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Yield and vegetative growth of cactus pear at different spacings and under chemical fertilizations

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Key words:
Opuntia
plant arrangement
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yield

ABSTRACT

The objective was to evaluate the effect of different spacings and mineral fertilizations on cactus pear growth and production in a randomized block design, with three replicates, in a 3 x 4 factorial scheme: three spacings, 1.00 x 0.50 m, 2.00 x 0.25 m and 3.00 x 1.00 x 0.25 m, and four fertilizations, 000-000-000, 000-150-000, 200-150-000 and 200-150-100 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. Plant growth was evaluated between 90 and 390 days and production and growth were evaluated at 620 days after planting. There were significant interactions between spacing and fertilization for plant height, number of cladodes and cladode area index from 90 to 390 days and for production of fresh and dry matter at 620 days after planting. Spacing influenced cladode area index, while fertilization influenced plant height, number of cladodes and cladode area index at 620 days after planting. Plant height showed cubic effect for the days after planting. Number of cladodes and cladode area index were dependent on spacing, fertilization and plant age, and fitted to cubic models. The best results of growth and production of fresh and dry matter are associated with NPK and NP fertilizations and the spacing of 1.00 x 0.50 m.

Palavras-chave:
Opuntia
arranjo de plantas
fertilização
rendimento

Produtividade e crescimento vegetativo da palma forrageira sob espaçamentos e adubações química

RESUMO

Objetivou-se, neste trabalho, avaliar o efeito de espaçamentos e adubação mineral sobre crescimento e produção da palma forrageira, em um delineamento em blocos casualizados, com três repetições, esquema fatorial 3 x 4 correspondente a três espaçamentos, 1,00 x 0,50 m; 2,00 x 0,25 m e 3,00 x 1,00 x 0,25 m e quatro adubações, 000-000-000; 000-150-000; 200-150-000 e 200-150-100 kg ha^{-1} de N-P_2O_5-K_2O. Avaliaram-se crescimento entre 90 e 390 dias após o plantio; produção e crescimento aos 620 dias. Ocorreram interações entre espaçamento e adubação para altura da planta, número de cladódios e índice de área de cladódios dos 90 aos 390 dias e para a produção de massa verde e matéria seca aos 620 dias após plantio. O espaçamento influenciou o índice de área de cladódio. Adubação influenciou: altura da planta, número de cladódios e índice de área de cladódio aos 620 dias após plantio. Altura da planta apresentou efeito cúbico para dias após plantio. O número de cladódios e o índice de área de cladódios foram dependentes do espaçamento, adubação e idade das plantas ajustando-se aos modelos cúbicos. O maior crescimento e a produção de massa verde e matéria seca são associados às adubações com NPK e NP no espaçamento 1,00 x 0,50 m.

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Introduction

Brazil has approximately 600 thousand hectares of cactus pear, with predominance of the species *Opuntia ficus-indica*, the 'Gigante' cactus (Araújo et al., 2005). Currently, there is expansion of cultivation in the semiarid region of Bahia, but with technologies that are insufficient for plants to express their entire potential. Changes in management, such as combination of spacings and fertilization, may increase production and nutritional composition. Population must vary with soil fertility, amount of rainfalls and type of activity (Oliveira Jr. et al., 2009). Ramos et al. (2011) and Silva et al. (2014) concluded that spacing influences phytomass production, with greater increments for increasing densities. Evaluating fertilization and population density, Silva et al. (2012) concluded that fertilizations increase production, contents of nutrients and improve the nutritional value. The plant has great potential of extraction of soil nutrients; thus, the sustainability of the production systems tends to decrease over time, due to reduction in fertility (Dubeux Júnior et al., 2006). The influence of fertilization on crop yield is evidenced by Stewart et al. (2005), who evaluated 362 plantations and observed that 30 to 50% of the yields of these crops are attributed to nutrients from fertilizers with N, P and K. Therefore, this study aimed to evaluate the effect of different spacings and mineral fertilization on cactus pear growth and production.

Material and Methods

The experiment was carried out at the Federal Institute of Bahia, campus of Guanambi-BA, Brazil, in a medium-textured dystrophic Red-Yellow Latosol, under an Aw climate, according to Köppen's classification, with annual means of rainfall and temperature of 664 mm and 26 ºC, respectively. The rainfall during the cultivation period, from September 2009 to July 2011, was equal to 611 mm, from September 2009 to May 2010 and to 782 mm from October 2010 to April 2011, with total of 1393 mm during the experimental period.

The experiment was set in randomized blocks with twelve treatments arranged in a 3 x 4 factorial scheme with three replicates, corresponding to three planting spacings: single row, 1.00 x 0.50 m; single row, 2.00 x 0.25 m and double row, 3.00 x 1.00 x 0.25 m, all with population of 20,000 plants ha^{-1}, and four combinations of fertilization (regional use): without chemical fertilization; phosphate fertilization (P), at the dose of 150 kg ha^{-1} of P_2O_5; nitrogen and phosphate fertilization (NP) at the doses of 200 kg ha^{-1} of N and 150 kg ha^{-1} of P_2O_5; nitrogen, phosphate and potassium fertilization (NPK), at the doses of 200 kg ha^{-1} of N, 150 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of K_2O.

Thirty six experimental units were delimited with dimensions of 16 x 4 m and evaluation area of 8.00 x 2.00 m. Soil samplings were performed at the depth of 0.20 m and the mean results were: pH in water = 5.3; P = 10.6 and K = 53.8 mg dm^{-3}; Na = 0.1; Ca = 1.4; Mg = 0.9; Al = 0.1; (H + Al) = 1.8; SB = 2.4; t = 2.6 and T = 4.4 cmol$_c$ dm^{-3}; V = 54.5 and m = 5.0%; Cu = 0.3; Fe = 7; Mn = 57.7; Zn = 2.0 mg dm^{-3}. The soil has sandy clay loam texture (20% of clay) and was subsoiled, harrowed and furrowed in each meter, at depth of 0.30 m. Planting was performed in late September 2009 using one cladode per hole. The obtained seedlings were maintained in the shade for 15 days, in order to heal harvest wounds.

At planting, the plots corresponding to the treatments received phosphate fertilization at the dose of 150 kg ha^{-1} of P_2O_5 (5.33 kg of single superphosphate). During the experiment, top-dressing fertilizations with nitrogen, 200 kg ha^{-1}, and potassium, 100 kg ha^{-1} (6.4 kg plot^{-1} of ammonium sulfate and 1.10 kg plot^{-1} of potassium chloride) were divided into four applications, corresponding to 15, 25, 30 and 30% of the total, respectively. The first application was performed after proper seedling development on December 28, 2009, the second one on February 23, 2010, the third and fourth on November 14 and December 27, 2010.

Evaluations of growth, plant height, number of cladodes, length, width, thickness and area of cladodes were performed every 30 days from 90 until 390 days after planting (DAP). Four random plants from the evaluation area of each plot were evaluated, in a total of 144 plants. Plant height and cladode width and length were measured using a tape measure. Cladode width and length measurements considered the region with greatest width and length, while plant height was measured from the soil surface until the tip of the highest cladode. Thickness was evaluated using a caliper in the intermediate region of the cladodes. In addition, the cladode area index (CAI) was obtained through the multiplication of the mean cladode area (both sides) by the number of cladodes on the plant, divided by the area occupied by the plant.

Plant height, number of cladodes, CAI, fresh matter production (FMP) and dry matter production (DMP) were evaluated at 620 DAP. For the determination of DMP, approximately 50 samples of 25 to 30 g were collected in each treatment, using a 5-cm-diameter hole saw. An order was established in such a way that all cladodes that would be harvested were sampled. From the collected samples, 1,000 g of fresh matter were dried in a forced-air oven at 60 ºC for 72 h, in order to obtain the dry matter (Silva & Queiroz, 2009).

The cladodes of the evaluation area, except the primary ones, were harvested for the determination of FMP (Mg ha^{-1}). DMP was calculated as a function of the content of dry matter (DM) multiplied by FMP.

The data were subjected to analysis of variance by F test at 0.05 probability level. Follow-up analyses were performed for significant interactions and means were compared by Duncan's test at 0.05 probability level. For monthly growth evaluations, from 90 to 390 DAP, regression analyses were used. The criteria used for the selection of regression models considered the adequacy of the model to the studied phenomena, the fitted values of coefficient of determination and the significance of regression parameters by t-test.

Results and Discussion

There were significant interactions ($p < 0.05$) between the planting spacings and the chemical fertilizations in the period comprehended between 90 and 390 DAP, for plant height, number of cladodes per plant and CAI (Table 1).

Table 1. Mean morphometric characteristics evaluated between 90 and 390 days after planting, in cactus pear subjected to different spacings and chemical fertilizations

Morphometric characteristics	Spacings (m)	N-P_2O_5-K_2O fertilizations (kg ha^{-1})				CV (%)
		000-000-000	000-150-000	200-150-000	200-150-100	
Plant height (cm)	S_1 - 1.00 x 0.50	64.06 bA	63.96 bA	70.46 aA	72.76 aA	7.6
	S_2 - 2.00 x 0.25	62.71 bcAB	62.18 cA	66.38 aB	65.02 abB	
	S_3 - 3.00 x 1.00 x 0.25	60.77 bB	63.06 abA	62.96 abC	65.29 aB	
Number of cladodes per plant	S_1 - 1.00 x 0.50	6.59 cA	6.97 cA	8.84 bA	9.53 aA	18.6
	S_2 - 2.00 x 0.25	6.04cA	6.11 cB	7.48 bB	8.56 aB	
	S_3 - 3.00 x 1.00 x 0.25	6.34 bA	6.25 bB	7.45 aB	7.27 aC	
Cladode area index (m^2 m^{-2})	S_1 - 1.00 x 0.50	0.65 dA	0.74 cA	0.96 bA	1.09 aA	20.3
	S_2 - 2.00 x 0.25	0.59 cA	0.64 cB	0.84 bB	0.96 aB	
	S_3 - 3.00 x 1.00 x 0.25	0.60 cA	0.67 bcB	0.75 abC	0.77 aC	

Means followed by the same letter, lowercase in the row and uppercase in the column, do not differ significantly by Duncan's test at 0.05 probability level; CV – Coefficient of variation

At the spacings of 1.00 x 0.50 m and 3.00 x 1.00 x 0.25 m, plants fertilized with NPK and NP showed greater height and higher number of cladodes ($p < 0.05$), respectively, compared with the treatments without fertilizer and with P application, while at spacings of 1.00 x 0.50 m, for the number of cladodes, and 2.00 x 0.25 m, for the number of cladodes and CAI, the values were higher in plants fertilized with NPK, in comparison to NP; plants fertilized with P and without fertilization showed the lowest values.

Plant height at the spacing of 2.00 x 0.25 m was higher for the treatment with NP in comparison to P and, at the spacing of 3.00 x 1.00 x 0.25 m, higher in plants fertilized with NPK, compared with those without fertilizer. Similar behavior occurred for CAI at the spacing of 3.00 x 1.00 x 0.25 m. At the spacing of 1.00 x 0.50 m, CAI differed between the fertilizations, with decreasing order of values, as follows: NPK → NP → P without fertilization.

In plants without fertilization, the number of cladodes and CAI were similar ($p < 0.05$) at the three spacings, while plant height was higher at the spacing of 1.00 x 0.50 m in relation to 3.00 x 1.00 x 0.25 m. Plants fertilized with NPK grew more in height at the spacing of 1.00 x 0.50 m and there was a decrease in the number of cladodes and CAI from 1.00 x 0.50 m to 2.00 x 0.25 m and 3.00 x 1.00 x 0.25 m. This result was also observed for plant height and CAI in plants under NP fertilization, while the number of cladodes was higher at the spacing of 1.00 x 0.50 m; in plants fertilized with only P, plant height was similar between the adopted spacings and the number of cladodes and CAI per plant were higher for the spacing of 1.00 x 0.5 m.

Fertilizations with NPK and NP stimulated the increase in plant height, number of cladodes and CAI. The fertilizers increased the availability and transport of nutrients, promoting greater absorption by plants, which resulted in higher growth and production (Novais & Mello, 2007). Stewart et al. (2005) claim that nitrogen is the nutrient that most increases yield gains in agricultural crops and the one that most limits production, particularly under adequate supply of phosphorus. Growth, leaf area and production are influenced by the applied doses of N and P and their interactions (Araújo & Machado, 2006). The application of nitrogen in the soil in the presence of phosphorus induces greater root and shoot growth, higher metabolism and greater absorption (Cantarella et al., 2007).

The similarity between the data of plants in the soil with and without P may have occurred because 'Gigante' cactus has low capacity of response to phosphate fertilization, with positive performance only when the P content in the soil is lower than 10 mg dm^{-3} (Dubeux Júnior et al., 2010), a situation close to that in the present study, in which soil P content was 10.6 mg dm^{-3}. Dubeux Júnior et al. (2010) observed no effect of P, K and their interaction on the number of cladodes. Teles et al. (2002) observed no influence of P and K on the number of primary cladodes. For the cactus pear IPA-20, under fertilization levels, Dubeux Júnior et al. (2006) reported increase in the number of cladodes with N in quadratic response at the level of P = 0 and in positive linear response with 76 kg ha^{-1} of P_2O_5.

In the absence of fertilization, the number of cladodes per plant and CAI were similar between plants at all planting spacings adopted. In general, there was a predominance of greater values for the morphometric characteristics associated with the single rows of 1.00 x 0.50 m for the fertilizations of NPK, NP and P. Plants in double row, spaced by 3.00 x 1.00 x 0.25 m, showed lower means when subjected to fertilization. This arrangement, despite providing the same area occupied by the plant, results in plants closer along the row, concentrating the root system and increasing the competition in the zone of absorption, which limits the explored area and the availability of nutrients. In this context, Silva et al. (2010) report that the arrangement of plants can be modified by varying plant population and the spacing between rows, changing the area and the form of the area available for each plant.

At the spacing of 1.00 x 0.50 m, there is higher uniformity of distribution of plants with greater soil exploration by the root system and less shading between neighboring plants, which favors the photosynthetic efficiency, i.e., there is greater growth.

In the evaluations of growth over time (90 to 390 days), cubic models were fitted to plant height (Figure 1) as a function of DAP.

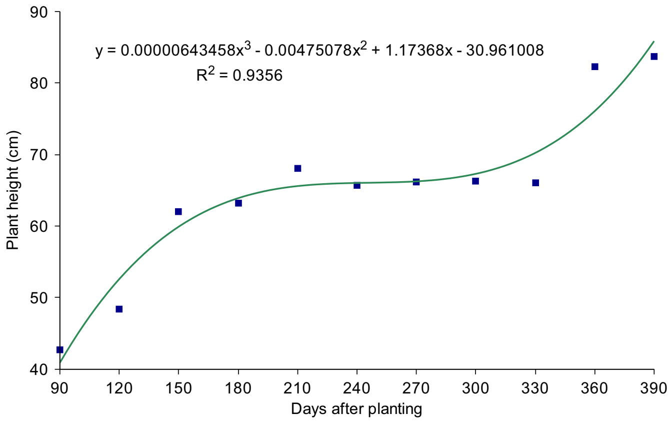

Figure 1. Mean plant height of cactus pear as a function of days after planting

The fitted models are justified by the alternance between periods with conditions favorable due to rainfall and unfavorable due to aridity to cactus pear growth. According to the comparison between rainfall data and growth curves (Figure 2) fitted as a function of DAP, the beginning of the evaluations coincided with the end of a rainy period (January to April 2010), followed by a drought period (May to September 2010) and restart of the rainfalls (October and November 2010), for the number of cladodes and CAI as a function of DAP and spacing (Figure 2A and B) and also as a function of DAP and fertilization (Figure 2C and D). The rainy periods in the initial and final stages accelerate plant growth due to the rainfalls and greater availability of nutrients resulting from the fertilizations performed in the same period. In the period without rains coincident with the intermediate stage (210 to 300 DAP), the lack of water and also the impairment in the availability of nutrients, result in growth stabilization.

First, there was an accelerated growth in the initial stage until the first 150 DAP in the rainy period, followed by a semi-dormancy stage coinciding with the dry period and then a new accelerated growth surpassing the initial stage. The values fitted to a cubic model, with adequate coefficients of determination, which varied from 0.88 to 0.92 (Figure 2A), 0.88 to 0.91 (Figure 2B), 0.90 to 0.93 (Figure 2C) and 0.91 to 0.93 (Figure 2D). Under these conditions, cactus pear has high growth in cladode area, with great accumulation of water as a mechanism of survival preferential to CO_2 balance and accumulation of dry matter.

The number of cladodes at the spacing of 1.00 x 0.50 m was higher during the entire evaluation period (Figure 2A). Until approximately 240 DAP, the number of cladodes at the spacing of 3.00 x 1.00 x 0.25 m was higher in comparison to 2.00 x 0.25 m; after 240 DAP, there was an inversion that can be explained by the growth of the crop, increasing the competition between plants for soil exploration and possibly for luminosity, because plants are closer along the row.

According to Figure 2B, the treatment with NPK, virtually during all the period, showed higher number of cladodes per plant and the treatment with P was similar to that without fertilization. At the end of the period, the curves of number of cladodes are similar between the treatments with NPK and NP, which can be explained by the increase in the root system, which explores larger areas, and the coincidence of high rainfall intensity, facilitating the availability of nutrients and making uniform the conditions between both treatments, besides the previously discussed reasons.

CAI depends on plant growth and arrangement and its curves also show a cubic behavior (Figure 2C and D). At the spacing of 1.00 x 0.50 m, plants showed greater CAI compared with the other spacings. The treatments with NPK showed greater CAI compared with the others. CAI curves for the treatments with P fertilization and without fertilization were similar during almost the entire evaluation period. At the final stage, the greater water availability resulting from rainfalls improved the diffusive flow of P in the soil and the use of fertilization; thus, CAI values in the treatment with P surpassed the treatment without fertilization.

Plant height and the number of cladodes at 620 DAP were influenced by fertilization ($p < 0.05$), regardless of the spacing. CAI varied ($p < 0.05$) with spacing and fertilization independently (Table 2).

The lowest plant height ($p < 0.05$) was observed in the soil without fertilization, compared with the use of NPK, NP and P (Table 2) and is consistent with the results of Silva et al. (2010), who studied the effects of organic and chemical fertilizers on 50 clones of cactus at 720 DAP, for a planting

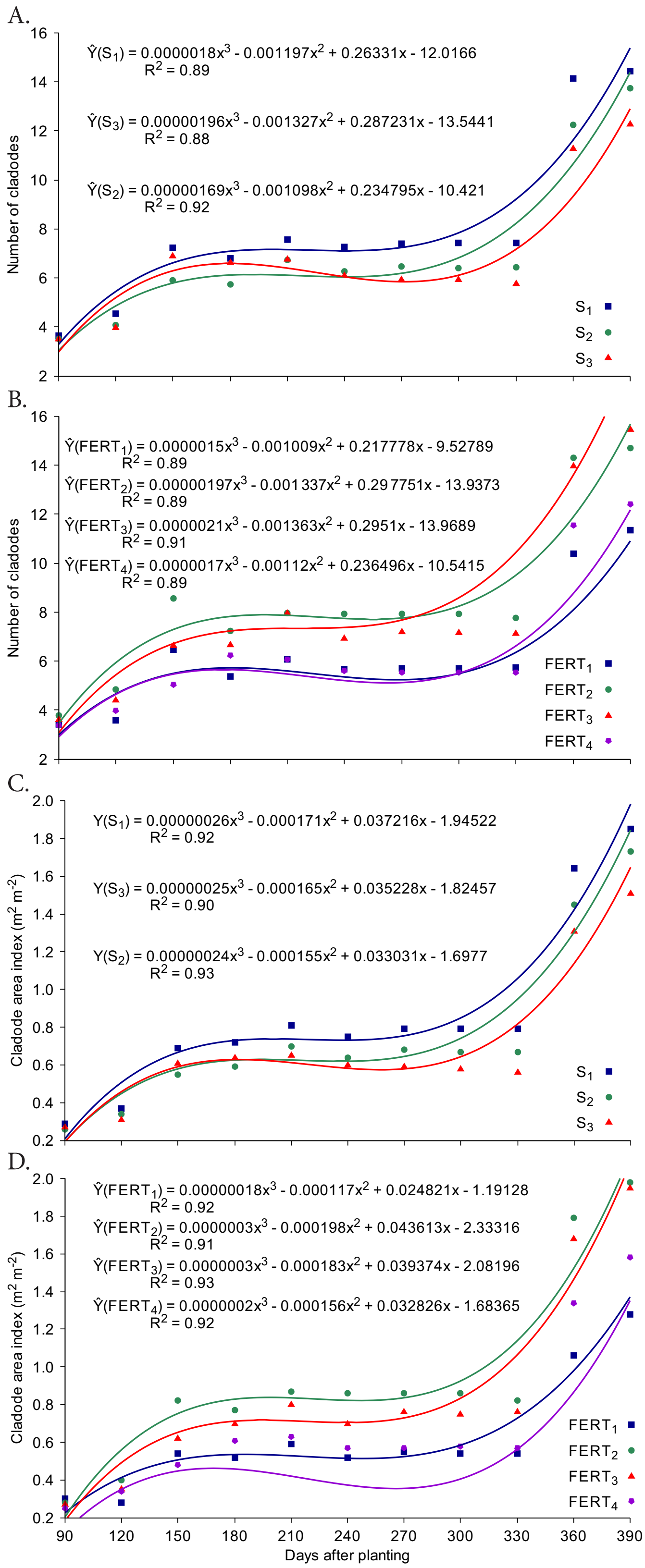

Figure 2. Number of cladodes and cladode area index of cactus pear subjected to different spacings (A and C) and N-P-K fertilizations (B and D) as a function of days after planting

Table 2. Mean morphometric characteristics evaluated at 620 days after planting in cactus pear subjected to different spacings and chemical fertilizations

Morphometric characteristics	Spacing (m)			N-P_2O_5-K_2O fertilizations (kg ha^{-1})				CV (%)
	S_1 – 1.00x0.50	S_2 – 2.00x0.25	S_3 – 3.00x1.00x0.25	000-000-000	000-150-000	200-150-000	200-150-100	
Plant height (cm)	87.92	85.29	83.83	75.72 B	86.53 A	87.61 A	92.86 A	9.25
Number of cladodes per plant	13.00	12.08	11.33	10.47 C	11.58 BC	12.61 AB	13.89 A	14.37
Cladode area index (m^2 m^{-2})	1.79 A	1.79 A	1.51 B	1.25 C	1.57 B	1.72 B	2.08 A	14.81

Means followed by the same letter, lowercase in the row, for spacing and types of fertilization, do not differ significantly by Duncan's test at 0.05 probability level; CV – Coefficient of variation

Table 3. Fresh and dry matter production (Mg ha^{-1}) at 620 days after planting in cactus pear subjected to different spacings and fertilizations

Production (Mg ha^{-1})	Spacings (m)	N-P_2O_5-K_2O fertilizations (kg ha^{-1})				CV (%)
		000-000-000	000-150-000	200-150-000	200-150-100	
Fresh matter	S_1 - 1.00 x 0.50	131.67 cB	227.67 bA	275.67 abA	309.67 aA	15.27
	S_2 - 2.00 x 0.25	200.00 aA	192.67 aA	200.00 aB	242.00 aB	
	S_3 - 3.00 x 1.00 x 0.25	157.67 bAB	224.67 aA	214.33 abB	208.00 abB	
Dry matter	S_1 - 1.00 x 0.50	13.40 bB	19.38 aA	20.87 aA	22.73 aA	15.36
	S_2 - 2.00 x 0.25	18.11 aA	14.87 aA	16.12 aB	18.24 aB	
	S_3 - 3.00 x 1.00 x 0.25	14.13 aAB	16.05 aA	15.67 aB	15.68 aB	

Means followed by the same letter, lowercase in the row and uppercase in the column, do not differ significantly by Duncan's test at 0.05 probability level; CV – Coefficient of variation

density of 20,000 plants ha^{-1} at the spacing of 1.00 x 0.50 m, and observed variation from 45.2 to 127.3 cm and mean of 90.1 cm.

The number of cladodes was higher in plants under NPK fertilization, in comparison to those not fertilized and fertilized with only P. Ramos et al. (2011) observed 11.45 cladodes at 455 DAP. Teles et al. (2002) observed differences ($p < 0.05$) between treatments with P and K for the number of secondary cladodes and total per plant. The highest mean CAI was caused by the NPK fertilization (Table 2). NP fertilization was similar to the treatment with P for CAI, while the lowest CAI value was observed in plants under no fertilization. The spacings in single rows, 1.00 x 0.50 and 2.00 m x 0.25 m, promoted higher CAI compared with the spacing in double row, 3.00 x 1.00 x 0.25 m. Teles et al. (2002), testing fertilization and nematicide in a greenhouse, observed CAI of 1.69 at 270 days. Dubeux Júnior et al. (2006) reported increasing effect on CAI as a function of P doses, with 40,000 plants ha^{-1}. A result similar to that of the treatment without fertilization was observed by Flores-Hernandes et al. (2004), with CAI of 0.67 for a one-year-old clone.

Fresh and dry matter productions at 620 DAP were dependent on the interactions ($p < 0.05$) between the planting spacings and fertilizations (Table 3). For Dubeux Júnior et al. (2006), production is dependent on the growth processes of the forage plant and may have its efficiency substantially improved by the arrangement of the plants and the use of fertilizers.

At the spacing of 1.00 x 0.50 m, the lowest FMP occurred in plants under no fertilization (Table 3). The FMP for plants fertilized with NPK was similar to that of plants fertilized with NP and higher than that of those fertilized with P, although plants fertilized with NP and P did not differ. At the spacing of 2.00 x 0.25 m, the FMP was similar for all fertilizations, while at the spacing of 3.00 x 1.00 x 0.25 m plants fertilized with P showed higher production in comparison to those under no fertilization. Ramos et al. (2011) observed yields of 130.06 Mg ha^{-1}, for the spacing of 1.00 x 0.50 m. Alves et al. (2007) observed no effect of spacings (2.00 x 1.00 m; 3.00 x 1.00 x 0.50 m and 7.00 x 1.00 x 0.50 m) on the FMP of the cultivar 'Gigante'.

The mean DMP was equal to 17.10 Mg ha^{-1} (Table 3), and plants at spacing of 1.00 x 0.50 m with NPK, NP and P produced more dry matter ($p < 0.05$) compared with plants under no fertilization. At the spacings of 2.00 x 0.25 m and 3.00 x 1.00 x 0.25 m, the productions of dry matter were similar for the different combinations of NPK. Dubeux Júnior et al. (2006) observed influence of population on the yield, with dry matter varying from 6 to 17 Mg ha^{-1} with 5,000 plants ha^{-1} (2.00 x 1.00 m) and from 17.8 a 33.7 Mg ha^{-1} with 40,000 plants ha^{-1} (1.00 x 0.25 m). Alves et al. (2007) obtained dry matter production of 5.6 Mg ha^{-1} without effect of spacing, with 5,000 and 10,000 plants ha^{-1}.

Plants without fertilization produced more fresh and dry matter ($p < 0.05$) at the spacing of 2.00 x 0.25 m, in comparison to 1.00 x 0.50 m; plants fertilized with NPK and NP produced more fresh and dry matter at the spacing of 1.00 x 0.50 m and, when fertilized with only P, they were similar at the three spacings. Evaluating the effect of fertilizations with P and K on the clone IPA-20, Dubeux Júnior et al. (2010) observed effect of K on fresh and dry matter production. Dubeux Júnior et al. (2006) reported significant variation of dry matter production of 11.5 and 23.8 Mg ha^{-1} as a function of the P_2O_5 doses of 0 and 76 kg ha^{-1}, respectively, at 720 DAP.

Conclusions

1. Cactus pear growth is dependent on plant arrangement.

2. Number of cladodes and cladode area index were dependent on spacing, fertilization and plant age, and fitted to cubic models.

3. Higher growth and production of fresh and dry matter of cactus pear is associated with fertilizations with NPK and NP and with the best arrangement of plants at the spacing of 1.00 x 0.50 m.

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