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Productivity and nutrient concentration in spineless cactus under different fertilizations and plant densities

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ABSTRACT

The objective was to evaluate the productivity and nutrient concentration in spineless cactus ‘Miúda’ (*Nopalea cochenillifera* Salm Dyck) under levels of nitrogen (N) fertilization (0, 150, 450 and 600 kg N ha^{-1} $year^{-1}$), P fertilization (0 and 150 kg P_2O_5 ha^{-1} $year^{-1}$), plant densities (5,000 and 40,000 plants ha^{-1}) in two sites (Caruaru and São Bento do Una). The productivity was greater in plots with 40,000 plants ha^{-1}, regardless of the site, with average of 16.8 and 7.2 t DM ha^{-1} two $years^{-1}$, for 40,000 and 5,000 plants ha^{-1}, respectively. In plots with 5,000 plants ha^{-1}, nitrogen fertilization did not affect productivity, however, there was a linear increase in plots with 40,000 ha^{-1} plants. The plant N concentration increased with nitrogen fertilization and ranged from 7.3 to 9.9 g kg^{-1}. The plant phosphorus (P) concentration was influenced by the interaction between all the factors evaluated and reduced until estimated fertilization of 322 kg N ha^{-1} in plots with 40,000 plants ha^{-1} and 150 kg P ha^{-1} and only in São Bento do Una, with P concentration of 1.19 g kg^{-1}. Nitrogen fertilization increased N concentration in cladodes and productivity when using high plant density. The increase in planting density increases productivity and reduces the concentration of most nutrients, except sulphur (S).

Key words: nitrogen; *Nopalea cochenillifera*; phosphorus; spacing

Produtividade e concentração de nutrientes na palma miúda sob diferentes adubações e densidades de plantio

RESUMO

O objetivo foi avaliar a produtividade e concentração de nutrientes na palma forrageira ‘Miúda’ (*Nopalea cochenillifera* Salm Dyck) sob níveis de adubação nitrogenada (0, 150, 450 e 600 kg N ha^{-1} ano^{-1}), adubação fosfatada (0 e 150 kg P_2O_5 ha^{-1} ano^{-1}), densidades de plantio (5.000 e 40.000 plantas ha^{-1}) em dois locais (Caruaru e São Bento do Una). A produtividade foi maior em parcelas com 40.000 plantas ha^{-1}, independentemente do local, com média de 16,8 e 7,2 t MS ha^{-1} dois $anos^{-1}$, para 40.000 e 5.000 plantas ha^{-1}, respectivamente. Em parcelas com 5.000 plantas ha^{-1}, a adubação nitrogenada não causou efeito na produtividade, entretanto, houve aumento linear em parcelas com 40.000 plantas ha^{-1}. A concentração de N na planta aumentou com adubação nitrogenada e variou entre 7,3 e 9,9 g kg^{-1}. A concentração de fósforo (P) na planta foi influenciada pela interação entre todos os fatores avaliados e reduziu até a adubação de 322 kg N ha^{-1} em parcelas com 40.000 plantas ha^{-1} e 150 kg P ha^{-1} e apenas em São Bento, com concentração de P de 1,19 g kg^{-1}. A adubação nitrogenada aumenta a concentração de N nos cladódios e eleva a produtividade quando se utiliza alta densidade de plantas. O aumento da densidade de plantio aumenta a produtividade e reduz a concentração da maioria dos nutrientes, exceto enxofre (S).

Palavras-chave: nitrogênio; *Nopalea cochenillifera*; fósforo; espaçamento

Introduction

Spineless cactus is an important forage resource for semiarid regions. It presents a high forage production potential, despite its low crude protein concentration (CP). Cactus presents lower water requirements compared to other forages (Santos et al., 2013; Dubeux Jr. et al., 2015; Lima et al., 2016). This plant has photosynthetic metabolism type CAM (crassulacean acid metabolism), consisting in opening of stomata to capture atmospheric CO_2 only at night, as the air temperature is lower and humidity higher, reducing water loss to the environment (Nefzaoui et al., 2014).

The importance of spineless cactus in the semiarid region, due to its high productivity in dry condition, contributes to preserve the native vegetation and mitigate degradation of Caatinga because of overgrazing. In Pernambuco, the *Opuntia* (Gigante, Redonda and IPA-20) are among the most cultivated cultivars. However, these cultivars are susceptible to carmine cochineal (*Dactylopius opuntiae* Cockerell), an insect that sucks the sap and inoculates toxins that cause yellowing and falling cladodes (Vasconcelos et al., 2009).

The 'Miúda' is an alternative for cultivation in areas of susceptibility, as it presents resistance to insect attack (Santos et al., 2013). This cultivar is more appreciated by animals, has a greater concentration of soluble carbohydrates, more cladodes per plant, faster multiplication and higher precocity than other cultivars (Santos et al., 1992; Vasconcelos et al., 2007; Santos et al., 2013). Thus, it is necessary to evaluate the response of this cultivar to the most widely used management practices in spineless cactus crop.

Plant density and fertilization have been considered essential to increase the productivity of spineless cactus. These management practices contribute to an increased efficiency of water use and light interception. Considering that *Nopalea* is resistant to carmine cochineal, there is a need to evaluate the response of this genus to the management practices used. Regarding the plant density, Silva et al. (2014) observed that in the soil and climatic conditions of Frei Paulo - SE, the 'Miúda' responded positively up to 80,000 plants hectare^{-1}. Amorim et al. (2015) studied 11 varieties of the genus *Nopalea* fertilized with 200 kg ha^{-1} N, 130 kg ha^{-1} P_2O_5 and 100 kg ha^{-1} K_2O, harvested with three years and observed that productivity varied between 6,31 and 16,08 t of DM hectare^{-1}. Regarding the fertilization, Silva et al. (2016) observed that the chemical fertilization improved the extraction of some nutrients. The application of 200-150-100 kg ha^{-1} year^{-1} of NPK caused an extraction of 413.4, 21.95 and 100.5 of nitrogen, phosphorus and sulphur, while in plots without fertilization the extraction was 180.2, 12.4 and 17.1, respectively.

The objective was to evaluate the effect of nitrogen and phosphorus fertilization, plant density and sites on productivity and chemical composition of the spineless cactus 'Miúda' (*Nopalea cochenillifera*, Salm Dyck).

Materials and Methods

The experiment was carried out the at experimental research station, Agricultural Institute of Pernambuco (IPA), located in Caruaru and São Bento do Una, both located in the Agreste region of Pernambuco State, from May, 1998 to May, 2000. The experimental research stations have coordinates and altitude of 8°31'56" S, 36°33'0" W, and 537 m for Caruaru, and 8°14'18" S, 35°55'20" W, 558 m for São Bento do Una, above sea level.

The rainfall during the experimental period was 1,008 mm in Caruaru and 806 mm in São Bento do Una, with 36.5% and 42.2% occurring in the first year of cultivation, respectively (Figure 1). The soil in both sites is classified as Entisol, with texture loamy sand (Dubeux Jr. et al., 2006; Santos et al., 2013a).

We evaluated cultivation site, N and P fertilization, as well as plant densities, in a randomized complete block design with split-split plot arrangement and 4 replications. The studied clone was 'Miúda' (*Nopalea cochenillifera* Salm Dyck). The main plot consisted of the sites (Caruaru and São Bento do Una); in the split-plot was evaluated levels of N fertilization (0, 150, 450 and 600 kg N ha^{-1} yr^{-1}) and P fertilization (0 and 150 kg P_2O_5 ha^{-1} yr^{-1}) with complete factorial arrangement, and the split-split plot consisted in plant density (5,000 plants ha^{-1} and 40,000 plants ha^{-1}). A spacing of 2.0 x 1.0 m was applied for 5,000 plants ha^{-1} and 1.0 x 0.25 m for 40,000 plants ha^{-1}. The split-plot was 40 m^2 and the split-split plot was 20 m^2 in total, with 12 m^2 and 6 m^2 of sampling area, respectively.

To assess the fertility of the soil in experimental areas, samples were collected from 0 to 20 cm layer, as described by Embrapa (1999). The results are shown in Table 1.

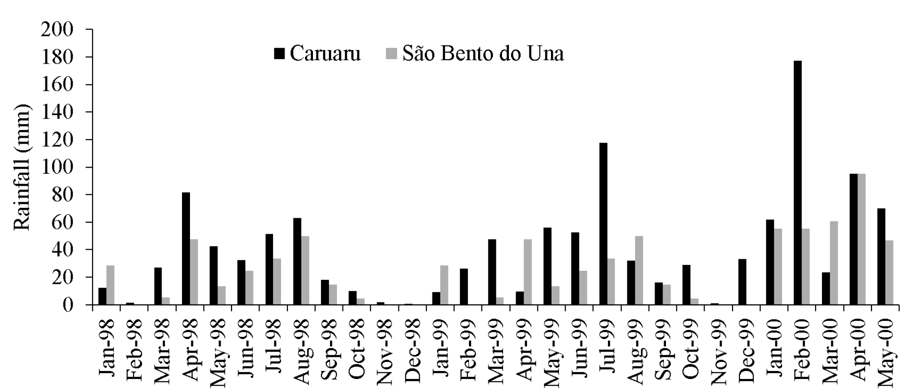


Figure 1. Rainfall (mm) Caruaru and São Bento do Una during the experimental period.

Table 1. Soil chemical characteristics at the experimental area before treatment application.

	Unit	Caruaru	São Bento do Una
pH (water)		6.78	6.10
Phosphorus[1]	mg dm^{-3}	>36	31.21
Potassium	$cmol_c\ dm^{-3}$	0.38	0.17
Calcium	$cmol_c\ dm^{-3}$	5.35	1.3
Magnesium	$cmol_c\ dm^{-3}$	0.25	0.95
Sodium	$cmol_c\ dm^{-3}$	0.13	0.05
Aluminium	$cmol_c\ dm^{-3}$	0.05	0.0
Hydrogen	$cmol_c\ dm^{-3}$	1.32	0.99
SB	$cmol_c\ dm^{-3}$	5.98	2.47
CEC	$cmol_c\ dm^{-3}$	7.48	3.46
V	%	76.72	71.39
OM	%	1.49	0.9

[1]Mehlich 1; SB - sum of bases; CEC - cation exchange capacity; V - base saturation; OM - organic matter.

Before planting, the soil was prepared for fertilization with P_2O_5 and the planting was performed later using a cladode per pit. The fertilization with N was divided in two applications (15 and 60 days after planting), according to treatments. For K fertilization, 133 and 300 kg of K_2O ha^{-1} two $years^{-1}$ were used in Caruaru and São Bento do Una, respectively, followed by soil analysis. Urea, potassium chloride, and single super phosphate were used as sources of N, K and P, respectively.

The variables analysed were dry matter productivity, and N, P, K and S concentrations. The harvest was performed two years after planting, preserving the secondary cladodes. Nutrients and dry matter (DM) concentrations were determined using the methodology described by Bezerra Neto & Barreto (2011). Data were submitted to normality test and transformed by √(x) for plant K concentration; Log(x) for productivity and plant N concentration; and Log (x + 1) for plant P and S concentration.

Data were submitted to analysis of variance using the Proc Mixed procedure from SAS (2002). LS Means were compared using the PDIFF procedure adjusted by Tukey. When the effect of quantitative factors (nitrogen fertilization) was significant ($p < 0.05$), polynomial orthogonal contrasts were used.

The statistical model used was:

$$\begin{aligned} Yijklm &= \mu + Si + bj + Nk + Pl + Dm + \\ &+ (SN)ik + (SP)il + (SD)im + (NP)kl + \\ &+ (ND)km + (PD)lm + (SNPD)iklm + \varepsilon ijklm \end{aligned}$$

in which: $Y_{ijklm =}$ represents the mean response of site i, in the block j, N fertilization k, P fertilization l and plant density m; μ = population mean; Si = site effect; b_j = block effect; ε_{ijklm} = random error; N_l = N fertilization effect; $P_{k =}$ N fertilization effect; D_m = plant density effect; $(SN)_{ik}$ = interaction effect between site and N fertilization; $(SP)_{il}$ = interaction effect between site and P fertilization; $(SD)_{im}$ = interaction effect between site and plant density; $(NP)_{kl}$ = interaction effect between N fertilization and P fertilization; $(ND)_{km}$ = interaction effect between N fertilization and plant density; $(PD)_{lm}$ = interaction effect between P fertilization and plant density; $(SNPD)_{iklm}$ = interaction effect between site, N fertilization, P fertilization and plant density.

Results and Discussion

According to the analysis of variance, all factors presented either single effect or interacted with other factor, affecting the productivity and cladode nutrient concentration (Table 2).

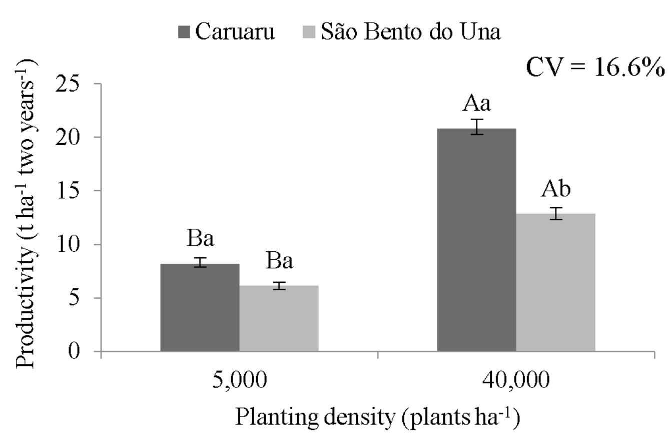
Productivity was influenced by site, plant density and by interactions between site with plant density and N fertilization with plant density. Plant density of 40,000 plants ha^{-1} resulted in greater productivity than 5,000 plants ha^{-1} in both sites. Dry matter productivity was 8.2 and 20.4 t ha^{-1} two $years^{-1}$ in Caruaru, and 6.12 and 12.8 t ha^{-1} two $years^{-1}$ in São Bento do Una, with 5,000 and 40,000 plants ha^{-1}, respectively. In plant density of 5,000 plants ha^{-1} there was no effect of site, however, with 40,000 plants ha^{-1}, the productivity was greater in Caruaru (Figure 2).

The increase in productivity due to plant density can be explained by the increase in the number of plants per area, thus increasing the area index of cladodes and, consequently, the photosynthetic efficiency caused by the reduction of bare soil (Nobel & Bobich, 2002; Silva et al., 2016a). In evaluation of plant densities in *Opuntia* and *Nopalea*, Cavalcante et al. (2014) observed that increasing plant density reduced number of cladodes per plant, length and width of cladodes; however, there was increase in DM productivity, accumulation of water and nutrients per area. Silva et al. (2014) tested plant densities ranging between 10,000 and 80,000 plants ha^{-1} and observed that

Table 2. Analysis of variance for plant N, P, K and S concentration and productivity of *Nopalea* fertilized with N and P in two plant densities and two sites.

Treatments	DMY	Nitrogen	Phosphorus	Potassium	Suphur
Site	0.035 *	0.001 **	0.190 ns	0.015 *	0.011 **
N	0.398 ns	0.0002 **	0.126 ns	0.335 ns	0.082 ns
P	0.280 ns	0.952 ns	0.211 ns	0.878 ns	0.149 ns
D	0.0004 **	0.006 **	0.220 ns	0.011 *	0.910 ns
Site x N	0.969 ns	0.039 *	0.302 ns	0.413 ns	0.219 ns
Site x P	0.443 ns	0.311 ns	0.547 ns	0.805 ns	0.391 ns
Site x D	0.031 *	<.0001 **	0.054 *	0.0006 **	0.942 ns
N x P	0.840 ns	0.516 ns	0.599 ns	0.899 ns	0.341 ns
N x D	0.007 **	0.060 ns	0.293 ns	0.060 ns	0.488 ns
P x D	0.071 ns	0.215 ns	0.031 *	0.364 ns	0.810 ns
Site x N x P x D	0.392 ns	0.121 ns	0.045 *	0.264 ns	0.290 ns

DMY - dry matter yield; N - nitrogen; P - phosphorus; D - plant density; Significance levels: **P<0.01, *P<0.05 nsP≥0.05.



Means followed by different letters, uppercase letter compare plant density and lowercase letter compare site, are different by the LSMEANS test to 5% probability; CV = coefficient of variation.

Figure 2. Productivity of *Nopalea* affected by plant density in two sites. Bars indicate standard error.

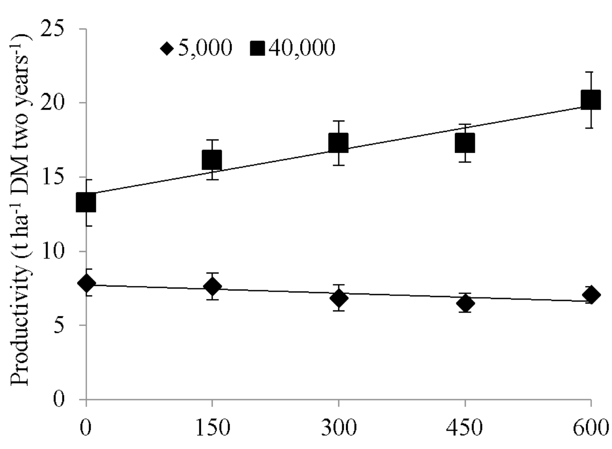
there was a positive response in the productivity of genotypes of *Opuntia* and *Nopalea*, including increased productivity in the 'Miúda', which showed the suitability of high plant density for this cultivar. Santos et al. (2006) evaluated clone IPA-20 in Caruaru with the same plant densities tested in this research. They found greater productivity with the greatest plant density for these two biennial crops.

Regardless of plant density, the productivity in Caruaru was greater than in São Bento do Una, which can be explained by differences in soil characteristics, with the greatest levels of macronutrients such as P, K and Ca or soil organic matter observed in Caruaru. Other characteristics that might explain the differences as physical characteristics of soil and/or rainfall during the experimental period, which probably allowed changes in the absorption of water and nutrients, root development, microbial activity and decomposition of soil organic matter (Troeh & Thompson, 2007).

The productivity was affected by interaction between N fertilization and plant density. In plots with 5,000 plants ha^{-1} there was no effect of N fertilization, however, in plots with 40,000 plants ha^{-1}, it was observed positive linear response. In plots with 40,000 plants ha^{-1}, the DM yield varied between 13.8 t of DM ha^{-1} two years^{-1}, on treatment without N fertilization and 19.8 t of DM ha^{-1} two years^{-1}, on treatment with 600 kg of N ha^{-1} year^{-1} (Figure 3).

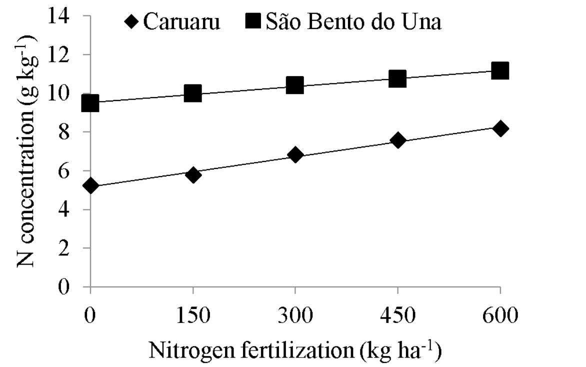
The lack of response of the plots containing 5000 plants ha^{-1} to the N fertilization can be justified by the greater area of bare soil and low light interception, which probably contributed to increase the losses of N. The difference in the response to N fertilization may be due to greater nutrient use efficiency per area with high plant density (Santos et al., 2006).

The plant N concentration was affected by site, N fertilization, plant density, site interaction with N fertilization, and site with plant density. Nitrogen concentration increased linearly with an increase of N fertilization in both sites, with greater N concentration observed in São Bento do Una. Nitrogen concentration ranged from 9.5 to 11.2 g kg^{-1} in plants of São Bento do Una and from 5.19 to 8.25 g kg^{-1} in plants of Caruaru, with increasing N levels from 0 to 600 kg N ha^{-1} year^{-1}, respectively (Figure 4).



Bars indicate standard error $\hat{Y}_{5,000}$ = 1.112 + 0.0003N (R^2 = 0.93; CV= 10.4 P< 0.0001); $\hat{Y}_{40,000}$ = 7,16.

Figure 3. Productivity of *Nopalea* affected by nitrogen fertilization and plant density.



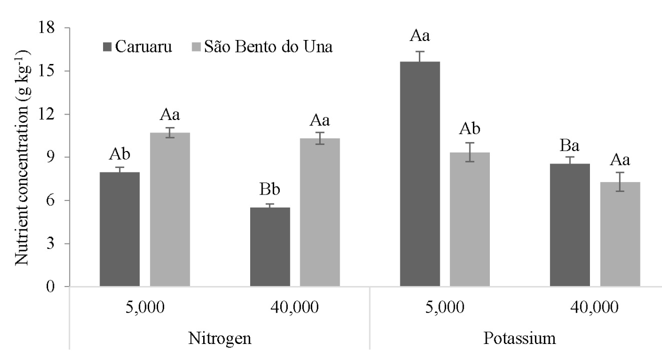
Bars indicate standard error. São Bento do Una: $\hat{Y}$= 9.523 + 0.0028N (R^2 = 0.99; CV= 19.7); P= 0.01; Caruaru: $\hat{Y}$ = 5.1919 + 0.0051N (R^2 = 0.99; CV= 13.2 P<0.0001).

Figure 4. Plant N concentration of *Nopalea* affected by nitrogen fertilization and plant density.

The elevation of N concentration in cladodes due to N fertilization can be explained by the greater availability of this nutrients in the soil, as reported by Silva et al. (2012). Dubeux Jr. et al. (2006) evaluated the effect of nitrogen fertilization on N concentration in cladodes of *Opuntia* grown in four sites of Pernambuco (Arcoverde, São Bento do Una, Sertânia and Serra Talhada) and observed that there was a linear effect of nitrogen fertilization in three evaluated sites, with variation in N concentration of cladodes between 6.7 and 13.9 g of N kg^{-1} of dry matter. Greater cladode N concentration in São Bento do Una can result from the dilution effect (Dubeux Jr. et al., 2006), promoted by the increased productivity of the plants in Caruaru.

Regarding the interaction between plant density and site, it was observed that at the two plant densities evaluated, plant N concentration in plants of São Bento do Una was greater than observed in plants grown in Caruaru. Cactus N concentration at 5,000 plants ha^{-1} ranged from 7.96 to 10.7 g kg^{-1} and at 40,000 plants ha^{-1} ranged from 5.50 to 10.01 g kg^{-1}, in plants of Caruaru and São Bento do Una, respectively (Figure 5). In Caruaru, plant N concentration was greater when cactus was grown at 5.000 plants ha^{-1}. However, in São Bento do Una there was no effect of plant density for plant N concentration.

Plant P concentration was affected by interaction among all tested factors. There was a quadratic response to N fertilization in plots of São Bento do Una, with 40,000 plants ha^{-1} and 150 kg P ha^{-1}. The reduction in plant P concentration with the



Bars indicate standard error. Means followed by different letters, uppercase letter compares plant density and lowercase letter compare site, are different by the LSMEANS test to 5% probability; CV for N concentration = 4.48%; CV for K concentration = 19.47%.

Figure 5. Plant N concentration affected by plant density in two sites.

Table 3. Plant P concentration affected by site, planting density, and P and N fertilization.

N (kg ha^{-1})	Caruaru				São Bento do Una			
	5,000 plants ha^{-1}		40,000 plants ha^{-1}		5,000 plants ha^{-1}		40,000 plants ha^{-1}	
	P fertilization (kg ha^{-1})				P fertilization (kg ha^{-1})			
	0	150	0	150	0	150	0	150
0	0.98	1.84	1.65	1.28	1.32	1.45	1.41	2.07
150	0.53	1.56	0.40	0.82	0.89	1.95	2.04	1.45
300	0.54	1.49	0.59	1.41	1.38	1.19	1.37	0.88
450	1.71	0.85	0.63	0.55	1.44	1.55	1.11	1.64
600	1.30	1.18	1.28	0.76	1.71	2.42	1.71	1.84
P – value	0.50 ns	0.43 ns	0.25 ns	0.45 ns	0.42 ns	0.12 ns	0.69 ns	0.005 **
SEM	0.29	0.26	0.28	0.21	0.16	0.15	0.17	0.13
CV	16.55	9.57	14.76	10.62	7.78	7.23	6.08	5.46

**Ŷ = 2.053 – 0.006N + 0.000009N^2; CV - coefficient of variation; SE - standard error of the mean; Significance levels: ^{ns}P>0.05; **P<0.01.

increase in nitrogen fertilization until the dose estimated of 322 kg N (maximum point), when the P in forage reached 1.19 g kg^{-1}, increasing thereafter. In other treatments, no significant effect was observed (Table 3).

The quadratic response for cladode P concentration observed in plants of São Bento do Una, with 40,000 plants ha^{-1} and 150 kg P ha^{-1}, might be explained by dilution effect, caused by the increase of N fertilization on plant development. The lack of effect occurred in Caruaru, with application of same treatments of São Bento do Una, might be justified by greater soil P (> 36 mg dm^{-3}), supplying the nutrients required by plants (Table 1). Cavalcante et al. (2008) observed that when soil P concentration is greater than 30 mg dm^{-3}, there is no need for P fertilization. Although in São Bento do Una soil P concentration was greater than this limit (31 mg dm^{-3}), the difference in plant response might be because of greater rainfall amount (Figure 1) or soil organic matter (Table 1) in the Caruaru trial, which are determinant factors controlling the release of this nutrient to plants. The difference in rainfall amount and soil organic matter between locations might have also contributed to the site effect.

Plant K concentration was affected by site, plant density, and interaction of cultivation site with plant density. Plant K concentration in plots with 5,000 plants ha^{-1} in Caruaru was greater than in plots 40,000 plants ha^{-1}, with values of 15.7 and 9.3 g kg^{-1}, respectively. In São Bento do Una, however, no effect was observed for plant density, with plant K concentration 8.56 and 7.28 g kg^{-1}, for 5,000 and 40,000, respectively. At 5,000 plants ha^{-1}, plant K concentration was greater in plots of Caruaru, but with 40,000 plants ha^{-1}, no effect was observed for site (Figure 5).

The greater plant K concentration in plants of Caruaru likely resulted from greater amount of K in this soil (Table 1). Furthemore, the leaching losses resulting from the greater solubility of K in the soil solution may have been lower in the soil at Caruaru, due to greater soil organic matter concentration and soil cation exchange capacity (CEC). The potassium is responsible by regulation of osmotic potential in the cells, essential in the water use efficiency and absorption of CO_2, being one of the main elements found in the spineless cactus, which explains the high extraction of this nutrient (Taiz & Zeiger, 2009; Contreras-Padilla et al., 2015). Silva et al. (2012) observed K concentration of 24.4 and 24.9 g kg^{-1}, to the 390 and 620 days after the planting, respectively.

For plant sulphur concentration, there was no effect of N or P fertilization and plant density, with average of 1.4 g S per kg of DM. However, there was an effect of site, where plants from São Bento do Una showed greater sulphur concentrations than plants from Caruaru. Mean values of 1.86 and 0.9 g kg^{-1} were observed for plants in São Bento do Una and Caruaru, respectively.

The sulphur is indirectly added to the soil by addition of formulations of low NPK concentration, as single super phosphate, ammonium sulphate and gypsum (Raij, 2011). The cladode sulphur concentration observed in this work was lower than the ones observed in the literature. Silva et al. (2012) observed that the S concentration in *Opuntia* was 3.0 and 3.7 g kg^{-1} at 390 and 620 days after plant, respectively. Dubeux Jr. et al. (2010) observed that cv. IPA 20 presented an average of 6.10 g kg^{-1} of S, at 180 days after plant. Part of the S requirement of crops can be supplied by organic matter of soil and, in industrial areas, by atmospheric deposition, resulting from the burning of wood or fossil fuels.

Conclusions

Nitrogen fertilization increase plant N concentration of *Nopalea cochenillifera* Salm Dyck. Nitrogen fertilization also increase the productivity but only at the higher plant density.

The higher plant density increased the productivity and reduced plant N and P concentrations, but the response is site dependent.

The association of high plant density and chemical fertilization is necessary to raise productivity and maintain adequate levels of nutrients in cactus 'Miúda'.

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