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POD POSITIONING AND GRAIN YIELD OF COMMON BEAN AS AFFECTED BY SOWING DENSITY, NITROGEN FERTILIZATION AND FERTILIZATION DEPTH

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Abstract
The positioning of pods in common bean directly affects grain losses in mechanized harvesting. However, only few studies have assessed facttors that can affect pods positioning. The objective of this work was to determine the effect of plant density, nitrogen fertilization, and fertilization depth on the distribution of pods of the common bean. The field experiments were carried out in two cropping seasons, 2017 and 2018, during the winter period in the Cerrado region. The experimental design was randomized blocks in a 4x2 factorial scheme, with four replications. The treatments consisted of the combination of four sowing densities (5, 10, 15, and 20 plants m^{-1}) with two depths of fertilizer application (6 and 12 cm). The results allowed inferring that the depth of the fertilization does not affect the distribution of pods in the common bean. Plant density does not affect common bean grain yield. More than a quarter of the common bean pods of the BRS FC104 are positioned close to the ground, below 100 mm, in the area where harvester machines operate. Nitrogen fertilization and plant density affect the distribution of pods in common bean plants. At higher doses of N (90 kg ha^{-1}), plant density should be increased. On the other hand, at lower doses (45 kg ha^{-1}), plant density must be reduced. It is concluded that the sowing density can be an efficient strategy to provide the highest positioning of pods in the upper part of the common bean plants, reducing harvest loss.

Keywords: Mechanized Harvesting. N-fertilizer. *Phaseolus vulgaris*. Pod Distribution.

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is the most important food legume for the direct consumption of the population worldwide (Ganascini et al. 2019), due to being the main cheap source of protein and minerals for the human diet (Sampaio et al. 2016). In Brazil, this legume is present in the diet of the poorest population, contributing to about 25% of their protein needs (Hungria et al. 1997; Souza and Ferreira 2017). In 2020 the world common bean production was 27,5 million tons, with Brazil standing out in the last decades as one of the largest world producers of this crop, just behind Myanmar and India (FAO 2022).

In Brazil, common bean cultivation is carried out in three harvest seasons, the first being the “summer season”, the second “drought season” and the third “winter season” (Tavares et al. 2013). In the 2021 agricultural year, the cultivated area of common bean in Brazil was about 2.8 million ha, distributed across the three harvest seasons, resulting in total grain production of about 2.9 million tons and average productivity of 1,035 kg ha^{-1} (CONAB 2022).

Nitrogen is one of the limiting factors for the common bean to reach high yields (Lopes et al. 2011; Nascente et al. 2011; Lacerda et al. 2019). In addition, sowing depth (Gabriel Filho et al. 2010; Orlando Junior et al. 2021) and the depth of fertilizer application can delay crop development (Compagnon et al. 2013; Lacerda et al. 2014; Orlando Junior et al. 2021), making it necessary to develop research focusing on the depth of fertilizer application.

Along the production process of the crop, the harvest is one of the most important stages since if not properly done, can result in losses and mechanical damage of the grains, interfering decisively in the quality of the product and its commercial value (Chicati et al. 2018; Pereira Filho et al. 2021). The mechanized harvesting of the common bean can be done in a direct or indirect way. In direct harvesting, the machines simultaneously perform all operations (cutting, threshing, and cleaning the grain), while in the indirect harvesting, equipment such as the reaper and the harvester are used in different operations, in that one is to cut and the other to thresh the plant (Soares et al. 2020; Pereira Filho et al. 2021).

The architecture of the common bean plant is a factor that can be related to the efficiency in mechanized harvesting (Kläsener et al. 2018). In mechanized common bean harvesting, the loss rate is high due to a low height of the pod in most cultivars, with most of the pods concentrated in the lower 2/3 of the plant (Pereira Filho et al. 2021). As a result of this, the cutting platform reaches many pods, resulting in a significant loss of grains (Pereira Filho et al. 2021). An alternative would be to cause changes in the distribution of the pods in the plants through crop management practices to increase the positioning of the pods at the top of the plant.

The increase in plant density provides an increase in the pod insertion height (Donato et al. 2021). However, the increase in plant density did not decrease the number of pods touching the soil surface (Horn et al. 2000; Santos et al. 2014). Studies performed to determine the effect of cultural practices on the distribution of pods in the common bean are scarce and performed a long time ago, while many new cultivars have been released in the last 10 years. Thus, the objective of this study was to determine the effect of plant density, nitrogen fertilization, and fertilization depth on the distribution of pods on the common bean plant.

2. Material and Methods

Description of the experimental site

The experiments were carried out in the winter seasons of 2017 and 2018 under irrigation by central pivot, at the Capivara Farm of the Embrapa Arroz e Feijão, located in the municipality of Santo Antônio de Goiás, GO, under the geographical coordinates 16°28'00"S and 49°17'00"W, and at an altitude of 823m. According to the Köppen classification, the region's climate is Aw, tropical savanna (Alvares et al. 2014). There are two well-defined seasons throughout the year, one being dry, from May to September (autumn/winter) and the other rainy, from October to April (spring/summer). The average annual rainfall ranges from 1,500 to 1,700 mm. The average annual temperature is 22.7 °C, ranging from 14.2 °C to 34.8 °C. The maximum air temperature during the period of the two field experiments are shown in Figure 1.

Before siting the experiments, the experimental areas were cultivated for five harvests under a no-tillage system, with corn/soybean grown in the summer and common beans in the winter. The soil in the experimental areas is classified as an Oxisol (Santos et al. 2018). Prior to the setup of the experiments, in June 2017, soil samples were collected to perform the chemical analysis (Teixeira et al. 2017), and the results are shown in Table 1.

Experimental design and treatments

In both cropping seasons (2017 and 2018), the experiments were laid out as a randomized blocks design in a 4x2 factorial scheme, with four replicates. The treatments consisted of four plant densities (5, 10, 15, and 20 plants m^{-1}) and two fertilization depths in the sowing furrow (6 and 12 cm). The plots consisted of ten rows of 6 m, and the six central rows being considered as useful area, discarding 2 m from each end.

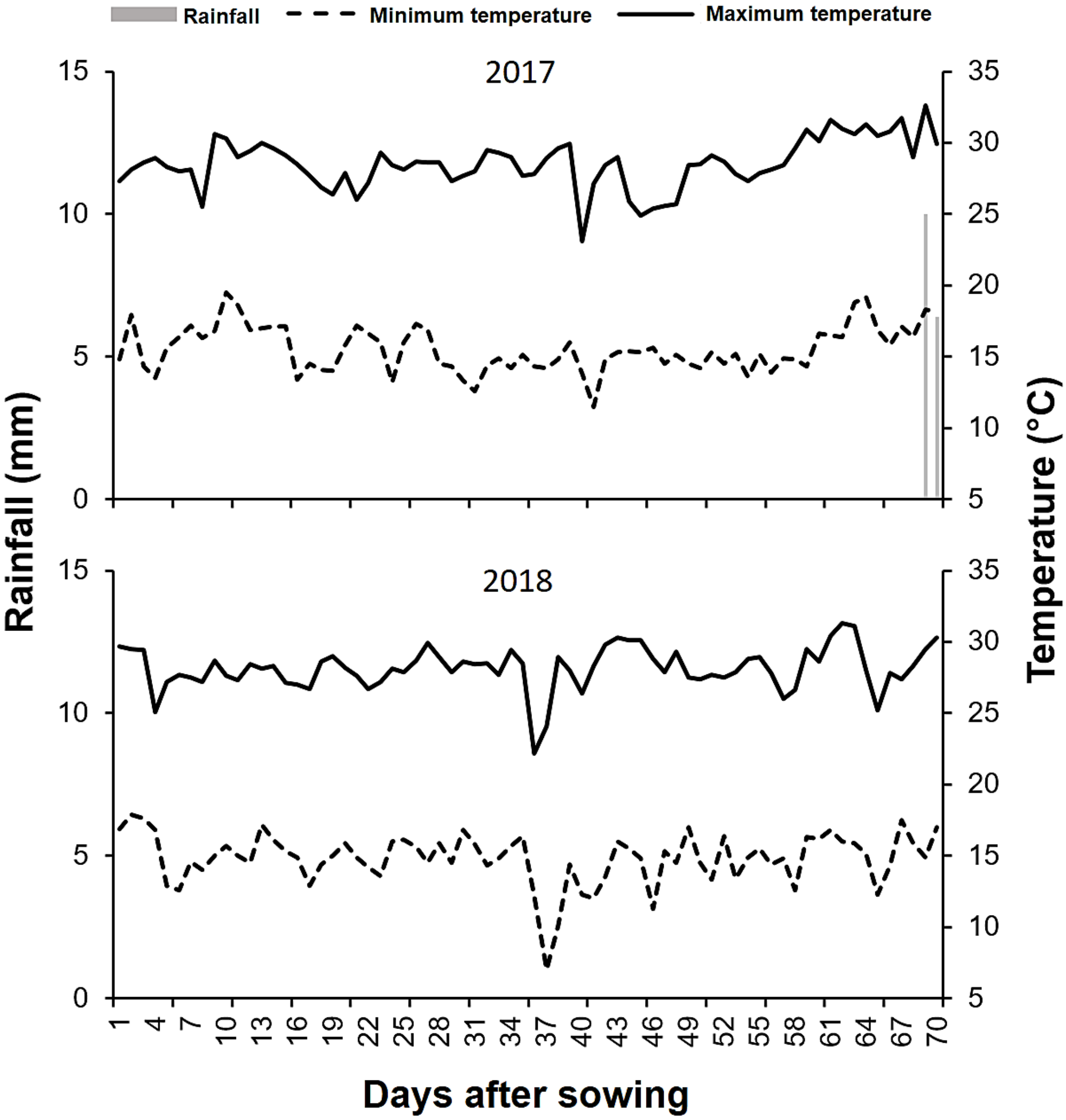

Figure 1. Daily rainfall, maximum and minimum temperatures in the experimental area during the period of the field experiments in the cropping seasons 2017 and 2018.

Table 1. Soil chemical and granulometric attributes of the experimental areas at 0-0.20 m depth before commencement of the experiments. Santo Antônio de Goiás, 2017.

pH	Ca	Mg	Al	H+Al	P	K	SB[a]	CEC[a]	BS	SOM[1]
In H_2O	cmol$_c$ dm^{-3}				mg dm^{-3}		cmol$_c$ dm^{-3}		%	g kg^{-1}
5.7	1.1	0.8	0.1	2.4	6.9	105	2.17	4.57	47.48	34.9

[a] SB = sum of bases; CEC = cation exchange capacity; BS = bases saturation = ((K+Ca+Mg)/Tcec)×100, where Tcec = K+Ca+Mg+total acidity at pH 7.0 (H+Al); SOM = soil organic matter. Granulometric properties were (in gram per kilogram): 420 (clay), 110 (silt), 470 (sand).

Cultivar and crop management

The BRS FC104 cultivar of common bean was used, which has a very early cycle, with a total of 65 days from sowing to harvest. Sowing was carried out in June 2017 and 2018 using a no-till seeder-fertilizer machine, provided with five rows spaced at 0.45 m and calibrated to distribute 25 viable seeds per meter. At the development stage of the first trifoliate leaf, thinning of plants was carried out in each plot in order to implement the treatments of plant densities (5, 10, 15, and 20 plants m^{-1}). The seeder-fertilizer machine was equipped with furrow rods for fertilization and double discs for seeding and was always operated in the same direction, at a speed of 4 km h^{-1}. The experiments were installed in the second half of June 2017 and 2018. Pre-sowing fertilization was done by applying 300 kg ha^{-1} of N–P–K (0–30–10) in furrow immediately before sowing. The experiments were managed following the recommendations for the common bean crop (Sousa et al. 2004). Seeds were inoculated with *Rhizobium tropici* using two doses ha^{-1} (=2.4 million cells $seed^{-1}$). Topdressing N fertilization using urea was performed at the V4 vegetative stage, at the third fully expanded trifoliate leaf. In 2017, the topdressing N fertilization was applied in a dose of 45 kg ha^{-1} in each plot and, while in 2018 the plots were subdivided into two, receiving doses of 45 and 90 kg ha^{-1} of N. Central pivot sprinkler irrigation was used according to the needs of the crop (Cunha et al. 2013). Phytosanitary management was carried out in order to keep the crop free from pests, diseases, and weeds.

Data collection and measurements

The following were evaluated: length of the stem (LS), the height of the highest pod (HHP), the distribution of pods (DP), number of grains per pod (NGP), the number of pods per plant (NPP); the mass of 100 grains (M100G), the percentage of grains retained in sieves 10 (PGS10 = 4 mm) and 12 (PGS12 = 4.5 mm) and the grain yield (GY). The LS was determined in five plants pulled from the outer rows of the useful area during the vegetative phase "V3". The HHP was determined in five plants, in each plot, in the reproductive phase “R9”. The DP was evaluated through an image of each subplot, in the R9 phase. The image was taken with a photographic camera positioned on the ground, perpendicularly and at 45 cm from the row of target plants. The plants were kept in their natural state and some leaves were removed from them to expose the pods. The camera was adjusted to take the image of the entire plants. Using the PowerPoint application, each image was processed to contain only the plants, from the base to the highest pod. Horizontal lines were projected on the image to divide it into 15 equal sections (Figure 2).

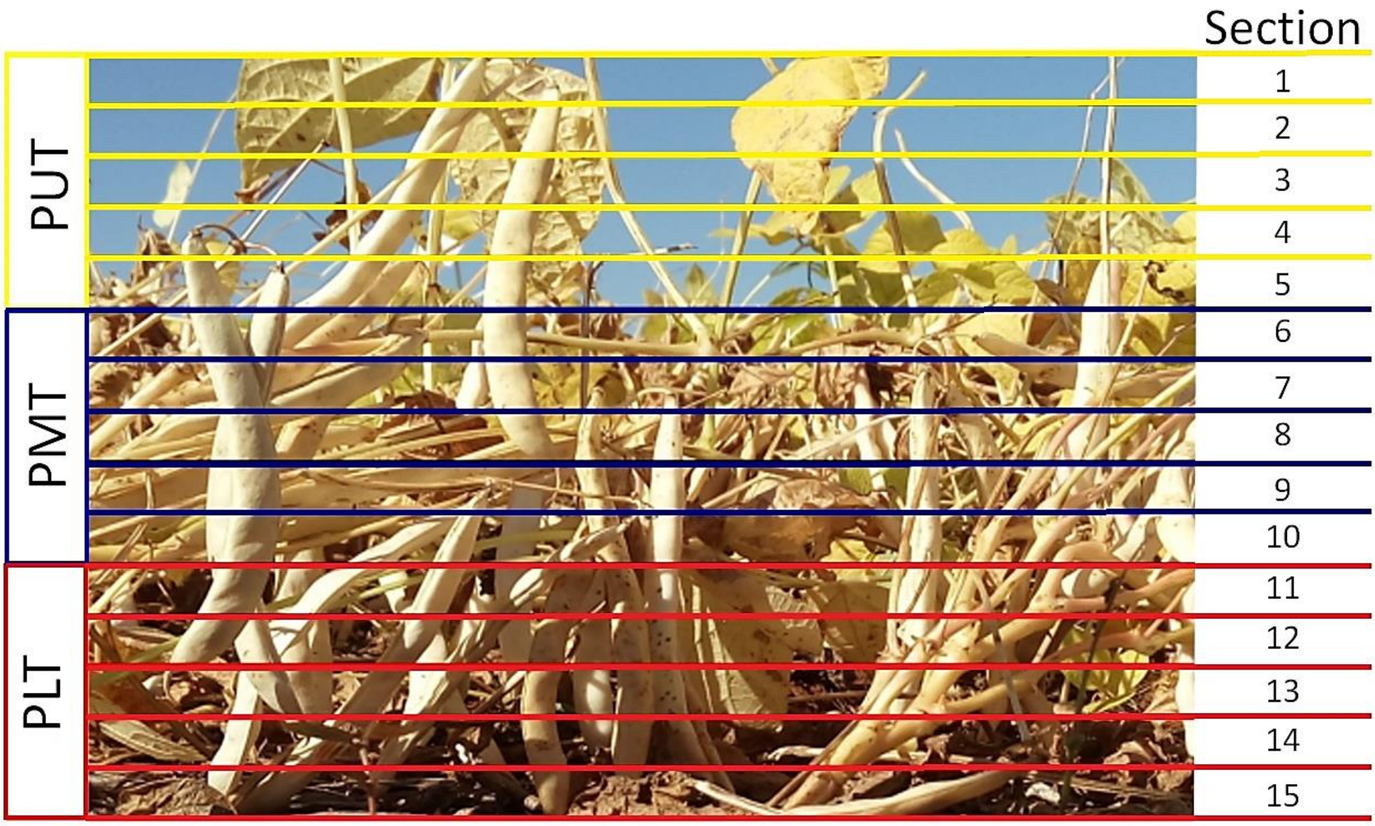

Figure 2. Pods distribution on the cultivar BRS FC104 of common bean. Pods in the upper third (PUT), pods in the middle third (PMT) and, pods in the lower third (PLT).

The counting of pods, or fractions of pods, were made in each of the 15 sections. Thus, the pods, or fraction of pods, counted in sections 1 to 5 were classified as pods in the upper third (PUT), those in sections 6 to 10 as pods in the middle third (PMT) and those in sections 11 to 15, as pods in the lower third (PLT). When the same pod appeared in two different sections, for example in sections 5 and 6 or 10 and 11, it was counted in both thirds. That is, the same pod was counted in the upper and middle third or in the middle and lower third, respectively.

The percentage of pods, or fraction of pods, in each third of the plant was obtained in relation to the total number of pods observed in the image. Knowing the average HHP and the percentage distribution of all pods in each section of the plant (PUT, PMT and PLT), the percentage of pods positioned at more than 100 mm from soil surface (P100) was calculated. PUT, PMT, PLT and, P100 parameters were determined only in 2018 and for the N fertilization applied at 12 cm depth.

NGP, NPP, M100G, PGS10 and PGS12 were evaluated in five plants randomly harvested in the center of the central row of each plot. GY was determined in the useful area of each plot. M100G and GY were expressed in g and kg ha^{-1}, respectively, after the moisture content was corrected to 13%.

Statistical analysis

Data from each experiment were first submitted to tests of normality and homogeneity of variances for each variable. The data obtained at the different locations were subjected to group experiment analysis. In case of significant differences between locations, the results of each location were analyzed separately. On the analysis of variance, the F test ($p \leq 0.05$) was applied and, when Fc was significant, mean values of the treatments were compared using the T-test at 5% of significance for the qualitative variables, and subjected to regression analysis for the quantitative variables, using the statistical software Sisvar (Ferreira 2019).

3. Results

Many attributes related to plant morphology were affected by the cropping season. Higher values of LS, HHP, PLT, and P100 were observed in 2017 and PUT in 2018. On the other hand, the effect of the plant density was only observed over HHP. Regarding fertilization, the application of fertilizer at a 12 cm depth resulted in higher LS, compared to fertilization at 6 cm depth. Besides, interactions were only observed between cropping season and plant density for HHP (Table 2).

Table 2. Length of the Stem (LS - mm), height of the highest pod (HHP - mm), pods in the upper third (PUT - %), pods in the middle third (PMT - %), pods in the lower third (PLT - %), and pods positioned at more than 100 mm from soil (P100 - %) of the common bean cultivar BRS FC104, based on the cropping season, the plant density and the fertilization depth in the sowing furrow.

Treatments	LS	HHP	PUT	PMT	PLT	P100
Cropping season (C)						
2017	123 a	325 a	21.8 b	50.5	27.7 a	72.3 a
2018	106 b	188 b	28.7 a	49.1	22.2 b	48.7 b
Plant density (D)						
5	112	235	21.9	49.7	28.4	56.2
10	112	243	25.5	50.4	24.1	60.9
15	115	271	27.2	49.5	23.3	62.0
20	118	279	26.3	49.8	23.9	62.8
Fertilization depth (F)						
6	111 b	246	24.6	49.9	25.5	60.4
12	117 a	268	25.9	49.7	24.4	60.6
Factors			ANOVA (p-value)			
C	<0.01	<0.01	0.01	0.40	0.02	<0.01
D	0.12	0.02	0.55	0.98	0.37	0.32
F	<0.01	0.06	0.64	0.93	0.61	0.93
CxD	0.64	0.05	0.30	0.10	0.25	0.32
CxF	0.20	0.11	0.20	0.23	0.52	0.39
DxF	0.75	0.42	0.67	0.13	0.44	0.58
CxDxF	0.12	0.71	0.66	0.71	0.80	0.68
CV	7.4	17.9	43.1	13.5	36.4	18.0

Means followed by different letters, within the same column and treatment, are significantly different by the T-test ($p \leq 0.05$). Adjusted equation for HHP ($HHP=3.2x+217$) as influenced by plant density.

The increase in the plant density linearly increased HHP, such that the HHP at 20 plants per meter was about 19% higher as compared to 5 plants per meter (Figure 3).

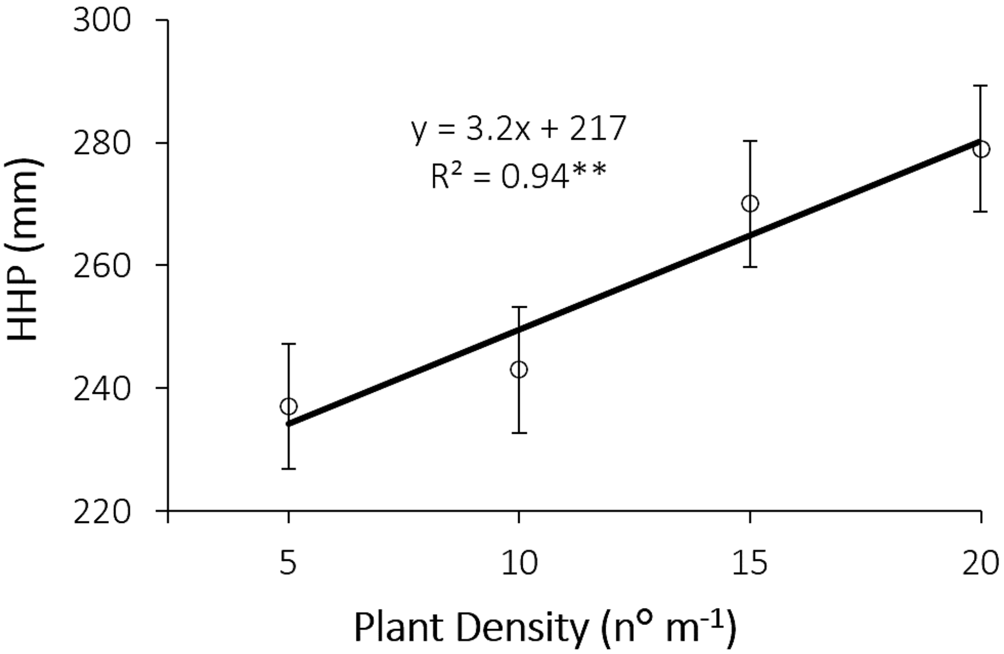

Figure 3. Height of the highest pod (HHP) in common bean as affected by the plant density ($p \leq 0.05$).

Table 3. Number of grains per pod (NGP - n°), number of pods per plant (NPP - n°); mass of 100 grains (M100G - g), the percentage of grains retained in sieves 10 (PGS10 - %) and 12 (PGS12 - g) and grain yield (GY – kg ha^{-1}) of the common bean cultivar BRS FC104, based on the cropping season, the plant density and the fertilization depth in the sowing furrow.

Treatments	NGP	NPP	M100G	PGS10	PGS12	GY
Cropping season (C)						
2017	5.2 a	18.6	21.3 b	66.5 b	7.2 b	2304 a
2018	3.5 b	16.6	24.2 a	72.1 a	10.0 a	1861 b
Plant density (D)						
5	4.3	22.3	23.3	73.1	7.0	2103
10	4.4	17.7	23.5	68.9	8.8	1947
15	4.4	16.9	22.7	66.2	10.8	2113
20	4.4	13.5	22.1	69.1	8.9	2168
Fertilization depth (F)						
6	4.3	17.0	22.6	69.6	8.7	2056
12	4.4	18.2	22.7	70.0	8.5	2110
Factors			ANOVA (p-value)			
C	<0.01	0.12	<0.01	<0.01	<0.01	<0.01
D	0.84	<0.01	0.29	0.10	<0.01	0.27
F	0.17	0.36	0.69	0.75	0.72	0.51
CxD	0.05	0.24	0.13	0.65	0.87	0.09
CxF	0.67	0.79	0.72	0.50	>0.05	0.12
DxF	0.82	0.78	0.13	0.46	0.20	0.13
CxDxF	0.83	0.87	0.40	0.80	0.52	0.46
CV	9.4	28.1	7.3	11.2	32.1	15.6

Means followed by different letters, within the same column and treatment, are significantly different by the T-test ($p \leq 0.05$). Adjusted equations for NPP ($NPP=-0.544x+24.4$) and for PGS12 ($PGS12=0.16x+6.9$) as influenced by plant density.

As observed in the parameters related to plant architecture, the parameters related to productivity components of the common bean were also affected by the cropping season. Higher values of NGP and GY were found in the 2017 cropping season, while for M100G, PGS10, and PGS12 higher values were observed in 2018. Fertilization depth did not affect the productivity components and the grain yield of the common bean, while Plant density influenced the NPP and PGS12. However, interactions between the cropping season and plant density and between the cropping season and fertilization depth affected NGP and PGS12, respectively (Table 3).

Linear but opposite responses occurred for NPP and PGS12 to the plant density. Regarding the NPP, its values reduced at higher values of plant density, while PGS12 values increased with the plant density of increasing (Figure 4).

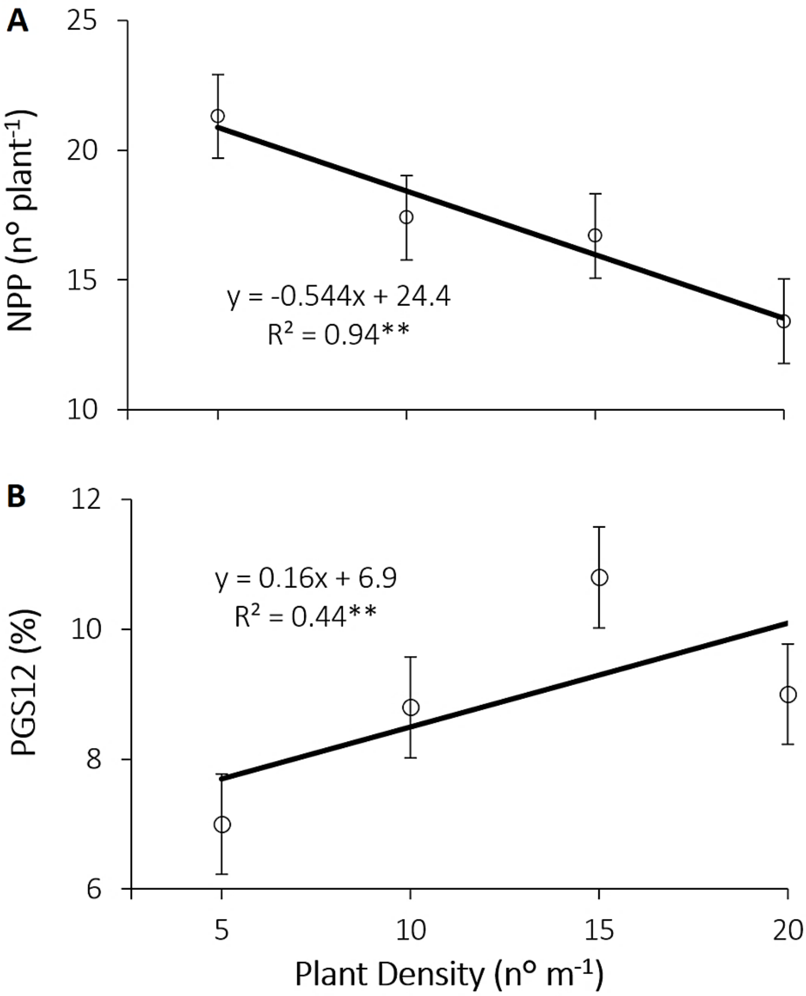

Figure 4. Number of pods per plant - NPP (A) and percentage of grains retained in sieve 12 – PGS12 (B) as affected by the plant density. NPP (p≤0.01) and PGS12 (p≤0.01).

Table 4. Height of the highest pod (HHP - mm), pods in the upper third (PUT - %), pods in the middle third (PMT - %), pods in the lower third (PLT -%), pods positioned at more than 100 mm from soil surface (P100 - %) of the common bean cultivar BRS FC104, based on the nitrogen dose and the plant density.

Treatments	HHP	PUT	PMT	PLT	P100
Nitrogen doses (N)					
45	190	28.7	49.0	22.3	52.8
90	188	26.8	47.3	25.8	55.8
Plant density (D)					
5	186	28.4	49.9	21.8	53.9
10	185	24.4	50.1	25.4	60.4
15	194	26.6	47	26.5	53.9
20	190	31.6	45.6	22.4	49.0
Factors	ANOVA (p-value)				
N	0.69	0.52	0.19	0.11	0.45
D	0.75	0.37	0.05	0.33	0.28
NxD	0.26	0.06	0.87	<0.01	0.01
CV	9.4	29.6	7.5	24.7	20.7

Means followed by different letters, within the same column and treatment, are significantly different by the T-test (p≤0.05).

Nitrogen doses and plant density did not affect the architectural parameters (HHP, PUT, PMT, PLT, and P100) of the common bean cultivar BRS FC104. However, there was a significant interaction between nitrogen doses and plant density for the parameters PLT and P100 (Table 4).

For the application of the 45 kg ha^{-1} of N, the plant density did not cause a significant effect on P100 (Figure 5A), while the higher plant density provided a reduction in PLT (Figure 5B). However, with the application of 90 kg ha^{-1} of N, there were significant increases in P100 with the increase in plant density, but for PLT, there was no significant effect (Figure 5).

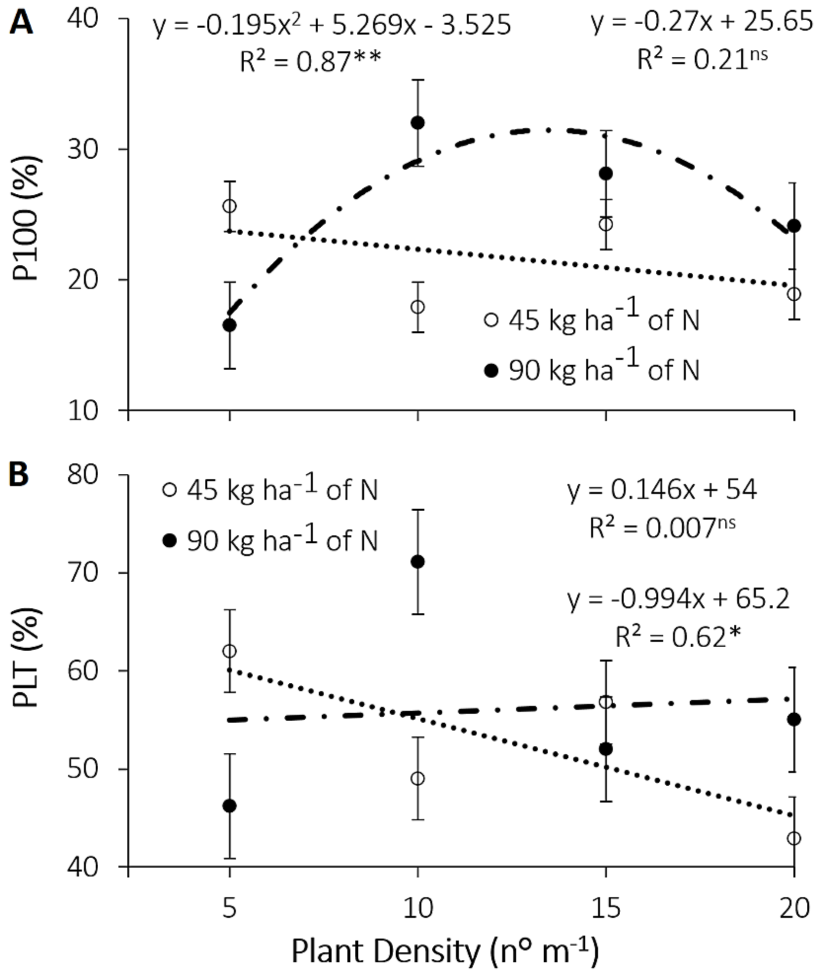

Figure 5. Pods positioned at more than 100 mm from soil surface – P100 (A) and pods in the lower third - PLT (B) as affected by the density of plants and doses of nitrogen. P100 ($p \leq 0.01$) and PLT ($p \leq 0.01$).

4. Discussion

Plant growth parameters may be influenced by edaphoclimatic conditions (Ribeiro et al. 2018; Araújo et al. 2020; Donato et al. 2021). The better development of plants in 2017 may be related to the air temperatures being more favorable for the crop development (Ribeiro et al. 2018; López-Hernández and Cortés 2019; Ribeiro and Maziero 2022). In 2018, during the common bean growing cycle, air temperatures were higher (Figure 1), which may have resulted in lower plants, with shorter lengths of hypocotyl and epicotyl and amounts of pods positioned in the upper portion of the plants, above 100 mm from the soil surface. The occurrence of temperatures above 30-32 °C along the day results in damages to the establishment, growth, and development of the crop (Somavilla et al. 2020; Ribeiro and Maziero 2022). Because common bean is a short-cycle crop, it is more sensitive to changes in environmental conditions (Pereira et al. 2014; Somavilla et al. 2020). This may have an even greater effect when it comes to the BRS FC104 cultivar evaluated in this work since it is a super early plant that has a cycle of 65 days.

Higher values of LS, HHP, and P100, as observed in 2017 (Table 2), are important results, since they benefit mechanized harvesting of the common bean, contributing to increasing the efficiency of mechanized harvesting, reducing grain loss. Threshing machines generally cut the plants at average heights close to 100 mm, which are considered too high (Soares et al. 2020). In 2017 and 2018, the percentage of pods positioned below P100 was 27.7% and 51.3% respectively, indicating a large number of pods in the action area of the cutting bar of the threshing machine. Thus, it can be inferred that losses in 2018 would be greater than in 2017 if the harvest was carried out with a combine harvester.

Our results show that by increasing the plant density, a linear increase on the HHP values occur in common bean. This increase in the plant density causes greater competition between plants for light, water, and nutrients, and plants tend to increase heights (Mondo and Nascente 2018). Consequently, the pods will occur at a higher height relative to the soil surface.

The deeper application of fertilizer (12 cm depth) promotes higher LS. This is probably related to greater root development, which favors greater nutrient absorption and better seedling growth, as previously reported (Girardello et al. 2014; Lacerda et al. 2014; Orlando Junior et al. 2021). Thus, it is likely that the deeper fertilization favored greater root development and caused significant effects on the initial growth of plants (Orlando Junior et al. 2021), which may explain the higher values of LS.

As reported for the plant architecture parameters, the productivity components were also influenced by the climatic conditions (Pereira et al. 2014; Amaro et al. 2014). The maximum air temperature in 2018 was higher than in 2017. Higher air temperatures cause an increase in the consumption of reserve substances by the plant, which may cause a reduction in productivity (Santos et al. 2014). Additionally, higher air temperature is the environmental factor which exerts the greatest influence on the abscission of flowers and pods, reducing grain filling in common bean, causing a significant reduction in the grain yield of the crop (Mondo and Nascente 2018). On the other hand, the higher NGP reduced M100G and, consequently, the grain size, reducing PGS12. This inverse relationship between NGP and M100G is usually reported, both in common beans and in soybeans (Dalchiavon and Carvalho 2012).

In our study, a clear reduction in the NPP was related to the increase in the plant density. Similar result has been reported in the literature (Souza et al. 2014). This is because the largest number of plants per area increases competition between plants and causes a reduction in the number of pods per plant, but provides an increase in grain size (Santos et al. 2014). Corroborating this information, the highest NPP affected the grain size, since PGS12 increased with a decrease in NPP (Figure 4). According to literature, the number of pods and grain size are inversely proportional (Costa et al. 1997; Locatelli et al. 2014).

The absence of fertilization depth effects over the productivity components and the grain yield of the common bean may be related to the characteristics of the plant and, also with the soil management (Lacerda et al. 2014). About 80% of the common bean roots are located within 20 cm (Pereira et al. 2014) and the experiments were conducted under no-tillage systems, in which the highest levels of nutrients are concentrated in the most superficial layers of the soil (Nascente et al. 2014). Thus, even providing greater development of the hypocotyl and epicotyl, it is likely that fertilization in deeper layers did not provide improvements in the absorption of nutrients that would allow greater productivity of grains, since in the surface layers there were nutrients enough for the full development of plants. Soils with adequate levels of nutrients and organic matter do not provide significant increases in grain yield of the common beans (Carvalho et al. 2014).

Nitrogen is a key nutrient that is part of several plant structures and thus significantly affects plant growth (Ribeiro et al. 2018). In this work we also observed significant interactions between nitrogen doses and plant density for the parameters PLT and P100. Thus, with the application of the 45 kg ha^{-1} of N, the higher plant density provided a reduction in PLT and did not cause a significant effect on P100. However, when 90 kg ha^{-1} of N was applied, there were significant increases in P100 with the increase in plant density and there was no significant effect on PLT. Thus, the use of higher doses of nitrogen, and a higher plant density, is a strategy to increase P100, providing a reduction in losses in the harvest (Santos et al. 2014; Lacerda et al. 2019).

5. Conclusions

About 25% of common bean's pods of the BRS FC104 cultivar, are positioned below 100 mm from the soil surface, corresponding to the height of the cutting bar in the most combine harvester.

Nitrogen fertilization and plant density affect the distribution of pods in the common bean, BRS FC104 cultivar.

To reduce the grain loss at the harvest the plant density must be increased for higher N doses (90 kg ha^{-1}) and reduced for lower N doses (45 kg ha^{-1}).

Authors' Contributions: DA SILVA, J.G.: conception and design, acquisition of data, analysis and interpretation of data, and drafting the article; NASCENTE, A.S.: drafting the article and critical review of important intellectual content; FERREIRA, E.P.B.: analysis and interpretation of data, drafting the article, and critical review of important intellectual content; SARMENTO, P.H.L.: drafting the article and critical review of important intellectual content; MESSIAS, M.: drafting the article and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

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