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INITIAL GROWTH AND NUTRIENT ACCUMULATION IN PITAYA PLANTS AT DIFFERENT PHENOLOGICAL STAGES[1]

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ABSTRACT - Information on nutritional management of pitaya crops are scarce. However, understanding the growth and nutrient accumulation in these plants at different developmental stages can assist in the development of rational soil fertilizer application programs for pitaya crops and decrease production costs. Thus, the objective of this work was to evaluate the growth and nutrient accumulation in pitaya plants throughout the crop cycle. Cladodes of pitaya plants of the *Hylocereus setaceus* species were grown in polyethylene pots containing a Typic Hapludult (Argissolo Vermelho-Amarelo Eutrófico) under full sun. The treatments consisted of six sampling times: 0, 60, 120, 180, 240, 300, and 360 days after planting (DAP). A randomized block experimental design with four replications was used. Four plants were sampled and evaluated for growth and nutrient accumulation at each sampling time. The pitaya plants presented an exponential growth up to 360 DAP and high nutrient absorption between 300 and 360 DAP. The nutrient and Na accumulations in the cladodes, in decreasing order, were: 3.91 (K), 2.56 (Ca), 1.95 (N), 1.24 (P), 0.45 (Mg), 0.30 (S), and 0.06 (Na) g plant^{-1}, and 14.86 (Zn), 12.72 (Fe), 12.37 (Mn), 5.37 (B), and 1.04 (Cu) mg plant^{-1}. The highest relative growth rate and relative nutrient absorption rate were found between 60 and 120 DAP.

Keywords: *Hylocereus setaceus*. Cactaceae. Mineral nutrition. Nutritional requirement.

CRESCIMENTO INICIAL E ACÚMULO DE NUTRIENTES EM PLANTAS DE PITAIA EM DIFERENTES PERÍODOS FENOLÓGICOS

RESUMO - A pitaia é uma cultura carente em informações a respeito do manejo nutricional. O conhecimento sobre o crescimento e o acúmulo de nutrientes nas diferentes fases de desenvolvimento da planta auxiliará na elaboração de programas de adubação racionais para a cultura, diminuindo os custos de produção. Objetivou-se com este trabalho avaliar o crescimento e o acúmulo de nutrientes na pitaia saborosa ao longo do tempo de cultivo. Cladódios de pitaia da espécie *Hylocereus setaceus* foram cultivados em vasos de polietileno, contendo um Argissolo Vermelho-Amarelo Eutrófico e conduzidas a céu aberto. Os tratamentos constituíram-se de seis épocas de amostragens: 0, 60, 120, 180, 240, 300 e 360 dias após o plantio e o delineamento experimental utilizado foi em blocos casualizados, com quatro repetições. Em cada época foram amostradas quatro plantas para avaliar o crescimento e o acúmulo de nutrientes. A pitaia saborosa apresentou crescimento exponencial até 360 dias após o plantio. Observou-se alta absorção de nutrientes no período de 300 a 360 dias após o plantio. O acúmulo de nutrientes nos cladódios, em ordem decrescente, foi: 3.91 (K), 2.56 (Ca), 1.95 (N), 1.24 (P), 0.45 (Mg), 0.30 (S) e 0.06 (Na) g planta^{-1}, e 14.86 (Zn), 12.72 (Fe), 12.37 (Mn), 5.37 (B) e1.04 (Cu) mg plant^{-1}. A TCR e a TARN apresentaram maiores valores entre 60 e 120 dias.

Palavras-chave: *Hylocereus setaceus*. Cactaceae. Nutrição mineral. Exigência nutricional.

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INTRODUCTION

Hylocereus setaceus (pitaya) is a fruit species of the Cactaceae family that is raising the interest of fruit growers by presenting high commercial value (MOREIRA et al., 2011); it has a high potential as an ornamental and fruit plant and is an excellent source of vitamins. However, one of problems that affect pitaya crops is the lack of information about the nutritional management of the plants (COSTA et al., 2015). Little information is found on the quantity of nutrients required for pitaya plants over the crop cycle to obtain satisfactory results regarding their growth, development, and production.

Some studies on pitaya crops have shown how nutrients can affect their growth and production. Fernandes et al. (2018), evaluated the production and quality of pitaya fruits grown on soils with potassium fertilizer applications and found that the application of 106 to 133 g of K_2O per plant in the first growth year and 200 g of K_2O in the second and third year increases the production and quality of white-fleshed (*Hylocereus undatus*) and red-fleshed (*Hylocereus polyrhizus*) pitaya fruits. In addition, the use 150 to 225 mg dm^{-3} of P, 4 to 6 mg dm^{-3} of Zn (CORRÊA et al., 2014), 300 to 450 mg dm^{-3} of N, and 150 to 225 mg dm^{-3} of K (ALMEIDA et al., 2014) results in a better growth of white-fleshed pitaya (*H. undatus*) seedlings.

However, the growth of pitaya still requires studies to determine the quantities of nutrients required throughout the crop cycle and define the times these nutrients are more required. This information would contribute to the development of rational soil fertilizer application programs for these crops. Soil fertilizer applications for pitaya crops in Brazil are done based on the experience of producers, or using rates that are recommended for other countries, which present ecological systems different from those of the Brazilian producing regions (CAVALCANTE et al., 2011), causing nutritional imbalances.

In this context, the objective of this work was to evaluate the growth and nutritional demand of pitaya (*H. setaceus*) plants and determine the times of the highest accumulations of different nutrients, relative growth rate, and relative nutrient absorption rate.

MATERIAL AND METHODS

The experiment was conducted at the Agriculture Sector of the Department of Plant Production Science of the Federal University of Ceará, in Fortaleza, state of Ceará, Brazil, from July 2016 to July 2017. The climatological data collected during the experimental period are presented in Figure 1.

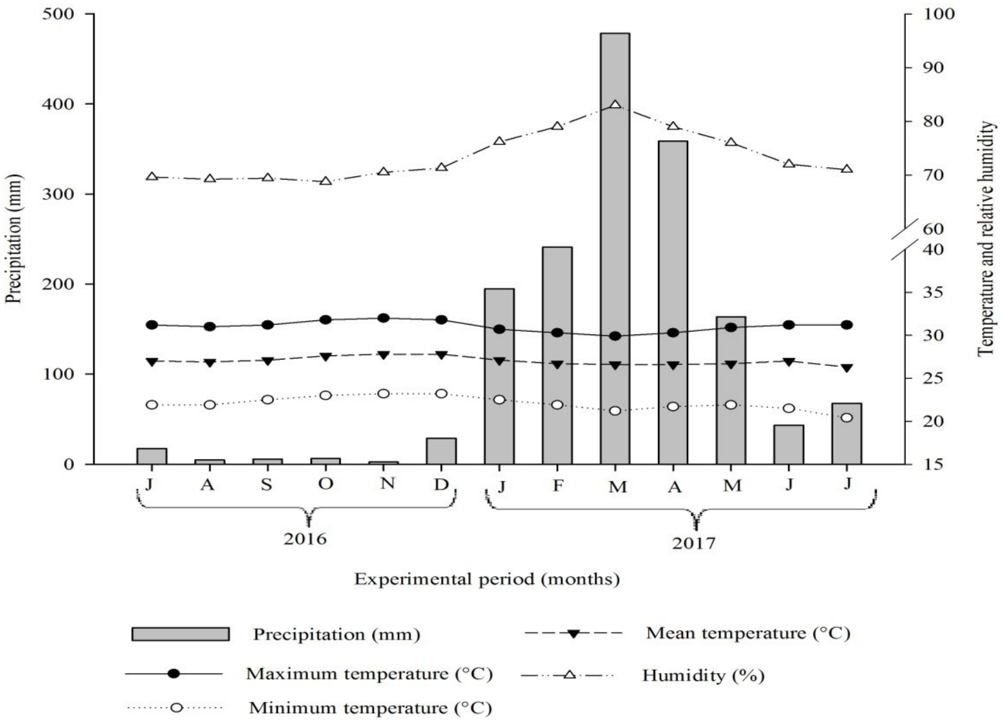

Figure 1. Climatological data, rainfall (mm), maximum, mean, and minimum air temperatures (°C), and relative air humidity (%) in the experimental period.

Pitaya seedlings were produced using cladodes with mean length of 25 cm (PONTES FILHO et al., 2014). The cladodes were planted at a depth of 3 cm in 3 dm^3 polyethylene bags containing sand soil + coconut fiber at the proportion of 1:1 v v^{-1}. They remained for 60 days in a protected environment, until the rooting, and subsequently transplanted to 25 dm^3 polyethylene pots.

The soil used to fill the pots was classified as a Typic Hapludult (Argissolo Vermelho-Amarelo Eutrófico), and analyzed for chemical characteristics according to procedures described in Embrapa (2009) (Table 1).

Table 1. Initial chemical attributes of the soil used to fill the experimental pots.

Soil chemical attributes	Unit	Values
P	mg dm^{-3}	4.0
Organic matter	g kg^{-1}	13.9
pH in water		5.5
K^+	$mmol_c$ dm^{-3}	2.1
Ca^{2+}	$mmol_c$ dm^{-3}	8.4
Mg^{2+}	$mmol_c$ dm^{-3}	5.2
Na^+	$mmol_c$ dm^{-3}	2.0
H+Al	$mmol_c$ dm^{-3}	17.3
Al^{3+}	$mmol_c$ dm^{-3}	1.5
SB	$mmol_c$ dm^{-3}	17.8
T	$mmol_c$ dm^{-3}	35.1
V	%	51.0
Cu	mg dm^{-3}	0.2
Fe	mg dm^{-3}	40.0
Zn	mg dm^{-3}	0.1
Mn	mg dm^{-3}	3.6
B	mg dm^{-3}	0.3

OM = organic matter; pH in water; P, Na and K, Mehlich-1 extractor; Ca, Mg and Al, KCl extractor; H+Al, calcium acetate extractor; SB = sum of exchangeable bases; T = cation exchange capacity at pH 7.0; V = base saturation; Cu, Zn, Mn and Fe, DTPA extractor; B, HCl extractor.

The soil pH was corrected based on the soil analysis, using agricultural limestone (total neutralizing power of 91%) to raise the base saturation to 70%; 9.1 g of limestone was applied per pot (25 kg of soil). The seedlings were transplanted to the pots after 30 days of soil incubation and grown under full sun.

The seedlings were transplanted to the pots with only the main cladode (primary cladode), and grown with a single stem up to 1.5 m height, when they were pruned to induce the primary lateral cladode emission (one cladode for each side). These cladodes were pruned when they reached 40 cm to stimulate the emission of secondary lateral cladodes (three cladodes for each side). Pitaya is a Cactaceae species that requires a stem conduction system; thus, a trellis system was used.

Soil fertilizers were applied using the nutrient rates recommended by Almeida et al. (2014) and Corrêa et al. (2014) for pitaya crops, which were 750 (N), 375 (P), 375 (K) and 10 (Zn) mg dm^{-3}. The nutrient source used were urea (46% N), simple superphosphate (18% P_2O_5, 25% CaO and 12% S), potassium chloride (62% K_2O) and FTE BR-12 (a granulated mixture of micronutrients containing 9% Zn, 1.80% B, 0.80% Cu, 2% Mn, and 0.10% Mo). The rates were adjusted to the soil volume used (25 dm^3). Therefore, the rates applied to each pot were 120 g of simple superphosphate, 2.8 g of FTE-BR-12, 40.7 g of urea, and 18.2 g of potassium chloride.

A randomized block experimental design with four replications was used; the treatments consisted of sampling times (0, 60, 120, 180, 240, 300, and 360 days after planting).

The planting soil fertilizer application was equal for all pots; the simple superphosphate and 50% of the FTE BR-12 rate were applied when the seedlings were transplanted to the pots. The other 50% of the FTE BR-12 rate was applied at 180 days after the transplant to the pots. The urea and potassium chloride were split in eleven equal rates of 3.70 g and 1.65 g, respectively, and applied monthly after solubilization in water to favor incorporation to the soil. Urea and potassium chloride applications tend to minimize the nutrient losses by leaching. The plants were manually irrigated three times a week, applying 1 L of water per pot; the irrigation was suspended at the beginning of the rainy season.

The characteristics evaluated at each sampling time were: a) sum of the lengths of all cladodes emitted, except the main cladode, whose results were expressed in cm plant^{-1}; b) shoot dry matter: all cladodes were placed in paper bags and placed in a forced air-circulation oven at 65 °C until constant weight; the results were expressed in g plant^{-1}; c) shoot macro and micronutrient (N, P, K, Ca, Mg, S, Cu, Fe, Zn, Mn, and B) accumulation and Na contents: determined according to the methodology described in Embrapa (2009), macronutrient (g plant^{-1}) and micronutrient (mg plant^{-1}) accumulations were determined by multiplying the contents of each nutrient in the shoot by the shoot dry matter weight.

The data obtained were subjected to analysis of variance and the means fitted to an exponential model, represented by Equation 1:

$$Y = e^{a-bX} \quad (1)$$

The relative growth rate (RGR) (Equation 2) and relative nutrient absorption rate (RNAR) (Equation 3) were determined according to the equations of Welbank (1962):

$$RGR = \frac{(\ln M_2 - \ln M_1)}{(t_2 - t_1)} \quad (2)$$

where RGR is the relative growth rate in g g^{-1} day^{-1}; *ln* is the Neperian logarithm; M_1 and M_2 are the dry matter weights of the plant or plant organ in g per plant at times t_1 and t_2, respectively; and t_1 and t_2 are the period, in days, between evaluations.

$$RNAR = \frac{(N_2 - N_1)(\ln M_2 - \ln M_1)}{(t_2 - t_1)(M_2 - M_1)} \quad (3)$$

where RNAR is the relative nutrient absorption rate in mg g^{-1} day^{-1} or µg g^{-1} day^{-1}; N_1 and N_2 are the nutrient quantities in the plant organ at times t_1 and t_2, respectively; ln is the Neperian logarithm; M_1 and M_2 are the total plant dry matter weights at times t_1 and t_2, respectively; and t_1 and t_2 are the period between evaluations.

The SAS program (SAS, 2012) was used for the statistical analysis.

RESULTS AND DISCUSSION

The initial growth of the pitaya plants was characterized by a small increase in cladode length up to 180 days after planting (DAP), with daily rates of 0.64 cm plant^{-1} (Figure 2A). A more vigorous cladode growth was found from 180 to 360 DAP, with a daily growth rate of 2.02 cm plant^{-1}.

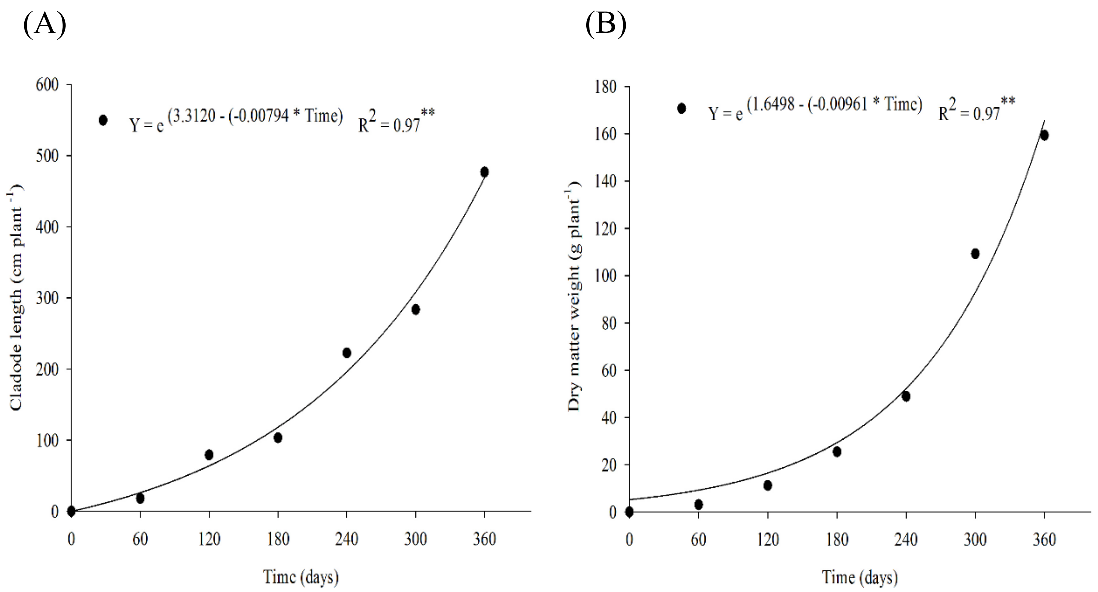

Figure 2. Cladode length (A) and dry matter weight (B) of pitaya (*Hylocereus setaceus*) as a function of sampling times.

The mean pitaya cladode length at 360 DAP was 478.377 cm plant^{-1}; this result is higher than that obtained by Cajazeira (2016), who found a mean pitaya cladode length of 84.9 cm at 270 DAP. This difference in cladode length may be related to the adequate supply of nutrients, such as the nitrogen, which can affect the growth of these plant structures. Nitrogen affects the cell division and stretching, promoting the cladode length (CUNHA et al., 2012).

The shoot dry matter accumulation presented small increases up to 180 DAP, with a daily increase rate of 0.163 g day^{-1}, and an increase of 0.756 g day^{-1} from 180 to 360 DAP (Figure 2B). The total accumulated dry matter weight in the plants was only 18% up to 180 DAP, the remaining 82% were accumulated in the following stage, up to 360 DAP. This small initial increase rate may be attributed to the low size and number of cladodes in the plants during this period; The CO_2 absorption and photoassimilate production were probably low at this stage, resulting in lower dry matter accumulation. Phosphorus is an important nutrient for photosynthesis and beginning of root growth; it improves water use efficiency and absorption and use of other nutrients (MALAVOLTA, 2006), including potassium. Potassium increases the pitaya cladode diameter (CAJAZEIRA et al., 2018) and is related to stomatal opening and closure processes, and carbohydrate translocations (MARSCHNER, 2012). According to Laredo (2016), the size and number of buds are important characteristics for pitaya plants; plants that present higher shoot vigor can better capture light and produce photoassimilates, improving the plant nutrition and accumulation of reserves.

The periods of higher cladodes growth and dry matter accumulation (Figures 2A and B) were those of higher nutrient demand (Figure 3). The pitaya nutrient absorption follows, in general, the standard of the growth curve or dry matter accumulation at this initial growth stage, presenting two different stages: the first with slow absorption, and the second with intense nutrient absorption.

The accumulation of nutrients and Na by the pitaya cladodes at the end of experimental period presented the following decreasing order: K > Ca > N > P > Mg > S > Na > Zn > Fe > Mn > B > Cu.

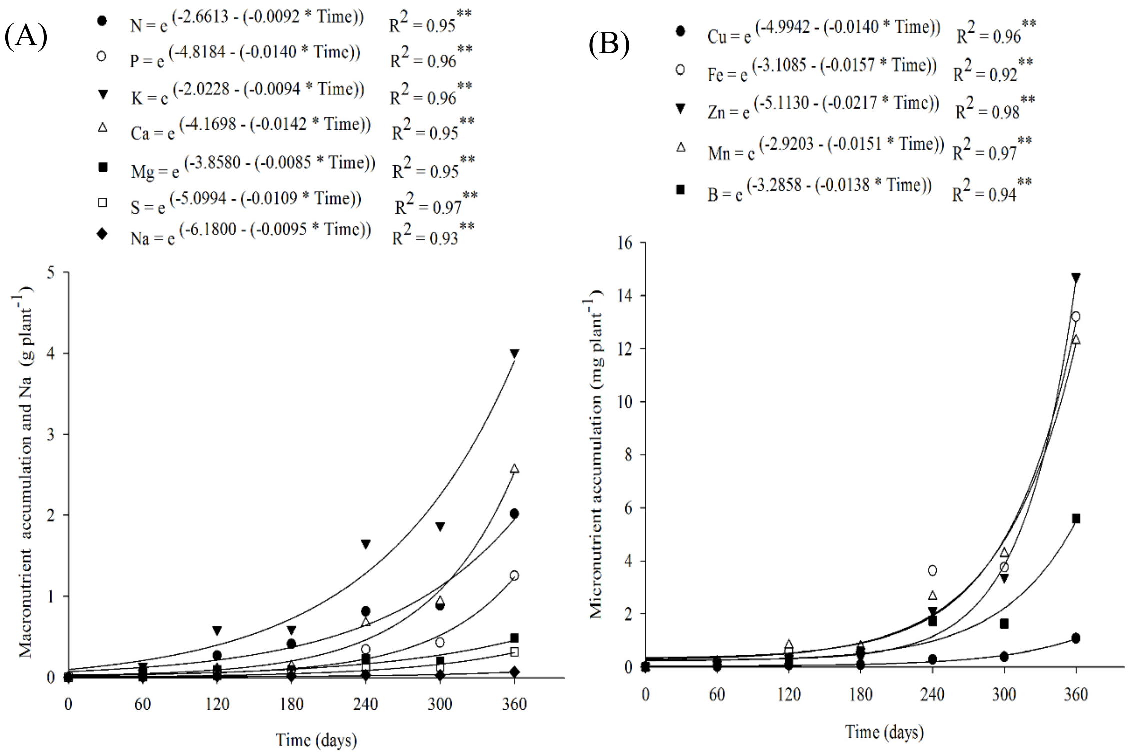

Figure 3. Macronutrient accumulation and Na contents (A) and micronutrient accumulation (B) in pitaya cladodes as a function of sampling times.

K, Ca, and N were the most accumulated macronutrients by the cladodes, all presenting maximum accumulation rate from 300 to 360 DAP. The maximum accumulation of these nutrients occurred in the period of intense plant growth (Figure 3A). The maximum accumulation rates of K, Ca, and N were 0.028, 0.024, and 0.013 g $plant^{-1}$ day^{-1}, respectively. The maximum accumulations of K, Ca, and N at the end of 360 DAP were 3.91, 2.56, and 1.95 g $plant^{-1}$, respectively.

K was the most demanded macronutrient by the pitaya plants, which makes the supply of this nutrient essential during the whole pitaya crop cycle. Despite K is not part of the structure of any organic compound, it is important to plants by affecting the stomatal opening and closure, translocation of sugars, photosynthesis, and osmotic regulation (MALAVOLTA, 2006). Studies on the effect of K on the development of pitaya plants indicate increases in cladode length, diameter, and thickness (CAJAZEIRA et al., 2018), and improvements in fruit quality (FERNANDES et al., 2018).

Ca accumulation was slow up to 180 DAP, with 0.199 g plant^{-1} in the pitaya cladodes; higher Ca accumulation in the plants were found after 240 DAP. The gradually increases in Ca in the cladodes up to 360 DAP may be related to the low mobility of Ca in the phloem, which prevents the redistribution of this element from the cladodes to other plant organs (MALAVOLTA, 2006); probably, the older the cladode, the higher the Ca accumulation. Lima et al. (2019) evaluated the growth and nutrient accumulation in red-fleshed pitaya shoots and found that Ca contents tend to increase as the plants age.

N was the third most accumulated macronutrient by the pitaya plants, presenting a maximum accumulation rate of 1.95 g plant^{-1} at 360 DAP. According to Luders and Mc Mahon (2006), nitrogen is required by pitaya during the whole vegetative growth stage, and is responsible for the emission of new cladode buds. Almeida et al. (2014) found that increases in N accumulation in pitaya (*Hylocereus undatus*) cladodes is induced by increasing N application rates.

P was the fourth most accumulated nutrient by the pitaya plants, with maximum accumulation rate of 0.011 g plant^{-1} day^{-1} form 300 and 360 DAP. Each plant had accumulated 1.24 g of P in the cladodes at the end of the experimental period. This result differs from those of Moreira et al. (2016), who found lower P accumulation in shoots of white-fleshed plants (0.16 g plant^{-1}). These differences were probably due to morphological and physiological aspects of the species, and the quantity of available P to the plants in the soil, since higher P rates were applied in the present study.

Mg and S were the least required macronutrients by the pitaya plants, with maximum accumulations of 0.45 g plant^{-1} and 0.30 g plant^{-1}, respectively, at 360 DAP. High K and Ca concentrations may inhibit Mg absorption, since K, Ca, and Mg compete for same absorption sites in the roots; thus, the cation with higher concentration in the soil solution is preferentially absorbed in detriment of the others (BRADY; WEIL, 2013). The S requirement for a good plant growth varies, in general, from 0.1% to 0.5% of the plant dry weight (MARSCHNER, 2012); thus, the total S accumulation found in the pitaya shoots is within this range.

Na accumulation reached 0.064 g plant^{-1} at 360 DAP, with a maximum accumulation rate of 0.028 g plant^{-1} from 300 to 360 DAP. According to Taiz et al. (2017), species that use C4 and CAM routes for carbon fixation require sodium ions, since these ions stimulate the growth upon the cell expansion. Na is absorbed by plants in the ionic form (Na^+), which has high mobility in plant tissues; Na concentrations in the shoot dry matter vary from 0.013 to 35.1 g kg^{-1} (INOCÊNCIO; CARVALHO; FURTINI NETO, 2014).

Regarding the micronutrients, Zn, Fe, and Mn were the most accumulated by the pitaya shoots. Zn accumulation in the pitaya shoots was 14.86 mg plant^{-1} at 360 DAP; the highest demand was found from 300 to 360 DAP, with accumulation of 10.82 mg plant^{-1} in this period, corresponding to 72.81% of the total zinc in the shoot. The maximum Zn accumulation rate from 300 and 360 DAP was 0.18 mg plant^{-1} day^{-1}. Corrêa et al. (2014) evaluated the initial growth of pitaya plants as a function of combination of phosphorus and zinc rates and found high Zn accumulation in the cladodes under good Zn availability conditions in the substrate.

Fe demand increased from 240 DAP (Figure 3B) probably due to the functions of this element in the photosynthetic process, since the cladode production is intensified in this period, increasing the plant Fe demand. The shoots of the plants had accumulated 7.37 mg of Mn at the end of the experimental period. According to Millaleo et al. (2010), high Mn accumulations in cladodes are probably related to the function of Mn in the plant; it is part of structures of photosynthetic proteins and enzymes and essential for photosynthesis. B and Cu were the least accumulated micronutrients by the pitaya shoots, with maximum accumulations of 5.37 and 1.04 mg plant^{-1}, respectively, at 360 DAP.

The relative growth rate (RGR) represents the increase in dry matter weight per unit of weight in a period. The highest RGR of pitaya plants was found from 60 to 120 DAP (0.022 g g^{-1} day^{-1}), with a subsequent decrease up to 360 DAP (Table 2). According to Gonçalves et al. (2017), decreases in RGR over the crop cycle decrease the plants' capacity to produce newly parts over the cycle.

Table 2. Relative growth rate (RGR) of pitaya (*Hylocereus setaceus*) cladodes as a function of sampling times.

Period	RGR (whole pitaya plants)
Days	g g^{-1} day^{-1}
0-60	0.019
60-120	0.022
120-180	0.014
180-240	0.011
240-300	0.013
300-360	0.006

The RGR was used to calculate the relative nutrient absorption rate (RNAR) for all plants. RNAR depends on the plant weight and factors intrinsic to the plant metabolism, related to the plant's physiological needs for each nutrient (ROZANE et al., 2013). The RNAR varied as a function of the nutrient and sampling time. The highest RNAR in the pitaya plants was found, in general, between 60 and 120 DAP (Table 3). Rozane et al. (2013) found that higher RNAR are found in the initial evaluation periods due to the small dry matter accumulations at this stage, which is denoted by the higher nutrient contents in the quotient of the equation and, therefore, a higher RNAR.

Table 3. Relative nutrient absorption rate (RNAR) of pitaya cladodes as a function of sampling times.

RNAR (whole pitaya plants)	Periods (days after planting)					
Nutrients	0-60	60-120	120-180	180-240	240-300	300-360
N (mg g^{-1} dia^{-1})	0.49	0.48	0.14	0.19	0.02	0.14
P (mg g^{-1} dia^{-1})	0.06	0.16	0.02	0.12	0.02	0.10
K (mg g^{-1} dia^{-1})	0.79	1.20	0.01	0.49	0.05	0.27
Ca (mg g^{-1} dia^{-1})	0.13	0.21	0.03	0.25	0.06	0.20
Mg (mg g^{-1} dia^{-1})	0.06	0.21	0.00	0.07	0.00	0.04
S (mg g^{-1} dia^{-1})	0.06	0.03	0.01	0.04	0.00	0.02
Na (mg g^{-1} dia^{-1})	0.06	0.00	0.00	0.00	0.00	0.01
Cu (µg g^{-1} dia^{-1})	0.06	0.16	0.00	0.09	0.02	0.09
Fe (µg g^{-1} dia^{-1})	1.22	1.01	0.00	1.44	0.03	1.19
Zn (µg g^{-1} dia^{-1})	0.49	0.61	0.06	0.81	0.28	1.42
Mn (µg g^{-1} dia^{-1})	1.16	1.65	0.00	0.87	0.36	1.01
B (µg g^{-1} dia^{-1})	0.79	0.45	0.28	0.53	0.00	0.50

The RNAR determines the quantity of nutrient accumulated as a function of the plant weight; determining this nutritional index is important to produce seedlings of fruit trees that are propagated vegetatively by cutting, including pitaya, since the biomass of pitaya seedlings at the transplant time is enough to obtain the RNAR (PRADO; FRANCO, 2007). In addition, the nutrient mobility/redistribution in plants affects physiological processes; according to Malavolta (2006), N, P, and Na are highly mobile; P, Cl, S, and Mg are mobile; Zn, Cu, Fe, Mn, and Mo are partially mobile; and Ca and B are not mobile in the plant. Moreover, the RNAR results are important for an adequate supply of nutrients in the first days after planting the seedlings, when the nutrient absorption is higher, to ensure an adequate development of the plants.

CONCLUSIONS

The pitaya (*Hylocereus setaceus*) plants presented an exponential growth up to 360 days after planting.

The highest nutrient accumulations were found from 300 and 360 days after planting.

The highest relative growth rate and relative nutrient absorption rate were found between 60 and 120 days after planting.

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