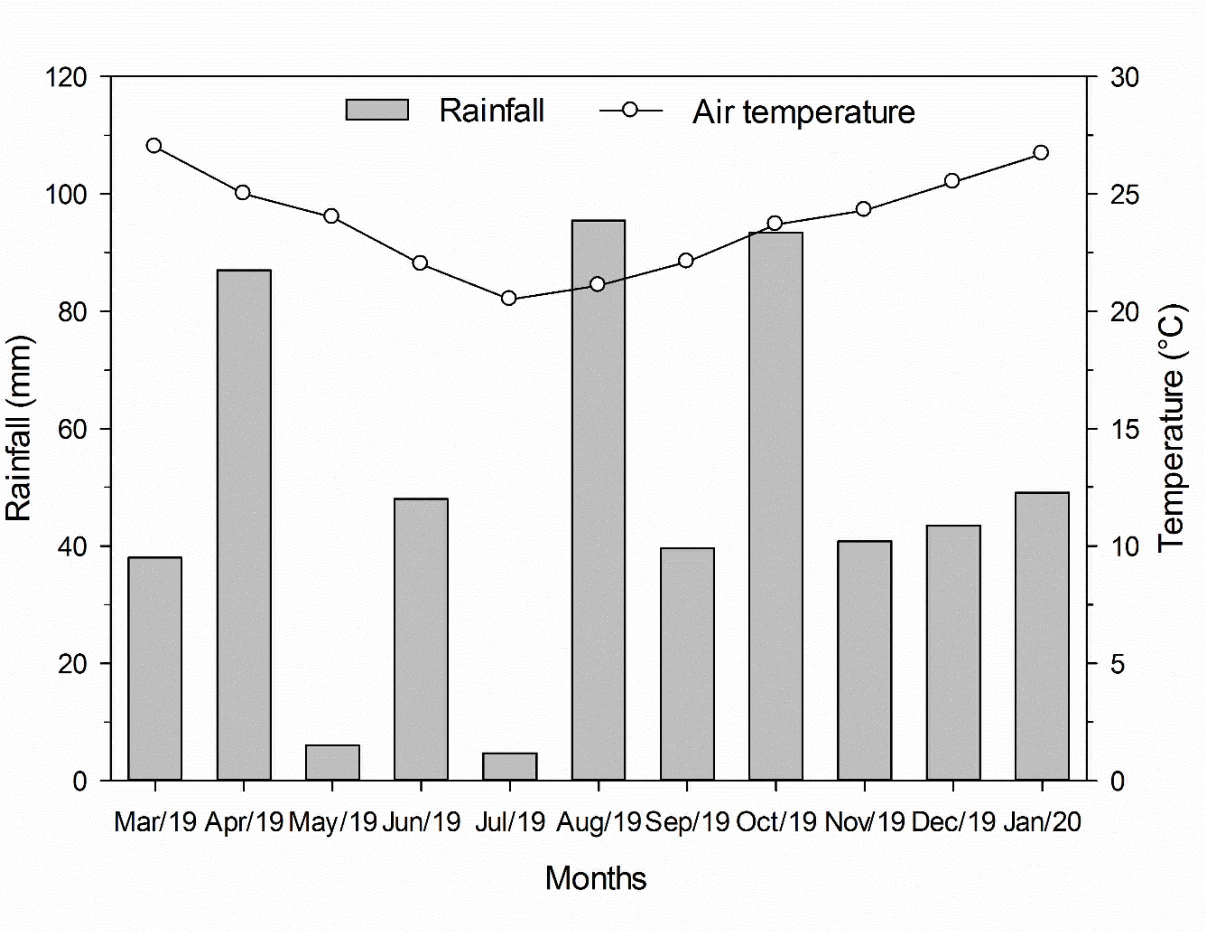
Materials and Methods

Location and plant material

This study was conducted at the Instituto Federal de Educação, Ciência e Tecnologia Baiano (IF Baiano), *Campus* Teixeira de Freitas (17° 34′ 21′′ S, 39° 43′ 51′′ W, 68 m altitude), state of Bahia, Brazil, in an area of 700 m^2, in the period from March 2019 to January 2020. The study site has a typical dystrophic Red Yellow Argisols soil type, weak A, of medium texture, the relief is flat, and the vegetation is typical of the Atlantic Forest. According to the Köppen-Geiger climate classification system, the region's climate is of the tropical "Am" type, characterized by high average air temperature (24 to 27 °C) and average of 1099 mm of rainfall per year (CLIMATE DATA, 2021). During the experimental period, the total accumulated precipitation was 546 mm of rainfall (average of 46.9 mm/month) and an average monthly temperature of 24 °C (Figure 1). The climatic data of air temperature and precipitation were collected by one of the meteorological stations of the National Institute for Space Research (INPE), which is installed at the IF Baiano, *Campus* Teixeira de Freitas.

The experimental area was prepared by weeding spontaneous plants and harrowing the soil. Then, manual digging of pits (40 x 40 x 40 cm) was performed. The dimensions of the pits and other cultural practices performed such as pruning and plant conduction were done following the recommendations for pitaya cultivation, according to Moreira *et al.* (2012). Cement stakes (0.12 x 0.10 x 2.50 m) were used to tutor the plants, and they were buried 80 cm deep in the soil. Weeds were controlled between the rows by mechanical weeding, and within the rows by manual weeding. The plants were irrigated twice a day (morning and afternoon) using the localized drip system. In all pits, 200 g (approximately 167 kg ha^{-1}) of dolomitic limestone with a total relative neutralizing power of 90.91% was applied 60 days before planting.

Figure 1. The average air temperature (°C) and accumulated rainfall (mm mounth^{-1}) from March 2019 to January 2020, Teixeira de Freitas - BA.



The seedlings used in the study were produced from cladodes collected from a 5-year-old commercial crop of *H. undatus*, variety "Vietnamese White," located in the Prado municipality, Bahia, Brazil. The cladodes collected in the field were left to rest in the shade for five days for the healing of the cuts made during the collection process. After this period, all cladodes were placed in a forest nursery covered and protected laterally with polypropylene mesh (50% of light interception) and kept in sand beds for rooting, for 30 days. The seedlings irrigation was performed manually three times a week. Only rooted and healthy seedlings were transplanted to the field. At planting, the seedlings were buried 5 cm deep in the soil.

Treatments

The experiment was carried out in the field following a randomized complete block design, with five treatments and three repetitions. The repetition consisted of a group of five plants, totaling 75 sampling units per treatment. The plants were grown at a spacing of 2 m between plants and 4 m between rows. A spacing of 5 m was left between the blocks to avoid interference between the blocks and treatments.

The five treatments consisted of the four combination different fertilizer dosages: T1 (00-120-320-120); T2 (04-080-160-080); T3 (06-060-100-060), T4 (08-000-000-000), and T5 (00-000-000-000) of bovine manure (kg pit^{-1}), urea (g pit^{-1}), super simple (g pit^{-1}) and potassium chloride (g pit^{-1}), respectively. The fertilizer levels used were selected according to recommendations available in other studies and technical bulletins on pitaya crops (CAVALCANTE *et al.*, 2011; MOREIRA *et al.*, 2012; COSTA *et al.*, 2014; LONE *et al.*, 2021). Treatment 5 (T5), without fertilizer addition, was used as a control treatment. All fertilizers, except urea and potassium chloride, were applied in a single dose at planting time. Urea and potassium chloride were applied in installments, 25% at planting and the rest at 30, 90, and 180 days after planting (DAP).

Soil condition analysis

Soil samples were collected at depths of 0 to 20 cm and 20 to 40 cm for chemical analysis and physical properties 30 days before planting. The soil samples collected were sent to the Agronomic and Environmental Analysis Laboratory of Linhares (FULLIN), Espírito Santo state, Brazil, by which used standard soil analysis techniques. The results of the soil analysis performed are presented in Table 1.

Leaf sampling and macronutrients determination

Five cladodes from different plants for each treatment were collected to evaluate the nutrient contents contained in the plant's aerial parts. The cladodes used in leaf analysis were collected at 320 DAP, from the central rib (rib perpendicular to the stalk), at a standardized height of 80 cm above the ground. After collecting, the cladodes were washed in running water, sectioned with the help of scissors, and then taken to a forced-air circulation oven at 65 °C until they reached a constant weight. After drying, the plant material was ground and chemically analyzed to determine the contents of N, P, K, Ca, Mg, and S according to the methodology proposed by Malavolta *et al.* (1997).

Nitrogen was determined by the Semi-Microkjeldahl method and titration with 1 mol L^{-1} NaOH. Phosphorus was quantified in an extract prepared from nitroperchloric digestion and subsequent absorbance reading in a photocolorimeter. Potassium and sodium contents were obtained by readings in a flame photometer coupled with a 766 and 589 µm wavelength filters, respectively. Calcium and magnesium contents were obtained by substrate readings employing the atomic absorption spectrophotometer. Sulfur determination was by turbidimetry.

Table 1. Values of chemical and physical variables from soil of the experimental area, at Instituto Federal Baiano, *Campus* Teixeira de Freitas, 2019-2020.

Variable	Unit	Soil depth	
		0 a 20 cm	20 a 40 cm
pH (H_2O)	-	6.00	5.90
Organic matter	g kg^{-1}	25.00	20.00
P (Mehlich-1)	mg dm^{-3}	37.00	20.00
K	mg dm^{-3}	52.00	30.00
Na	mg dm^{-3}	7.00	3.00
S	mg dm^{-3}	17.00	16.00
Ca	$cmol_c$ dm^{-3}	2.60	1.50
Mg	$cmol_c$ dm^{-3}	0.50	0.30
Al	$cmol_c$ dm^{-3}	0.00	0.00
S value[a]	$cmol_c$ dm^{-3}	3.30	1.90
CEC eff.[b]	$cmol_c$ dm^{-3}	3.30	1.90
CEC (pH 7.0)[c]	$cmol_c$ dm^{-3}	6.60	5.00
BS[d]	%	49.70	37.90
AS[e] (m)	%	0.00	0.00
B	mg dm^{-3}	0.84	0.54
Fe	mg dm^{-3}	253.00	257.00
Zn	mg dm^{-3}	2.20	1.00
Cu	mg dm^{-3}	0.30	0.10
Mn	mg dm^{-3}	13.00	10.00
Soil texture		Sandy Clay Loam	Clay Sandy

[a]Sum of Ca, Mg, K, and Na; [b]Effective cation exchange capacity; [c]Cation-exchange capacity; [d]Base saturation; [e]Aluminium saturation.

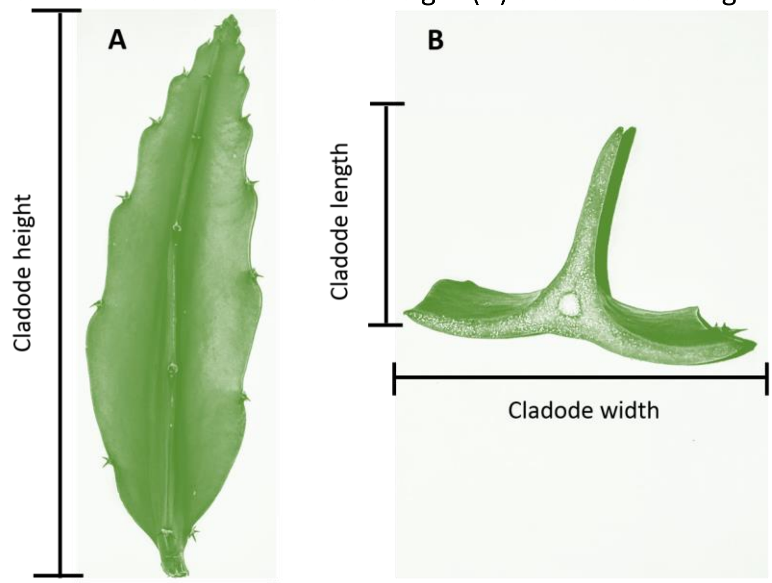
Growth measurements

To evaluate plant development, morphometric characteristics were evaluated at 20 and 320 days after planting (DAP). Evaluations at 20 DAP were performed to evaluate the initial development of the plants. At this stage of development, morphometric characteristics were evaluated in the new shoots present in the planted seedlings. The evaluations performed at 320 days allowed the determination of the plant's morphometric characteristics during the production stage. At this stage, measurements were carried out on the plant crown cladodes (i.e., those normally left for production purposes). Thus, it was possible to evaluate the effect of different fertilizer dosages at two stages of plant development, the initial and production stages.

The morphometric characteristics evaluated were the number (N), height (H), length (L), width (W), area (A), and volume (V) of cladodes. Cladode height for plants at 20 DAP was taken as the measurement of the distance from the apex of the cladode to its insertion into the seedling (Figure 2A). Cladode height for plants at 320 DAP was the distance between the apex of the plant crown cladode to its insertion into the primary cladode (Figure 2A). A tape measure was used to measure the height of the cladodes. Width and length were evaluated from measurements taken at the median position of the cladodes using a digital caliper (Digimess®, capacity - 150 mm). The cladode surface with the greatest amplitude was considered the width, by which the distance between the largest surface of the cladode to its vertex was considered the length (Figure 2B).

The area (A) and volume (V) of cladodes were estimated using width, length, and height data, following a methodology adapted from Padilha Junior *et al.* (2016). To estimate these characteristics, the following equations were used: A (cm^2) = W x [L + (3 x H)] e V (cm^3) = (W x L x H)/2, where L is cladode length (cm), W is cladode width in (cm) and H is cladode height. For these estimates, the shape of the cladode was considered like a triangular prism (Figure 2B).

Figure 2. Reference for measurement of cladode height (A) and cladode length and width (B).



Yield measurement

The production of the plants was determined by counting the total number of fruits on each plant for each treatment. This evaluation was performed from the beginning of flowering (November/2019) until the end of the reproductive period.

Data Analysis

Data for the morphometric traits evaluated were subjected to normality and homogeneity of variance testing using the PROC UNIVARIATE (Shapiro-Wilk test) and PROC GLM (Levene Test) procedures of SAS software, respectively (SAS INSTITUTE, 1999). The data of cladode numbers and cladode volume for plants at 20 DAP and cladode height, cladode area and cladode volume for plants at 320 DAP data did not meet the assumptions of the error normality and homogeneity of variance and, therefore, they were transformed using the log (x + 1) formula. To test the hypothesis of the occurrence of a difference between treatments, the data were subjected to multivariate analysis of variance (MANOVA) and an analysis of variance (ANOVA) in SAS (PROC GLM and PROC MIXED, respectively). Then, a comparison of means test was performed using the generalized linear model (GLM) with Tukey's studentized range (HSD) test option (SAS INSTITUTE, 1999). Plant yield data were analyzed using the GLM procedure (SAS INSTITUTE, 1999).

Plant morphometric characteristics and plant yield data potentially associated with the treatments were also subjected to principal component analysis (PCA) using the Canoco 4.5 system program (TER BRAAK; SMILAUER, 2002). After that, a biplot ordination gradient was generated with Canodraw 3.0. Vectors with origin at the center point of the two axes of the sorting diagram represent the response gradient. The length of the vector is proportional to the importance of the variable. Vectors with the same direction and orientation represent variables with a positive correlation, while vectors with the same direction and opposite orientation represent a negative correlation. Variables are not correlated when the angle between vectors is 90°.

RESULTS AND DISCUSSION

The data of all morphometric characteristics evaluated adjusted to the error normality and homogeneity of variances (p-value > 0.05). Significant differences in morphometric characteristics were found between treatments (Wilks' Lambda; $F_{24;193}$ = 2.22; *P* = 0.001 and Wilks' Lambda; $F_{24;179}$ = 3.72; *P* < 0.001) and between blocks (Wilks' Lambda; $F_{12;110}$ = 5.18; *P* < 0,001 and Wilks' Lambda; $F_{12;102}$ = 1.90; *P* = 0.0426) at 20 and 320 DAP, respectively. In contrast, no significant difference was found for interacting of treatments and blocks in the two evaluation dates (20 DAP: Wilks' Lambda; $F_{48;274}$ = 1.68; *P* = 0.056; 320 DAP: Wilks' Lambda; $F_{48;255}$ = 0.86; *P* = 0.720).

At 20 DAP, fertilization significantly influenced height ($F_{4;60}$ = 5.53; *P* < 0.001) and on the number of cladodes ($F_{4;60}$ = 5.17; *P* < 0.001) (Table 2). These results show that even in a short period after planting, the plants responded to fertilizer applied. This rapid response can be related to the quality of the seedlings that were planted, by which were rooted. Seedlings with a greater amount of root dry mass provide a greater capacity to absorb water and nutrients from the soil (MARQUES *et al.*, 2011). Furthermore, according to Mizrahi and Nerd (1999), pitaya seedlings propagated by the asexual method, when produced in sand substrates, develop numerous roots, and respond better to initial fertilization, since the vigor of the root system is determinant for developing of the plants aerial part. From an agronomic perspective, this initial response is important since pitaya aerial part growth is a determining factor for the crop's early production and productivity (GONÇALVES *et al.*, 2019).

Fertilization had a significant effect (*P* < 0.05) on all morphometric characteristics evaluated at 320 DAP (Table 3). This result can be associated with increased nutrient uptake capacity as plant growth occurred and, consequently, the growth of its root system. Pitaya plants tend to significantly increase their vegetative growth of both the main cladode and lateral cladodes starting at 60 DAP (LIMA *et al.*, 2019).

The fertilization absence led to a lower height and number of cladodes at 20 and 320 DAP (Tables 2 and 3). All other treatments containing fertilization resulted in higher values for these morphometric characteristics (Tables 2 and 3). The fertilization absence also resulted in the lowest values of length, width, area, and volume of the cladodes at 320 DAP compared to the treatments that received fertilization (Table 3). These results indicate that the nutrients supply to the pitaya plants, even at a less than ideal dosage, somehow favors their development. For example, greater availability of nitrogen in the soil, whether from any source of fertilization, can stimulate the emission of more vigorous roots and shoots and, consequently, provide better vegetative growth of plants (LUDERS, 2004). Similarly, greater availability of potassium in the soil promotes an increase in the diameter of the pitaya stem (INTA, 2002).

The height of the cladodes at 20 DAP was highest in the plants that received the fertilizer dosages (06-060-100-060) and (08-000-000-000), treatment 3 and 4, respectively (Table 2). At 320 DAP, a greater height of the crown cladodes was obtained in the plants that received the fertilizer dosage of 06-060-100-060 (Treatment 3) (Table 3). These results can be explained in part because the combination of treatment 3 supplied larger amounts of the main elements demanded by pitaya, which are nitrogen (N), phosphorus (P), and potassium (K), present in mineral form and bovine manure (Hernández, 2000). Besides, both treatment 3 and treatment 4 may have provided a considerable amount of organic matter through bovine manure affecting the growth of the cladodes. Indeed, pitaya is a demanding plant in organic matter to have good development (CAVALCANTE, 2008).

Table 2. Means ± standard error of the mean (SEM) of the measurements for morphometric characteristics of pitaya *Hylocereus undatus* "*Var.* Vietnamese White" grown with different fertilizer dosages at 20 days after planting. Instituto Federal Baiano, *Campus* Teixeira de Freitas, 2019-2020.

Treatments[(1)]	Evaluated characteristics					
	H (cm)	L (cm)	W (cm)	N (un)	A (cm²)	V (cm³)
T1	20.86 ± 3.10ab	4.03 ± 0.31	5.38 ± 0.34	3.00 ± 0.75ab	853.9 ± 145.6	574.2 ± 106.3
T2	21.26 ± 2.37ab	4.40 ± 0.27	5.71 ± 0.27	4.00 ± 0.80ab	885.5 ± 91.4	650.7 ± 98.0
T3	26.73 ± 2.74a	4.47 ± 0.36	5.11 ± 0.38	5.00 ± 0.27a	1017 ± 108.5	771.3 ± 118.7
T4	30.36 ± 4.56a	4.73 ± 0.17	6.16 ± 0.20	4.00 ± 0.92ab	1132.3 ± 62.5	865.2 ± 57.1
T5	12.27 ± 3.30b	4.63 ± 0.28	5.69 ± 0.36	1.00 ± 0.28b	898.3 ± 122.5	718.1 ± 118.7
CV (%)	50.1	24.2	21.9	44.6	44.3	55.7
F	5.53	0.95	1.67	5.17	1.25	1.32
P	< 0.001	0.440	0.169	< 0.001	0.299	0.273

[(1)]T1 (00-120-320-120); T2 (04-080-160-080); T3 (06-060-100-060), T4 (08-000-000-000), and T5 (Control: 00-000-000-000) of bovine manure (kg pit^{-1}), urea (g pit^{-1}), super simple (g pit^{-1}) and potassium chloride (g pit^{-1}), respectively. H = Cladode height; L = Cladode length; W = Cladode width; N = Cladode numbers; A = Cladode area; V = Cladode volume. Means followed by the same letter in the column did not differ significantly by Tukey test ($P < 0.05$).

Table 3. Means ± standard error of the mean (SEM) of the measurements for morphometric characteristics of pitaya *Hylocereus undatus* "Var. Vietnamese White" grown with different fertilizer dosages at 320 days after planting. Instituto Federal Baiano, Campus Teixeira de Freitas, 2019-2020.

Treatments[(1)]	Evaluated characteristics					
	H (cm)	L (cm)	W (cm)	N (un.)	A (cm²)	V (cm³)
T1	40.21 ±11.80ab	3.78 ± 0.80a	2.50 ± 0.54a	2.00 ± 0.46bc	479.7 ± 141.9bc	462.2 ± 143.6bc
T2	25.87 ± 7.73bc	3.67 ± 0.79a	2.57 ± 0.56a	1.00 ± 0.52c	330.4 ± 104.6c	302.8 ± 101.1c
T3	64.78 ± 7.70a	6.01 ± 0.72a	4.07 ± 0.54a	6.00 ± 0.90a	866.8 ± 96.7a	907.0 ± 113.3a
T4	52.06 ± 5.16a	5.64 ± 0.47a	4.16 ± 0.34a	4.00 ± 0.65ab	712.4 ± 69.0ab	690.7 ± 73.2ab
T5	5.53 ± 3.82c	0.63 ± 0.43b	0.54 ± 0.37b	0.13 ± 0.09c	70.9 ± 49.2c	55.2 ± 39.4c
CV (%)	63.5	63.0	61.8	63.5	61.6	62.0
F	9.98	12.25	11.51	13.75	11.29	11.62
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[(1)]T1 (00-120-320-120); T2 (04-080-160-080); T3 (06-060-100-060), T4 (08-000-000-000), and T5 (Control: 00-000-000-000) of bovine manure (kg pit^{-1}), urea (g pit^{-1}), super simple (g pit^{-1}) and potassium chloride (g pit^{-1}), respectively. H = Cladode height; L = Cladode length; W = Cladode width; N = Cladode numbers; A = Cladode area; V = Cladode volume. Means followed by the same letter in the column did not differ significantly by Tukey test ($P < 0.05$).

According to Chang *et al.* (2007), mineralized bovine manure increases the humus content of the soil, the water retention capacity of sandy soils, provides nutrients, increases microbial activity, improves the buffering power of the soil, and modifies the pH. However, excessive amounts of organic matter can have harmful effects, such as an unbalanced increase in the concentration of cations and anions, depleting the productive capacity of the soil (CAVALCANTE *et al.*, 2002). Therefore, the tested bovine manure dosage can be an adequate amount for pitaya fertilization and corresponds to the general recommendations for this crop that are usually 20 to 30 liters of manure per pit (CAVALCANTE *et al.*, 2011; MOREIRA *et al.*, 2012; LIMA *et al.*, 2019).

Fertilization did not affect the length and width of the primary cladodes at 20 DAP (Table 2). However, fertilization influenced these characteristics in the crown cladodes at 320 DAP (Table 3). We observed a difference between the best mean and treatment without fertilization, of 90% and 78% in length and width, respectively, indicating the plant response to the presence of fertilization. Other studies also show fertilization effects on pitaya stem diameter having greater increments in plants at the most advanced development stage (CAVALCANTE *et al.*, 2011; LIMA *et al.*, 2019; DIÓGENES *et al.*, 2020).

The mean number of cladodes (5.00 ± 0.27) at 20 DAP was higher in plants that received treatment 3 (06-060-100-060). This pattern was maintained for the average number of crown cladodes at 320 DAP (6.00 ± 0.90) (Table 3). This result is due to the greater balance between the number of nutrients in this treatment compared to the others, especially, between N and K, which act stimulating the emission of roots and sprouts (CAVALCANTE, 2008). Moreira *et al.* (2011) and Almeida *et al.* (2014) also found higher cladode production in response to fertilization, corroborating with the results found in this study.

A significant difference in cladode area and volume was not found among treatments at 20 DAP ($P > 0.05$). However, at 320 DAP, fertilization significantly affected the area of the crown cladodes. In the absence of fertilization, the average cladode area was much lower (70.92 cm^2) compared to the other treatments that reached up to 866.78 cm^2. Regarding the volume of the cladode, at 320 DAP, there was also a significant difference between the treatments. For plants that did not receive fertilization, the average cladode volume was 55.22 cm^3, by which much lower than the volumes of the other treatments, which reached up to 907.05 cm^3 (i.e., treatment 3). These results bring important implications for the pitaya culture, in which the cladode is the photosynthesizing organ of the plant. Therefore, a larger area and volume of the cladodes will allow a greater interception of solar radiation and, consequently, a maximization of carbohydrate production and biomass accumulation (ORTIZ-HERNANDEZ *et al.*, 1999; CRUVINEL *et al.*, 2017).

The concentrations of macronutrients (N, P, K, Ca, Mg, and S) in dry matter of the aerial pitaya parts for each treatment are presented in Table 4. According to Rozane *et al.* (2011), the variation in nutrient accumulation can occur when different genetic materials and different plant growth media are employed. In this study, only one variety of pitaya was used, therefore, the variation in the concentration of macronutrients in the aerial part can be more related to the different treatments, i.e., the different fertilizer formulations employed. However, this is only a hypothesis since no statistical analysis was done to verify significant differences in the concentration of macronutrients in the aerial part of the plants between treatments. Future studies will still be necessary for this confirmation.

Table 4: Macronutrient concentrations (N, P, K, Ca, Mg and S) in the cladodes of the pitaya *Hylocereus undatus* "Var. Vietnamese White" grown with different fertilizer dosages at 320 days after planting. Instituto Federal Baiano, *Campus* Teixeira de Freitas, 2019-2020.

Macronutrient (g kg^{-1})	Treatments[(1)]				
	T1	T2	T3	T4	T5
N	10.80	11.62	14.70	16.10	9.10
P	1.99	2.92	4.69	2.80	0.70
K	19.80	23.87	19.57	15.34	26.41
Ca	19.80	20.48	23.02	16.86	20.96
Mg	11.31	17.84	20.48	19.54	14.10
S	2.65	2.00	1.89	2.15	0.96
∑	66.35	78.73	84.35	72.79	72.23

[(1)]T1 (00-120-320-120); T2 (04-080-160-080); T3 (06-060-100-060), T4 (08-000-000-000), and T5 (00-000-000-000) of bovine manure (kg pit^{-1}), urea (g pit^{-1}), super simple (g pit^{-1}) and potassium chloride (g pit^{-1}), respectively.

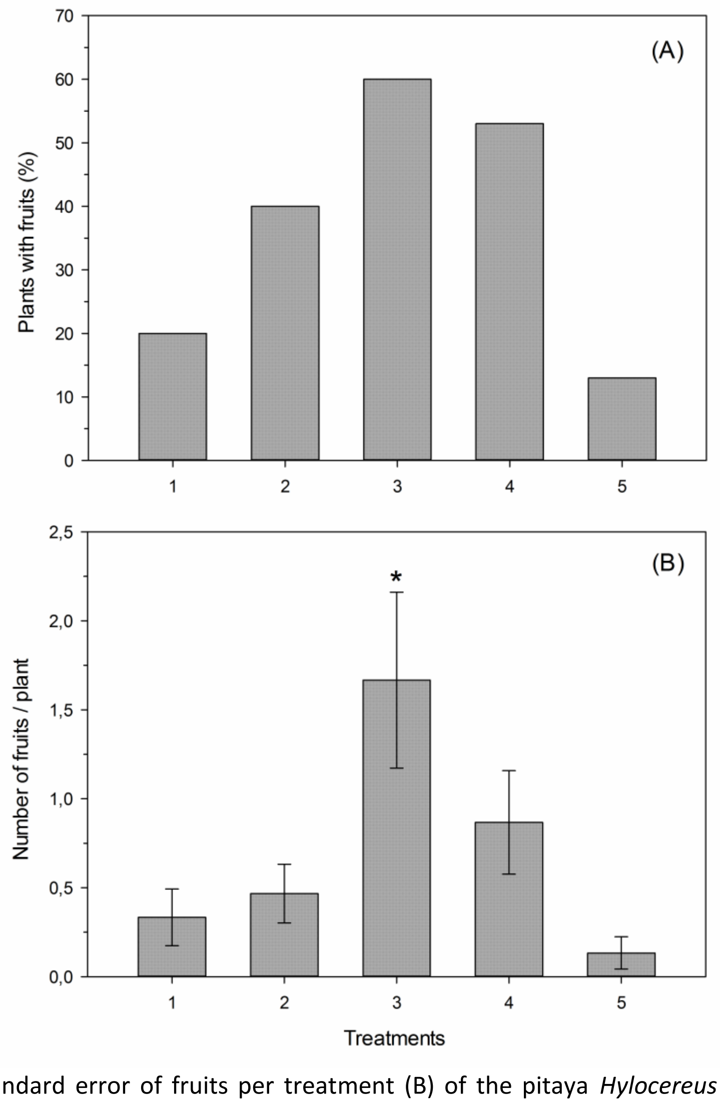
The total macronutrients concentration was higher in treatment 3 (06-060-100-060, manure, urea, super simple, and potassium chloride, respectively) (Table 4). However, in this treatment, only a few macronutrients had higher values than the others. Treatment 1 (T1), even with the highest dosages of N, P and K applied, was not the one that obtained the highest concentration of these nutrients in the cladodes. The N concentration in the plant pitaya tissue, for example, increased according to the increase in the dose of bovine manure supplied to the plant, with treatment T4 (only containing manure) reaching the highest N concentration. This result agrees with those found by Cavalcante (2008), in which the authors reported that 08 kg pit^{-1} of manure (equivalent to 20 L pit^{-1}) corresponded to the highest N accumulation in the plant pitaya tissue. This may have occurred due to the slower availability of nutrients that the organic matter of bovine manure, while fertilizers such as urea are easily lost by volatilization, leaching process, or are absorbed more quickly (PAVINATO; ROSOLEM, 2008).

Cavalcante (2008) found a tendency of the K accumulation contents like N, in which there was an increase in the K accumulation when larger amounts of bovine manure were applied. However, in this study, the K content was lower than the values found by the author. The treatment (T5), even without receiving fertilization, accumulated K and Ca contents like other treatments that received fertilization. However, the levels of the other macronutrients in the cladodes were lower than in the other treatments that received fertilizer.

A significant difference (P = 0.015) was found for fruit production among treatments. The treatment (T3) showed the highest total and average number of fruits per plant (Figure 3). The other treatments, although varying in the total fruits number and averages per plant, did not differ statistically. This result shows the importance of nutrient balance to the fruit pitaya production. In addition, in treatment 3, a higher dosage of organic fertilizer was added compared to the other treatments that contained in their formulations the combination of mineral and organic fertilizers. This higher dosage of organic matter added may have contributed to higher production of this treatment, considering that the minimum soil organic matter content recommended for pitaya culture is 7% according to Cavalcante (2008) and the soil organic matter level where the crop was grown was low (2.50 g dm^{-3} or 0.25% for the layer 0 to 20 cm) (Table 1). The higher content of organic matter in the soil, besides fertility, may have provided greater soil humidity, less compaction and greater biological activity, by which impacts the vegetative development and, consequently, the production of plants.

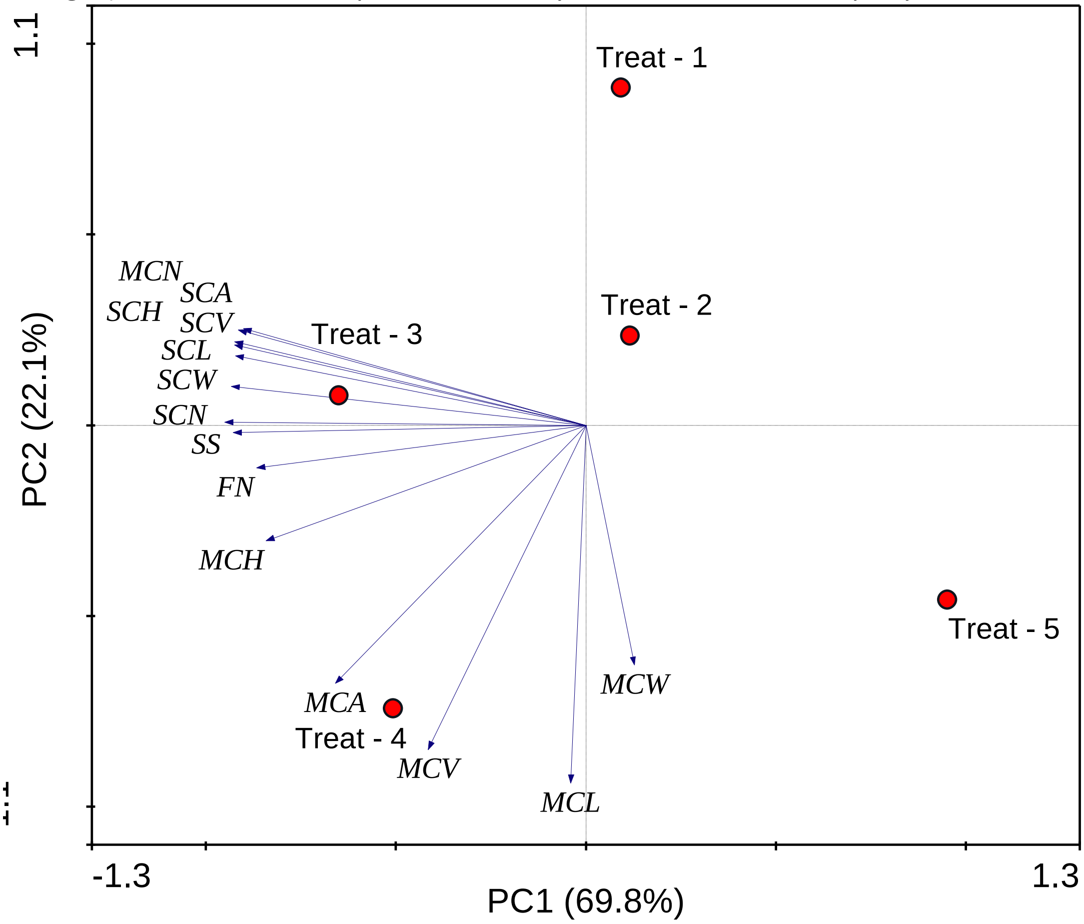
In the principal component analysis (PCA) with the treatments and the morphometric characteristics and the number of fruits the first two axes explaining 91.8% of the total variance (axis 1: 69.8%; and axis 2: 22.1%) (Figure 4). According to the variable ordering plot, a high relationship (direction and orientation of vectors) and influence (size of vectors) of treatments 3 and 4 on morphometric characteristics and number of fruits produced by the plants are verified (Figure 4). The morphometric characteristics of the secondary cladodes (i.e., the productive cladodes) and the number of fruits were positively correlated with treatment 3, while the morphometric characteristics of the main cladodes correlated with treatment 4. The number of fruits produced also correlated positively with the morphometric characteristics of the secondary cladodes (Figure 4). The PCA results corroborate the results previously found in this study, showing that treatments 3 and 4 had the greatest effect on the morphometric characteristics and fruit production.

Figure 3. Percentage of plants with fruits



(A) and mean + standard error of fruits per treatment (B) of the pitaya *Hylocereus undatus* "Var. Vietnamese White." Treatments 1, 2, 3, 4, and 5 are T1 (00-120-320-120); T2 (04-080-160-080); T3 (06-060-100-060), T4 (08-000-000-000), and T5 (00-000-000-000) of bovine manure (kg pit^{-1}), urea (g pit^{-1}), super simple (g pit^{-1}) and potassium chloride (g pit^{-1}), respectively. The asterisk indicates a significant difference by GLM test (P < 0.05).

Figure 4. Ordination diagram of principal component analysis (PCA) between treatments (fertilizer dosages) and different morphometric and yield characteristics of pitaya.



Correlated variables show vectors with similar direction and orientation. Perpendicular vectors indicate independent or uncorrelated variables. Treat - 1 (00-120-320-120), Treat - 2 (04-080-160-080), Treat - 3 (06-060-100-060), Treat - 4 (08-000-000-000), and Treat - 5 (00-000-000-000) of bovine manure (kg pit^{-1}), urea (g pit^{-1}), super simple (g pit^{-1}) and potassium chloride (g pit^{-1}), respectively. MCW = Main cladode width; MCL = Main cladode length; MCH = Main cladode height; MCN = Number of main cladodes; MCA = Area of main cladode; MCV = Volume of main cladode; SCW = Secondary cladode width; SCL = Secondary cladode length; SCH = Secondary cladode height; SCN = Number of secondary cladodes; SCA = Area of secondary cladode; SCV = Volume of secondary cladode; FN = Number of fruits.

CONCLUSIONS

The formulation (6 kg of bovine manure, 60 g of urea, 100 g super simple, and 60 g of potassium chloride) is the one that promotes better vegetative plants growth, both initially and in more advanced stages of plant development. Furthermore, this formulation shows a superiority in the total nutrients' accumulation in the cladodes and a greater number of fruits per plant. Both mineral and organic fertilizers (bovine manure) are present in this formulation, confirming that mineral fertilization for pitaya has its benefits multiplied when the organic soil matter was added. Additionally, when we analyze the dosages of mineral fertilizers applied in the treatments and compare them with treatment 3, we see that it is possible to reduce by approximately 1/3 the mineral fertilization of P and 50% for N and K. However, this reduction in the dosage must be compensated by the addition of organic matter, in this case, added by the application of 6 kg of tanned bovine manure.

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DECLARATION OF INTEREST STATEMENT

All authors declare that they have no conflict of interest.

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