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Original Article

Agronomic parameters of sugarcane under planting densities in different cultivation cycles

Parâmetros agrônomicos da cana-de-açucar sob densidades de plantio em diferentes ciclos de cultivo

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Abstract

Low density sugarcane plantation (LDSP) has been implemented by some sugarcane producers in Brazil, aiming to save seeds and operational costs. The study was carried out in the municipality of Areia, Paraíba, Brazil. Five planting densities were used, varying from 5 to 25 m^{-2} of buds arranged in randomized blocks, with four replications. Data were measured annually over three cultivation cycles (2017 to 2020), during which the field was fertilized with NPK and the harvests were carried out manually without prior burning. The lower planting density presents higher productivity only in the cane plant (101.03 t ha^{-1}) due to the higher plant height (2.37 m) and the higher number of stalks (11 stalks m^{-2}), suggesting that these variables are due to the greater availability of light, water and photosynthate. However, there is a drastic reduction in sugarcane yield for this lower population in the 2nd ratoon by up to 65.62%, which is correlated with number of stalks per meter. We demonstrate the agronomic viability of LDSP in the population of 10 buds m^{-2} in relation to conventional planting of sugarcane until the 2nd ratoon. Data are important for future studies to present additional considerations for other production factors, such as the effects of mechanized harvesting and the management of nutrients and water, assessing the sustainability of this large-scale planting system.

Keywords: plant population, *Saccharum* spp., spatial arrangement, yield.

Resumo

O método de plantio de cana-de-açúcar de baixa densidade (LDSP) vem sendo implementado por alguns produtores de cana-de-açúcar no Brasil, visando economia de sementes e custos operacionais. O estudo foi realizado no município de Areia, Paraíba, Brasil. Utilizou-se cinco densidades de plantio, variando de 5 a 25 m^{-2} de gemas dispostas em blocos casualizados, com quatro repetições. Os dados foram medidos anualmente ao longo de três ciclos de cultivo (2017 a 2020). Menor densidade de plantio mostrou maior produtividade (101,03 t ha^{-1}) devido à maior altura de planta (2,37 m) e ao maior número de hastes (NS) (11 hastes m^{-2}), sugerindo que essas variáveis são devido à maior disponibilidade de luz, água e fotoassimilados. No entanto, houve redução drástica na produtividade da cana-de-açúcar para esta população menor na 2ª soca em 65,62%, estando correlacionado com o número de colmos por metro. Demonstramos a viabilidade agronômica do LDSP em uma população de 10 gemas m^{-2} em relação ao plantio convencional de cana-de-açúcar até a 2ª soca. Os dados são importantes para que estudos futuros apresentem considerações adicionais sobre outros fatores de produção, como os efeitos da colheita mecanizada e do manejo de nutrientes e água, avaliando a sustentabilidade desse sistema de plantio em larga escala.

Palavras-chave: população de plantas, *Saccharum* spp., arranjo espacial, produtividade.

1. Introduction

Modern agricultural practices are indispensable for the cultivation of sugarcane (*Saccharum* spp.), as this plant is an important component in the energy and food matrix of Brazil (Rossetto et al., 2022). The country stands out as the largest producer of sugarcane in the world, with estimated production of 652.9 million tons for the 2023/24 harvest (CONAB, 2023) and has favorable tropical climatic conditions for the development and growth of C4

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metabolism plants, such as those of the family Poaceae, however, due to its area there are soil, climate and seasonal variations that hinder the standardization of the agronomic management of the crop. Regional studies are important to enable efficient, low-cost agriculture and less exploitation of natural resources (Kurina et al., 2018).

Considering that the conventional sugarcane planting operation uses 15 to 21 buds per linear meter of furrow, which represents up to 25 tons of seedlings cane ha^{-1} (Rossi Neto et al., 2018), and that the number of seeds in planting is an important cost in the production process, the low density sugarcane planting system (LDSP) has been proposed as a strategy to reduce the consumption of seed cane. This, increase the sugarcane for processing, in addition to the lower entry of heavy machinery, diesel consumption and agricultural inputs into the cultivation area, which brings energy gains to the system by mitigating soil compaction and GHG emissions due to the burning of fossil fuels, in addition to contributing to the economic viability of cane fields. Therefore, under ideal growing conditions, this crop tends to respond positively in terms of plant development (Silva et al., 2023).

Despite this, because it is a perennial crop, sugarcane has a longer life cycle than other economically important crops such as corn, rice and soybean (Jiang et al., 2019). No information is currently available on the influence of the low-density plant population on sugarcane production.

A concern with the adoption of this planting system is long-term sustainability, and a detailed assessment of the interactions between planting densities on land use is opportune. In addition, sugarcane growth characteristics such as tillering can promote changes in crop productivity (Vasantha et al., 2012).

Our hypothesis is that the planting of low-density sugarcane, therefore, with a smaller number of buds distributed in the bottom of the furrow, influences the sugarcane yield, making it an agronomically viable planting method throughout the successive annual cuts. Thus, a long-term field experiment was carried out to analyze the effect of planting densities after three sugarcane cycles.

2. Materials and Methods

2.1. Study site

Field studies were performed consecutively for three years in 2017-2018, 2018-2019 and 2019-2020, in the municipality of Areia, state of Paraíba, Brazil (06°57'46" S and 35°41'31" W and variable altitude between 400 and 600 m). The clayey-sand soil of the experimental area is classified as a Oxisol. The local climate according to the Köppen classification is Aw', hot and humid (Alvares et al., 2013), with an average annual temperature of 22ºC, high humidity and an average annual rainfall of 1,400 mm, rainiest four-month period from April to July (Ribeiro et al., 2018).

The characterization of the chemical properties of the soil (Table 1) was carried out prior to the beginning of the experimental procedures, using samples collected in the 0-0.20 m layer.

2.2. Experimental design and treatments

The experimental design adopted was complete randomized blocks, in plots subdivided over time, with four replications. The treatments consisted of five planting densities (5, 10, 15, 20 and 25 buds m^{-2}) in the main plots and three cultivation cycles in the subplots. Each experimental unit measured 5 m × 6 m, and consisted of four simple rows with spacing between rows of 1.2 m.

2.3. Implementation and conduct of the experiment

For soil preparation, conventional cultivation was adopted with a plowing, leveling harrow, followed by furrowing of the area. All plots received basal planting fertilizer at the row, applying doses equivalent to 90 kg N ha^{-1}, 150 kg P ha^{-1} and 120 K ha^{-1} via ammonium sulfate, single superphosphate and potassium chloride, respectively, based on the recommendation for the crop (Ribeiro et al., 1999). The variety of sugarcane used was the RB867515, middle to late cycle, fast growth, high size, erect growth habit, high stalk density and easy unburned sugarcane straw, which presents good results in Brazil (Peloia et al., 2019; Matoso et al., 2021).

2.4. Evaluated variables

Cane lenght (m): Ten plants randomly collected at harvest in each plot were measured from the base to the apex (discarding the tip), and the average values were recorded.

Cane diameter (m): Ten canes were collected randomly per plot at the time of harvest. The apex, middle and base of the cane were used to determine the diameter with a digital caliper and to calculate the average.

Number of internodes: At harvest, internodes of ten plants per experimental unit were counted.

Number of stalks per meter: From each experimental unit, the number of stalks was computed at harvest and averaged per linear meter.

Table 1. Soil chemical properties in the experimental area. Areia, state of Paraíba, Brazil.

	$pH_{(H2O,\ 1:2.5)}$	P	K^+	Na^+	$H+Al^{3+}$	Al^{3+}	Ca^{2+}	Mg^{2+}	SB	CEC	OM
		mg dm^{-3}		cmol$_c$ dm^{-3}							g kg^{-1}
2017	5.60	3.26	50.16	0.11	3.40	0.10	3.47	2.41	6.11	9.61	14.83
2018	6.12	3.15	34.20	0.10	0.27	0.0	4.76	3.5	8.44	8.71	17.00
2019	6.06	2.10	30.00	0.08	0.34	0.0	2.24	2.28	4.67	5.01	24.00

Note: P and K - Mehlich Extractant; SB - Sum of bases; CEC - Cation exchange capacity; Al, Ca and Mg - KCl; H + Al - Calcium acetate; OM: Organic matter.

Sugarcane yield (t ha^{-1}): All canes in each plot was weighed and then the values converted to t ha^{-1}.

Brix (º): Brix was the only component of technological analysis evaluated. Ten stalks per plot were pressed to obtain the juice from the basal and apical part at the time of harvest with the aid of a portable refractometer, and then the average values were obtained.

2.5. Statistical analysis

All analyses were conducted in R software 3.6.3 (R Core Team, 2020). Data were tested for normality by the Shapiro-Wilk test, homogeneity of variances by the Bartlett test and analysis of variance by F test ($P \leq 0.05$) according to the criteria of Banzatto and Kronka (2011) for experiments with plots subdivided over time. Subsequently, the effects of the treatments were tested by Tukey' test at $P \leq 0.05$. In the studied variables, the following statistical model (Equation 1) was used:

$$y_{ijk} = \mu + a_i + block_j + (a \times block)_{ij} + b_k + (a \times b)_{ik} + e_{ijk} \quad (1)$$

Where y_{ijk}: observation that receives density i, cultivation cycle k and is in block j; μ: overall mean effect; a_i: density effect i, i = 5, 10, 15, 20 and 25 buds m^{-2}; $block_j$: effect of block j, j = 1, 2, 3, 4; $(a \times block)_{ij}$: residual at the level of plot of density part i in block j; b_k: effect of cultivation cycle k, k = plant cane, 1st and 2nd ratoon; $(a \times b)_{ik}$: effect of the interaction of density i with cycle k; e_{ijk}: experimental error attributed to the subplot of density i, of cycle k, of block j.

3. Results

According to the analysis of variance, there was a significant interaction between planting densities × cultivation cycles ($P \leq 0.01$) for all the variables analyzed, so the different planting densities over the three years of cultivation simultaneously interfere with growth and sugarcane yield (t ha^{-1}).

As for plant height (Figure 1A), in plant cane the population of 5 buds m^{-2} was statistically higher than the populations 15, 20 and 25 buds m^{-2}. However, in the 1st ratoon, it presented the lowest growth in height, with a reduction of 11.81% in relation to the plant cane. In the 2nd ratoon, the population of 10 buds m^{-2} showed the highest value and differed statistically from the others.

The effect of years within populations showed significant interference with plant height. In the population of 5 buds m^{-2}, the greatest increase in height was found in the 1st year of cultivation (plant cane) and the smallest in the 2nd ratoon. Whereas in the population 10 buds m^{-2}, cultivation in the 2nd ratoon provided greater height and differed statistically from the 1st ratoon. In the population of 15 buds m^{-2}, there were no significant differences over the years, that is, the growth in height remained statistically similar over the years. In the populations of 20 and 25 buds m^{-2}, the 1st ratoon and the plant cane stood out in this variable.

Regarding cane diameter (Figure 1B), plant cane obtained the greatest increase in the population with 20 buds m^{-2}, which differed statistically from the populations with 10, 5 and 15 buds m^{-2} ($P \leq 0.01$). At the same time that in the 1st ratoon, plants of this population had the smallest cane diameter. In the 2nd ratoon, plants from the population with 25 buds m^{-2} showed a greater increase in diameter and differed statistically from plants with a population of 20 buds m^{-2}. In the population of 5 buds m^{-2}, plant cane and 2nd ratoon showed the highest values in cane diameter. At the same time, populations of 10 and 15 buds m^{-2} showed superiority in diameter in plants of the 2nd ratoon.

The highest number of internodes in plant cane (Figure 1C) was found in treatments that had a population of 15 buds m^{-2}, which differed statistically from plants with a population of 20 buds m^{-2}. While in the 1st ratoon, plants belonging to 10 buds m^{-2} showed an increase in the number of internodes and were statistically superior to the other populations. In the 2nd ratoon, plants with a population of 25 buds m^{-2} stood out and lower values for populations 5 and 10 buds m^{-2}.

In all populations, the highest number of internodes was obtained in the cane plant and the lowest in the 2nd ratoon. For the population of 25 buds m^{-2}, the lowest value of internodes was obtained in the 1st ratoon. In plant cane plant and 1st ratoon, the largest number of canes were obtained in populations with 5 and 15 buds m^{-2} sugarcane, in contrast to the 2nd ratoon, the population with 25 buds m^{-2} stood out in relation to the other populations. When observing the behavior of the years within the populations, plants with 10 and 15 buds m^{-2} did not show statistical difference during the three years in the number of canes (Figure 1D). Plants from the population of 5 buds m^{-2} showed higher cane values in plant cane and 1st ratoon.

Sugarcane yield (tons of stalk per hectare, TSH, t ha^{-1}) values were significantly influenced by years and populations ($P \leq 0.01$), with a gradual reduction in productivity averages obtained from the 1st cycle (plant cane) to the following (Figure 1E). In plant cane, plants belonging to the population of 5 buds m^{-2} had higher TSH, differing statistically from the other populations. In the 1st ratoon, the highest values of TSH were obtained for populations of 5, 20 and 25 buds m^{-2}, and the lowest value in the population of 15 buds m^{-2}, while in the 2nd ratoon, plants grown with 10 buds m^{-2} presented higher TSH.

In populations of 5, 10 and 15 buds m^{-2}, TSH was higher in plant cane, however in populations of 20 and 25 buds m^{-2}, the highest values of TSH were found in plant cane and 1st ratoon, differing statistically from the 2nd ratoon, possibly due to the lower quality and amount of radiation incident on the photosynthetically active leaves due to the lower sugarcane elevation seen in the cane length variable, while there was an increase in NC.

In sugarcane, the highest brix values (percentage of soluble solids in sugarcane juice) were found in plants grown in populations of 25 buds m^{-2}, while for the second ratoon it was with 10 and 15 buds m^{-2}. Plants from the population of 5 buds m-^{2} presented the lowest values for this variable (Figure 1F). In the 1st ratoon, plants with a population of 10 buds m^{-2} were higher with the highest averages. Regardless of the populations studied, the highest values of brix were obtained in plant cane and the lowest in the 1st and 2nd ratoon. Another important point to be highlighted is in relation to the low population of 5 buds m^{-2}, in which for the first two cycles productivity remained high and stable, however in the 2nd ratoon (third cycle) productivity showed a significant reduction in sugarcane yield (Figure 2).

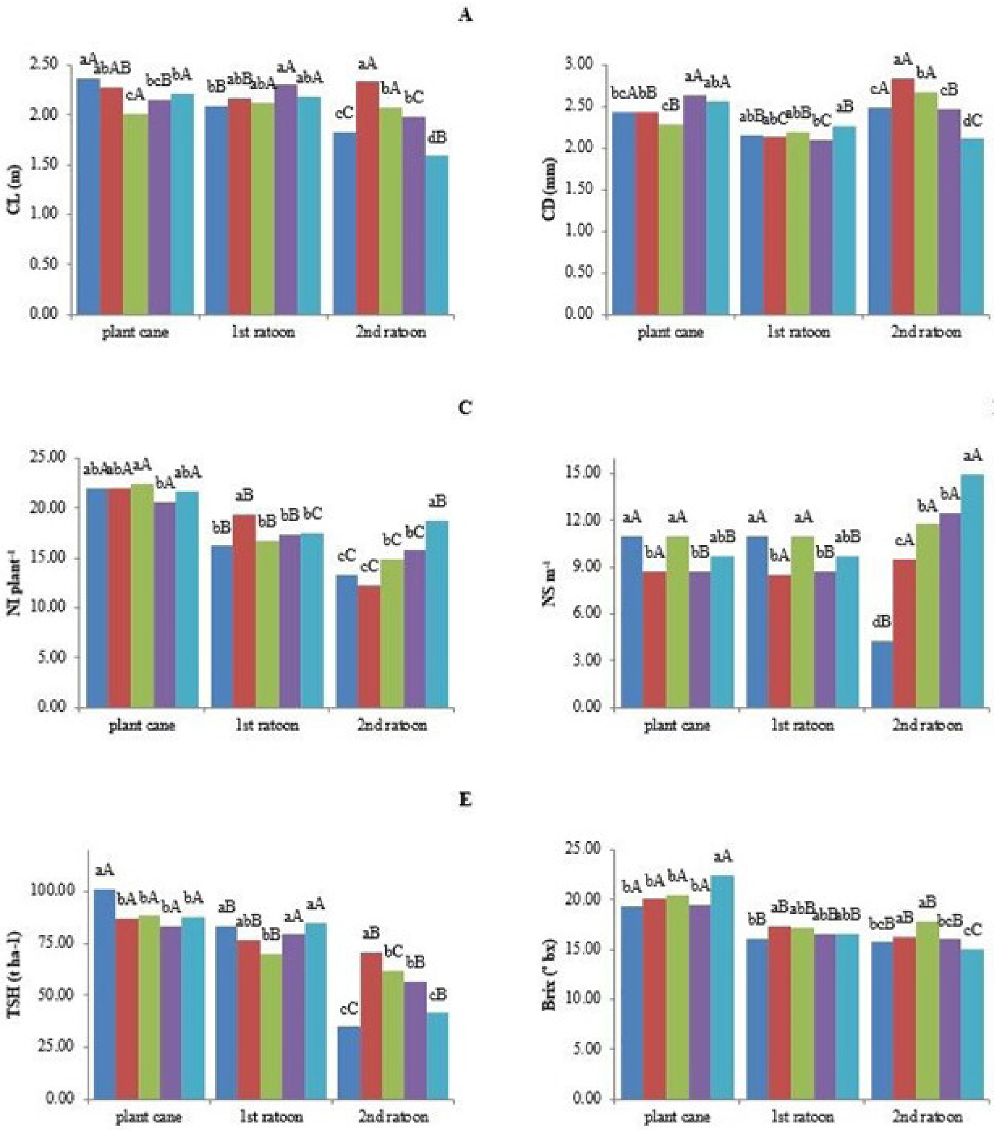

Figure 1. Effect of planting densities in three successive sugarcane cultivation cycles on cane lenght (A), cane diameter (B), number of internodes per stalk (C), number of stalks per meter (D), sugarcane yield t ha^{-1} (E) and brix content (F), in the municipality of Areia, state of Paraíba, Brazil. Different uppercase letters indicate a significant difference over the crop cycles for the same planting density, while different lowercase letters indicate a significant difference between planting densities within each cultivation cycle by means of least squares ($P \leq 0.05$). Source: Prepared by the authors (2020).

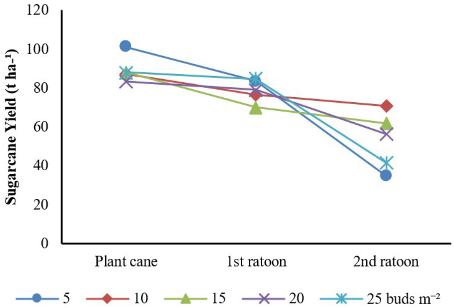

Figure 2. Sugarcane yield (cv. RB867515) according to planting densities during three growing cycles (2018-2020), in Areia, state of Paraíba, Brazil. Source: Prepared by the authors (2020).

4. Discussion

The results of plant height in the 1st ratoon found in this study may be associated with physical-chemical changes in the soil due to the low accumulation of residues after the first harvest (Coonan et al., 2020). The populations of 20 and 25 buds m^{-2} stood out in plant cane in this variable. Plants adjust their yield components according to the dynamic abiotic stresses (water and light, etc.) and management (macro and micronutrients, etc.) caused during their development, which may justify the behavior of cane diameter in this study. Studies indicate that water stress inhibits leaf and stalk expansion, tiller production and causes changes in cane elongation orientation (Gomathi et al., 2015).

The growth of sugarcane is closely linked to water restriction, influencing the reduction in the remobilization of water, nutrients and transport of carbohydrates to the roots, leading to the lowest rates of cane cell elongation, consequently, in the length of internodes (Marchiori et al., 2017). Cane elongation is desirable for sugarcane, contributing to increased sucrose.

Whereas, plants from populations of 20 and 25 buds m^{-2} presented higher number of canes in the 2nd ratoon, which can be justified by the tillering stimuli, an important component in grass yield that is favored by the indirect effect of straw on plants, with increased moisture retention in the soil due to the supply of organic matter and availability of nutrients throughout the cycles (Borges et al., 2020). Our TSH results corroborate the data by Rossi Neto et al. (2018), in which they stated that variations in sugarcane productivity are linked to environmental conditions in each cycle.

The inconsistent influence of plant population on the sugarcane brix in the different growing cycles is related to the physiological process of sucrose accumulation that reaches its maximum when the plant has limited resources for its growth, either due to lack of resources, nutrients, water or climatic conditions (Julius et al., 2017). Genetic effects are predominant for the responses expressed in the traits of productivity (lenght and cane diameter, number of internodes and canes per linear meter and sugarcane yield) even under the influence of cultivation cycles on the studied genotype (Dutra Filho et al., 2014).

As for the productivity results obtained, probably, they may be related to the reduction in plant population over the years of study, for several causes such as pests, diseases, death of buds at the time of cutting, in this case manual harvesting, may have interfered so that the population may have reduced further. This research was carried out with manual harvesting and other studies on density are important to be done with mechanized harvesting, which can bring the producer other relevant information in population management.

Moreover, sugarcane grown without irrigation in Northeastern Brazil has low productivity in relation to irrigated areas, directly reflecting on the reduction of plant physiological performance and sugarcane yield, since the occurrence, intensity and duration of abiotic stresses, such as water deficit, cause morphophysiological changes in the plant, with reduced gas exchange, greater sensitivity in stomatal conductance (*gs*), leaf transpiration (*E*), liquid photosynthesis (*A*), in water use efficiency (Marchiori et al., 2017), lower growth of leaf area, reduction in the appearance of new leaves and increase in leaf abscission due to a higher concentration of abscisic acid in the plant, which is associated with the amount of light absorbed and the total photosynthetic activity of the plant, reducing the production of photoassimilates (Smit and Singels, 2006; Lawson, 2009; Soleh et al., 2018).

The results expressed simultaneously imply that genotype RB867515 does not have stability of production in relation to the number of canes and consequently in sugarcane yield (t ha^{-1}). The experiments here studied the biometry and sugarcane yield, but did not investigate the implications of low planting density over different cultivation cycles using mechanized harvesting or the use of irrigation water associated with fertilization levels, a pattern in conventional production processes. In the first case, there is a risk of damage to the roots that may impair the recovery of plants after successive cuts. In the second, the management of water and/or nutrients can directly influence tillering in each cycle, resulting in productive responses that are different from our work.

5. Conclusions

There was interaction between the planting pattern and the cultivation cycles, and the use of between 10 and 15 buds m^{-2} is a practical agronomical recommendation to be considered for the variety used in this study.

This recommendation markedly reduces the conventional 15 to 25 buds m^{-2} and demonstrates that planting low density cane can be adopted as a viable production strategy.

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