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'Gigante' cactus pear cultivated at different population densities in a mechanizable arrangement

Varley A. Fonseca[1], Luzinaldo C. Costa[2], João A. da Silva[2], Sérgio L. R. Donato[2], Paulo E. R. Donato[2] & Evilasio dos S. Souza[2]

[1] Universidade Estadual de Montes Claros/Departamento de Ciências Agrárias/Programa de Pós-Graduação em Produção Vegetal no Semiárido. Janaúba, MG, Brasil . E-mail: varley.ibce@ig.com.br (Corresponding author) - ORCID: 0000-0002-1562-2190

[2] Instituto Federal de Educação, Ciência e Tecnologia Baiano/Setor de Agricultura/Mestrado Profissional em Produção Vegetal no Semiárido. Guanambi, BA, Brasil. E-mail: luzinaldo01@hotmail.com - ORCID: 0000-0003-0746-0010; joao.silva@ifbaiano.edu.br - ORCID: 0000-0001-5358-356X; sergio.donato@ifbaiano.edu.br - ORCID: 0000-0002-7719-4662; paulo.donato@ifbaiano.edu.br - ORCID: 0000-0001-8696-8378; evila.mts@gmail.com - ORCID: 0000-0001-9625-2445

ABSTRACT: Cactus pear is a crop adapted to the climatic conditions of the Brazilian semiarid region, so it has contributed to the socioeconomic development of this region. The objective of this study was to evaluate the response of 'Gigante' cactus pear cultivated at different population densities in a mechanizable arrangement. The experimental design was in randomized blocks, with six population densities: 22,857; 34,286; 51,428; 62,857; 80,000 and 95,000 plants ha^{-1} and four repetitions. The following variables were evaluated: plant height, number of cladodes, cladode length, cladode width and cladode area index, green and dry matter yields, extraction/export of nutrients and soil chemical characteristics. Increase in population density in a mechanizable arrangement decreases the number of cladodes and increases the cladode area index. The maximum green and dry matter yield of cactus pear cultivated in arrangement that allows mechanization is expected with populations of 69,111.79 and 64,445.91 plants ha^{-1}, respectively. Maximum values of extraction/export of nutrients in cactus pear tissue are expected at intermediate population densities (62,721.52-74,741.93 plants ha^{-1}). Soil potential acidity has maximum value with 64,525.51 plants ha^{-1}.

Key words: *Opuntia ficus-indica*, yield, management

Palma forrageira 'Gigante' cultivada em diferentes densidades populacionais em arranjo mecanizável

RESUMO: A palma forrageira é uma cultura adaptada às condições climáticas do semiárido brasileiro, por isso tem contribuído para o desenvolvimento socioeconômico desta região. Objetivou-se avaliar a resposta da palma forrageira 'Gigante' cultivada em diferentes densidades populacionais em arranjo mecanizável. O delineamento experimental utilizado foi em blocos casualizados, com seis densidades populacionais: 22.857; 34.286; 51.428; 62.857; 80.000 e 95.000 plantas ha^{-1} e quatro repetições. Foram avaliadas as seguintes variáveis: altura da planta, número de cladódios, comprimento, largura e índice de área do cladódio, produção de massa verde e seca, extração/exportação de nutrientes e as características químicas do solo. O aumento da densidade populacional em arranjo mecanizável diminui o número de cladódios e aumenta o índice de área do cladódio. A máxima produção de massa verde e seca da palma cultivada em arranjo que permite a mecanização é estimada quando se utiliza respectivamente a população de 69.111,79 e 64.445,91 plantas ha^{-1}. Valores máximos de extração/exportação de nutrientes em tecido de palma são estimados em densidades populacionais intermediárias (62.721,52-74.741,93 plantas ha^{-1}). A acidez potencial do solo apresenta valor máximo com 64.525,51 plantas ha^{-1}.

Palavras-chave: *Opuntia ficus-indica*, produtividade, manejo

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Introduction

Cactus pear (*Opuntia ficus-indica* Mill) has contributed to the socioeconomic development of the Brazilian semi-arid region, as it is a forage crop adapted to the climatic conditions of the region, with tolerance to long periods of drought and high efficiency in water use (Bispo et al., 2007; Pinheiro et al., 2014; Silva et al., 2015).

Cactus pear yield is still considered low, although with improvements in recent years (Barros et al., 2016). As the production system and the use of cactus pear are still characterized by low adoption of technologies (Silva et al., 2012), it is necessary to improve the cultivation techniques to obtain better production indices.

Planting spacing in cactus pear crop can affect light interception and photosynthetic efficiency, influencing its development and yield. Cultivation at dense spacing has been used more recently. In these situations, cultural practices and harvest are hampered, which increases labor costs. In addition to these aspects, in this case, there is a greater amount of nutrients extracted from the soil, so greater caution with fertilization is required (Teles et al., 2002).

Depending on the planting arrangement used in the crop, the number of plants per area is the same and, in certain arrangements, it is possible to use agricultural mechanization, which can facilitate cultural practices such as fertilizer application, phytosanitary control and mainly harvest, the most costly operation of the cultivation (Padilha Júnior et al., 2016). Additionally, it has a direct impact on costs, leading to their reduction, besides maximizing the activities carried out.

In this context, the objective was to evaluate the response of 'Gigante' cactus pear cultivated at different population densities in a mechanizable arrangement.

Material and Methods

The experiment was carried out in the agriculture sector of the Instituto Federal de Educação, Ciência e Tecnologia Baiano (IF Baiano), Guanambi Campus, located in the municipality of Guanambi, Southwestern Bahia, Brazil, at latitude of 14° 13` 30" S, longitude of 42° 46` 53" W of Greenwich, altitude of 525 m, and the following annual averages: rainfall of 680.00 mm and temperature of 26 °C.

During the experiment, climatic data were obtained from an automatic weather station installed close to the experimental area (Figure 1).

The conduction of the experiment was in an Oxisol, medium texture, flat to gently undulating relief. The chemical characterization of the soil after anthropic modification is found in Table 1. For soil collection, random points were chosen in the experimental area and samples were collected from the 0-20 cm layer and sent for chemical analysis according to EMBRAPA (1997).

The high concentrations of P and K in the soil of the experimental area (Table 1) are due to the history of use of the area with experiments involving organic fertilization with high doses of cattle manure (Donato et al., 2014; Barros et al., 2016). Soil organic matter as well as the concentrations of P, K, Ca, Mg

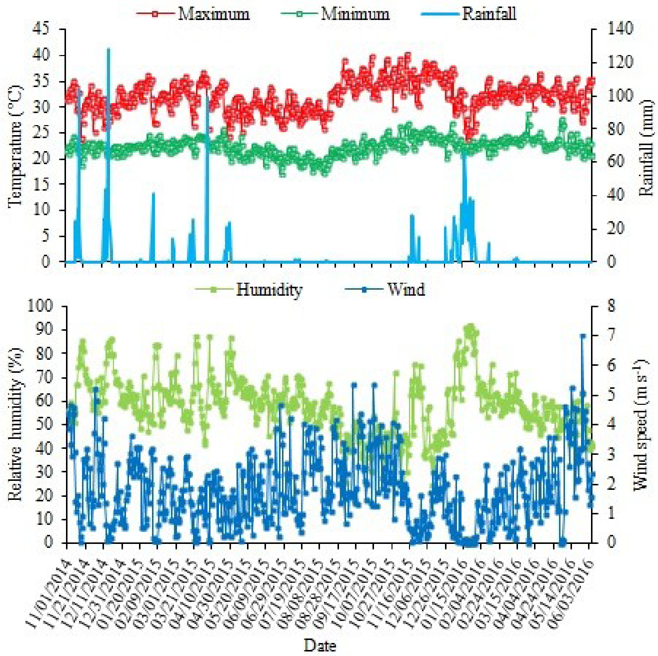


Figure 1. Rainfall, maximum and minimum temperatures, air relative humidity and wind speed during the period from 2014 to 2016

Table 1. Chemical characteristics of the soil in the experimental area

Attributes								
pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^+	H^+	S.B.[1]
(H_2O)	(mg dm^{-3})		($cmol_c$ dm^{-3})					
5.46	88.18	193.75	0.10	2.17	0.84	0.02	2.17	3.59
t[2]	T[3]	V[4]	m[5]	B	Cu^+	Fe^{++}	Mn^{++}	Zn^{++}
($cmol_c$ dm^{-3})		(%)		(mg dm^{-3})				
3.36	5.79	60.83	0.67	0.43	0.45	20.95	62.53	3.56

[1] Sum of bases; [2] Effective cation exchange capacity, effective CEC; [3] CEC at pH 7.0; [4] Base saturation; [5] Aluminum saturation

and values of SB, t, T and V are increased by the management with manure application (Padilha Junior et al., 2020).

The experimental design used was randomized blocks, with six population densities: 22,857, 34,286, 51,428, 62,857, 80,000 and 95,000 plants ha^{-1} and four repetitions.

Tillage in the area was carried out in October 2014, with cleaning, subsoiling and harrowing operations, followed by opening of furrows with a furrower regulated to an average depth of 0.30 m. The spacing between plant rows was one meter, arranged in quadruple rows, spaced apart by 4 m, arrangement used to allow mechanization. The different population densities were obtained with variations in plant spacing within the rows: 25.00, 16.70, 11.10, 9.00, 7.10 and 6.00 cm, respectively, for each population described above.

Each experimental unit consisted of four 15-m long rows, in which the usable plants were those located in the four rows and in the central 11 m. This dimension of experimental unit allows good precision, according to results obtained by Guimarães et al. (2019), who evaluated the number of plots for experiments with 'Gigante' cactus pear.

Cactus pear, cultivar 'Gigante', was planted in early November 2014 using one cladode in the vertical position, with the cut part facing the soil, at a depth where it was half buried.

Fertilization in the experiment was based on results of studies with organic and chemical fertilization for 'Gigante' cactus pear (Silva et al., 2012; Donato et al., 2014). At planting, the following fertilizations were performed: phosphate fertilization, applying 270 kg ha^{-1} of P_2O_5, using single superphosphate as source; potassium fertilization, applying 600 kg ha^{-1} of K_2O, using potassium chloride split into two applications; and basal organic fertilization, applying 30 Mg ha^{-1} of bovine manure, and topdressing organic fertilization at 60 days after planting with the dose of 60 Mg ha^{-1}, totaling 90 Mg ha^{-1} of bovine manure in the first year of the crop. Along the experiment, in addition to fertilization, crop maintenance practices, such as the control of weeds and pests, were performed.

At 540 days after planting (DAP), the following evaluations were performed: morphometric characteristics - plant height, number of cladodes, cladode length, cladode width and cladode area index; production characteristics - green matter yield (GMY), dry matter content and also dry matter yield (DMY), extraction/export of nutrients and soil chemical characteristics.

For morphometric evaluations, eight plants were randomly chosen in each usable plot, totaling 192 plants evaluated. Plant height, cladode length and cladode width were determined with a measuring tape. Plant height was determined considering the distance from the soil to the highest cladode in the plant.

Cladode length and width data obtained were used to estimate the cladode area index. Cladode area was determined adopting the methodology used by Barros et al. (2016), Eq. 1.

$$CLA = CLL \cdot CLW \cdot 0.693 \qquad (1)$$

where:

CLA - cladode area, cm^2;

CLL - cladode length, cm;

CLW - cladode width, cm; and,

0.693 - correction factor for the ellipse shape of the cladode.

After obtaining the cladode area of the plant, the cladode area index (CAI) was calculated. According to Barros et al. (2016), CAI is determined by measuring the total area of the cladodes of the plant, considering both of their sides, and dividing it by the area occupied by the plant in the soil (m^2 of cladode area m^{-2} of soil), thus determining the photosynthetically active area of the plant.

Yield was evaluated after the evaluation of morphometric characteristics, and all plants from the usable area of the plot were harvested. Harvest was carried out with a knife, preserving the three primary cladodes per plant. The cut was performed at the junction between the cladodes in order not to cause damage to the preserved cladodes. All cladodes harvested were placed in boxes for weighing and determination of GMY (Mg ha^{-1}).

In each experimental plot, tissue samples were collected from the cladodes to determine dry matter content and nutritional composition. This collection was performed using the methodology proposed by Donato et al. (2017), which consists in removing the tissue with a hole saw, coupled to a battery-charged drill. Sampling was carried out in different cladodes distributed in the plant. About 1 kg of cladode tissue samples were taken in each plot, which were properly identified, placed in plastic bags and taken to the Animal Nutrition Laboratory of IF Baiano, Guanambi Campus, where they were sliced and dried in a forced air circulation oven at 65 °C for 72 hours. One part of the sample was weighed before and after the drying process to determine the dry matter content. DMY (Mg ha^{-1}) was calculated as a function of the dry matter content, multiplied by the green matter yield, obtained in each treatment.

After drying, the samples were weighed on a precision scale, ground in a Wiley-type mill, using 1-mm-mesh sieve, and then identified, placed in plastic pots and analyzed in the laboratory of EPAMIG Norte (Empresa de Pesquisa Agropecuária de Minas Gerais - Unidade Norte de Minas). Samples taken from the cladodes were analyzed for the concentrations of the following nutrients: nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), expressed in dag kg^{-1}; and boron (B), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and sodium (Na), expressed in mg kg^{-1}. The analytical determinations were performed according to Malavolta et al. (1989): N by sulfuric digestion with the Kjeldahl method; P, K, S, Ca, Mg, Cu, Fe, Mn, Zn, and Na by nitric-perchloric digestion; and B by dry digestion. The extraction/export of nutrients (kg ha^{-1}) was calculated based on the dry matter yield and on their concentrations in the cladode.

Soil samples were also collected in each experimental plot at 0-20 cm depth at a 20 cm distance from the plant. These samples were sent to the EPAMIG Norte laboratory for chemical analysis according to EMBRAPA (1997).

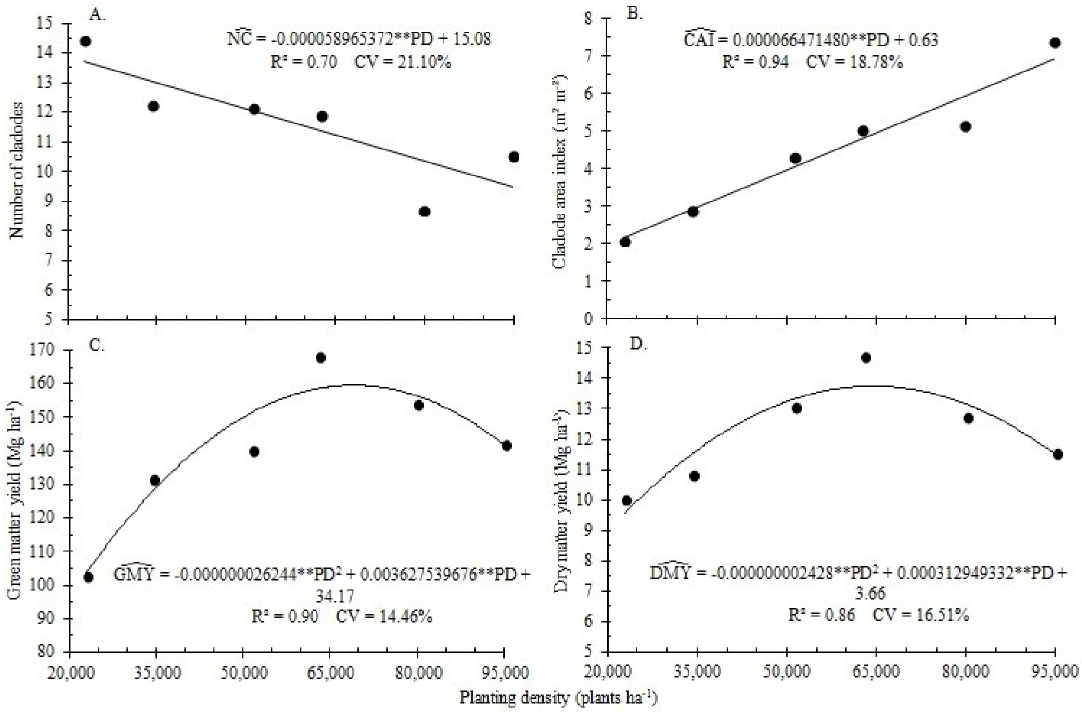
Normality tests were performed to meet the assumptions of ANOVA. After verifying the normal distribution of the data, they were subjected to analysis of variance. Variables that had significant effect were subjected to regression analysis. The models were chosen based on the significance of beta coefficients by the t-test, the magnitude of the coefficient of determination, the smallest difference between the adjusted R^2 and R^2, and the adequacy of the model for the biological phenomenon studied.

Results and Discussion

Among the morphometric characteristics, only the number of cladodes and the cladode area index showed significant difference as a function of population densities.

Green matter yield, dry matter yield and the extraction of phosphorus, potassium, calcium, sulfur, boron and copper were significantly affected by the different population densities studied. The other nutrients did not show significative effect. Regarding the chemical characteristics of the soil, potential acidity was the only one that was significantly affected by the population densities. It is worth pointing out that standardized chemical and organic fertilizations and the various reactions that occur in the soil contributed to the absence of alterations in its chemical characteristics with the treatments applied.

The number of cladodes decreased linearly in response to the increase in planting density (Figure 2A). A 30.97% reduction in the number of cladodes was estimated from the



** - Significant at p ≤ 001 by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

Figure 2. Number of cladodes (A), cladode area index (B), green matter yield (C) and dry matter yield (D) of 'Gigante' cactus pear in function of population densities

lowest density (22,857 plants ha^{-1}) to the highest density (95,000 plants ha^{-1}). This result is probably related to the smaller space for plant growth at the highest planting densities, which leads to increased competition between plants for nutrients and light and, consequently, to the reduction in cladode production.

The competition for light was verified by Brito et al. (2018), who studied the photochemical efficiency in cladodes of 'Gigante' cactus pear and found, for the same dose of manure applied in the present study (90 Mg ha^{-1}), higher values of quantum efficiency and quantum yield of photosystem II at the spacing that promotes less shading. As these variables indicate the functioning of photosystem II (PSII) and, consequently, the efficiency in the use of photochemical radiation in carbon assimilation by plants, it is evident that in smaller populations the plant has more reserve and consequently greater capacity for producing cladodes.

Similar results were found by Cavalcante et al. (2014), who studied cactus pear genotypes and observed that increasing planting density caused a negative linear effect on the number of cladodes per plant, possibly due to greater competition between plants for space, which resulted in reduction in cladode production.

The values of cladode area index increased linearly in response to the increase in planting density (Figure 2B). A 223.07% increase in CAI was estimated from the lowest to the highest planting density. As cladode length and width showed no significant difference and there was a reduction in the number of cladodes per plant with the increase in planting density, this result is related to the smaller spacing between plants at the highest densities, considering that CAI is a ratio of the total area of the cladodes by the area occupied by the plant in the soil.

Dubeux Júnior et al. (2006), studying populations from 5,000 to 40,000 plants ha^{-1}, also found that higher planting density promoted an increase in CAI. Ruiz-Espinoza et al. (2008) reported that higher population densities contribute to increasing the net assimilation rate, which has a close relationship with leaf area index. CAI is an important characteristic from the physiological point of view of the plant, because it indicates a larger area for capturing of photosynthetically active radiation and consequently leads to higher crop yield.

Green matter yield data were described by a quadratic model as a function of planting densities (Figure 2C). The fitted model estimates that 69,111.79 plants ha^{-1} allows maximum GMY (159.62 Mg ha^{-1}). Dry matter yield also responded quadratically as a function of planting densities (Figure 2D). The fitted model estimates that 64,445.91 plants ha^{-1} allows maximum DMY (13.74 Mg ha^{-1}).

The positive quadratic response for green and dry matter yields in cactus pear is directly related to the increase in the number of plants per hectare, reaching maximum yield, with subsequent decrease as the planting density increases. Dubeux Júnior et al. (2006), report that dense cultivation enables greater economic profitability when compared to conventional plantations with low plant population, due to higher efficiency in crop management practices and the maximization of land use capacity. However, when certain population levels are reached there is competition between plants for light and nutrients, which no longer results in an increase in crop yield.

Menezes et al. (2005) highlight that higher population densities enable greater light interception due to increased CAI, which results in higher yield. In the present study, CAI increased linearly up to the highest planting density tested, reaching the value of 7.36 m^2 m^{-2}, but the maximum yields were obtained at intermediate densities, which reinforces the competition between plants in larger populations. According to Nobel (2001), CAI between 4 and 5 promotes maximum yield; however, yield is reduced when it exceeds these values.

Silva et al. (2014), evaluating cactus pear genotypes grown at different planting densities, found a positive quadratic response with increase in green and dry matter yields of 'Gigante' cactus pear up to the highest density (80,000 plants ha^{-1}). This result differs from those obtained in the present study, but it is worth mentioning the plant arrangement used, which enables mechanization and promoted a smaller spacing between plants and, consequently, greater competition for light and nutrients and thus the maximum yield was obtained at lower densities.

In a study with 'Gigante' cactus pear, Donato et al. (2014) used the same plant population, but modifying its distribution in the cultivation area, and found that the arrangement which promoted smallest space for plant development (3.0 x 1.0 x 0.25 m) led to the lowest dry matter yield compared to the arrangements with larger space (1.0 x 0.5 and 2.0 x 0.25 m). This corroborates the results obtained in the present study, as it indicates the influence of the space required by the cactus pear plant for optimization in the use of light and nutrients and consequently obtaining of higher yields.

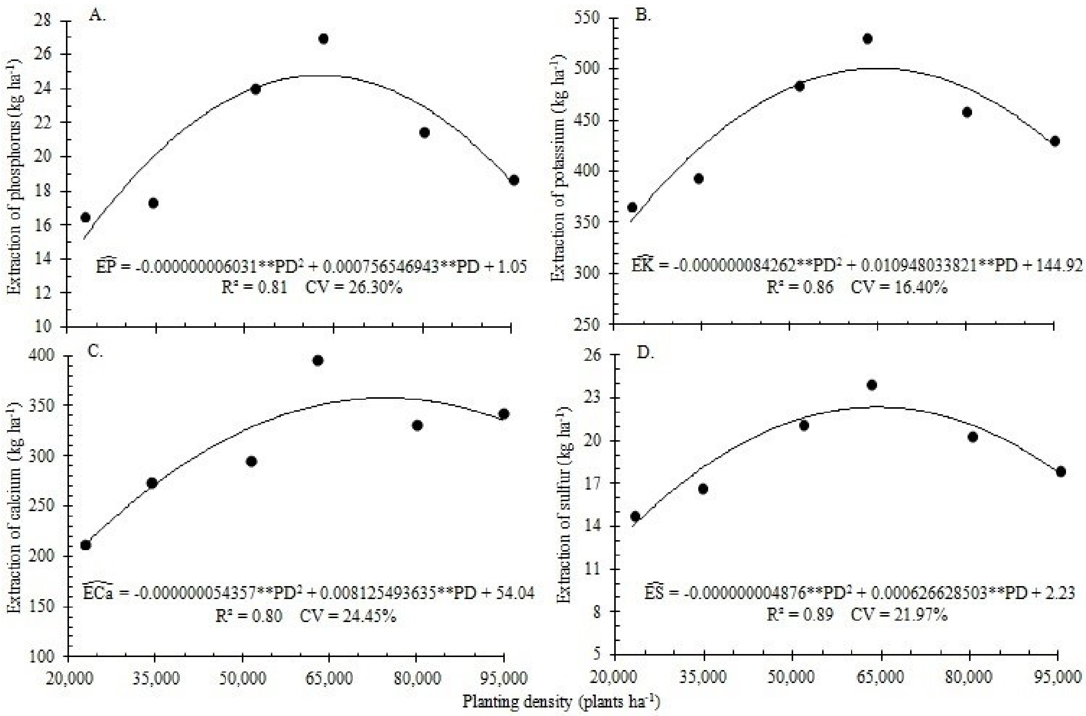
The extraction/export of phosphorus, potassium, calcium and sulfur responded quadratically as a function of planting densities (Figure 3). The maximum extractions/exports of phosphorus and potassium (24.78 and 500.53 kg ha^{-1}) were estimated respectively at the densities of 62,721.52 and 64,964.24 plants ha^{-1} (Figures 3A and B), whereas the maximum extractions/exports of calcium and sulfur (357.70 and 22.36 kg ha^{-1}) were estimated respectively at the densities of 74,741.93 and 64,256.41 plants ha^{-1} (Figures 3C and D).

The values of nutrient extraction/export are consistent with those obtained by Silva et al. (2016) and Donato et al. (2017), who report that the most extracted/exported nutrients are potassium and calcium. Despite the organic and chemical fertilization performed at planting and along the cultivation, the highest planting densities studied did not result in maximum extraction/export. These results are consistent with the yield levels obtained, that is, the planting density range that promoted the maximum green matter and dry matter yields is virtually the same as the one that promoted the maximum extraction/export of nutrients. This indicates that, at high planting densities, there is competition for nutrients in the soil, which causes restriction in plant development and there is no more response in crop yield level.

The competition of plant roots for nutrients occurs in the case of those preferentially transported by mass flow, such as calcium, with the increase in plant population, with the reduction in the distance between plants or when the roots of two neighboring plants come into contact in the case of immobile nutrients (Novais et al., 2007).

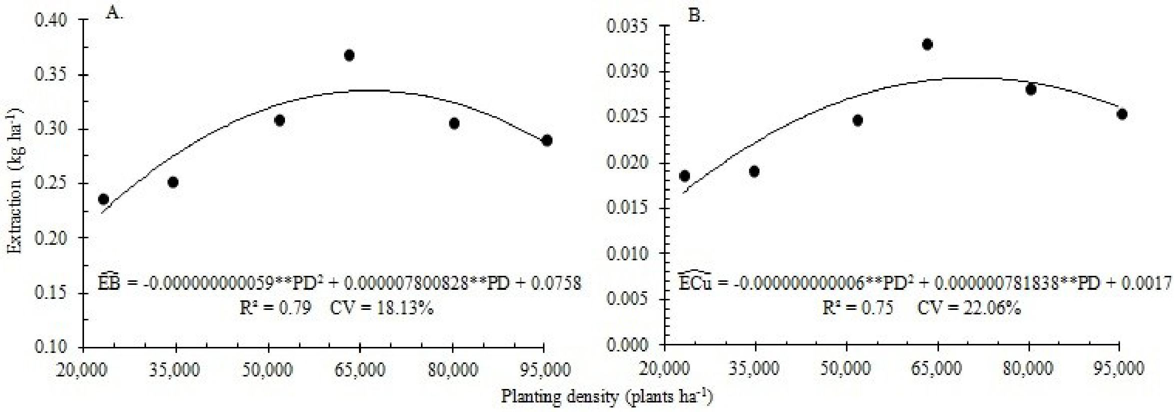
The extraction/export of boron and copper responded quadratically as a function of planting densities (Figure 4). The maximum extraction/export of boron (0.33 kg ha^{-1}) was estimated at the density of 66,108.71 plants ha^{-1} (Figure 4A). For the micronutrient copper, the maximum extraction/export (0.0271 kg ha^{-1}) was estimated at the density of 65,153.17 plants ha^{-1} (Figure 4B).

Silva et al. (2016), working with different formulations of chemical fertilization (NPK) in 'Gigante' cactus pear, observed that all micronutrients showed a negative balance, indicating the need for their application in order to preserve soil reserves and ensure an ideal supply for the crop to express its potential production. As occurred for macronutrients, the effect of competition for micronutrients at higher densities was verified. The results obtained are consistent with those reported by Silva



** - Significant at $p \leq 0.01$ by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

Figure 3. Extraction/export of phosphorus (A), potassium (B), calcium (C) and sulfur (D) in cladode tissue of 'Gigante' cactus pear in function of population densities

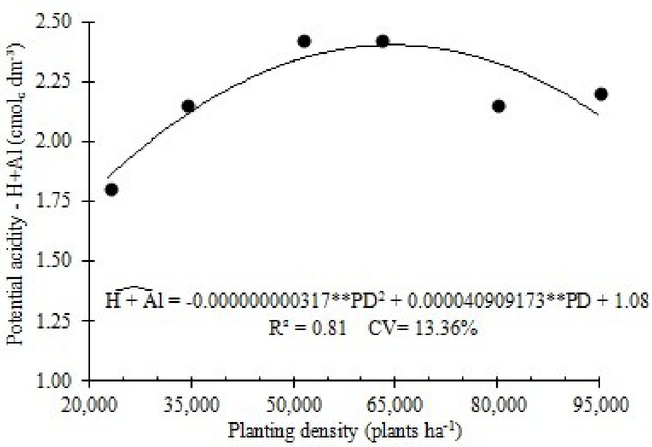


** - Significant at $p \leq 0.01$ by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

Figure 4. Extraction/export of boron (A) and copper (B) in cladode tissue of 'Gigante' cactus pear in function of population densities

et al. (2012), who observed reduction of copper content in the cactus pear cladode tissue when a smaller spacing between plants was used.

The potential acidity of the soil responded quadratically as a function of the planting densities (Figure 5). The maximum potential acidity (2.40 $cmol_c\ dm^{-3}$) was estimated at the density of 64,525.51 plants ha^{-1}. It is observed that this soil characteristic also showed similar results to those of the others evaluated, with maximum value reached at intermediate planting density. This is possibly related to the process of absorption of nutrients by the plant, in which the roots release acid secretions (H^+) to replace the absorbed cation, hence increasing acidity near the rhizosphere region.



** - Significant at $p \leq 0.01$ by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

Figure 5. Potential acidity of the soil cultivated with 'Gigante' cactus pear in function of population densities

Conclusions

1. Increase in population density in a merchandisable arrangement decreases the number of cladodes and increases cladode area index.

2. The maximum yields of green and dry matter in cactus pear cultivated in an arrangement that allows mechanization is expected when using respectively the populations of 69,111.79 and 64,445.91 plants ha^{-1}.

3. Maximum values of nutrient extraction/export in tissue of cactus pear cultivated in an arrangement that allows mechanization are expected at intermediate population densities (62,721.52-74,741.93 plants ha^{-1}).

4. The potential acidity of the soil shows a maximum value under the population density of 64,525.51 plants ha^{-1}.

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