Hole spacing in soybean hill drop sowing

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ABSTRACT

The aim of this study was to evaluate the development, yield and its components of soybean sown in hill drop method with variation in hole spacing, compared to the conventional sowing method in lines. The experiment was conducted in a randomized block design, with six treatments and four replications, using the variety M7739 RR IPRO with four plans per hole. The treatments consisted of population variation from 50 to 150% of the recommended one, obtained by the holes spacing alteration and a control sowed in lines with the recommended population. The control was compared to the other treatments using the Dunnett test and the hole spacing effect was evaluated by regression. The cultivar 7739 RR IPRO responds to hill drop sowing, obtaining even in lower populations, yields similar to the conventional sowing in lines. The highest yields in the hill drop sowing method are obtained in the higher populations, with a linear decrease in yield with an increase in hole spacing. Increasing hole spacing increases the number of pods and branches and reduces leaf cover, light interceptcion, plant height and first pod height.

Keywords: space arrangement; population density; *Glycine max.*

INTRODUCTION

Soybean is one of the main products in the world and in Brazil, in the 2019/2020 season, the cultivated area was over 36.8 million hectares and the production estimate is 124.8 million tons (CONAB, 2020) being considered the main agricultural crop in the country. In a study of historical series from the 1976/1977 season, CONAB (2017) found that in the first two decades, the yield increase was responsible for the gains in national production. However, in the rest of the period, the yield showed less growth, with the cultivated area being multiplied by ten while productivity increased only about 50%. In the main soybean producing centers, United States, Brazil and Argentina, the value of 3 thousand kg ha^{-1} represents a level of average yield beyond which it is not possible to advance significantly. Also according to this study, the prospects for soybean yield in the future depend on the disruption and leverage of the current productive balance, since the potential for soybean yield is still far from being reached in large producing centers.

Intense research activity is noted on soybean crop to obtain information that can allow yield increases and costs reduction (Barbosa *et al.*, 2013). It is important to note that the crop yield depends not only on good management practices, but also on their interaction with the plant and the production environment (Mauad *et al.*, 2010). The soybean has high phenotypic plasticity, that is, it has the ability to modify its morphological components to suit different conditions of the production environment, which facilitates modifying the arrangement of plants in the field (Pires *et al.*, 2000). So, in order to obtain better yields, it is necessary to study factors as the plant arrangement, which can be manipulated through changes in sowing density, spacing between lines and plants distribution in the lines (Torales *et al.*, 2014). According to Balena *et al.* (2016) changes related to plant population can increase yield gains. This effect can be attributed to the plants spatial distribution in the area, in order to minimize intraspecific competition and maximize the environmental resources use represented by water, light and nutrients (Balbinot Junior *et al.*, 2015).

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Another aspect influenced by the plant arrangement is the diseases occurrence. Knebel *et al.* (2006) observed that end-of-cycle diseases can be influenced by the spatial arrangement of soybeans, with less severity in lesser density. Madalosso *et al*. (2010) report that the reduction of the soybeans line spacing facilitated the Asian rust establishment and reduced control efficiency.

Seeking improvements in cultural practices and soybean yield gains some seedling disc manufacturers and farmers have tested the soybean seeds distribution in a grouped arrange, usually three to four seeds every 30 to 40 cm (Santos *et al*., 2018). According to Serraglio & Simonetti (2017) grouped sowing emerges as an alternative to improve sunlight use, as it gives more space to plants, including the lower leaves, which are ineffective in the conventional spatial arrangements.

This work hypothesis is that the soybean plants spatial arrangement modification in the hill drop sowing will cause changes in light availability, with a greater incidence in the plant lower portions. This will cause changes in the plant's morphology, with greater branching and number of nodes, promoting yield gains even in lower populations. Given the above, this research objective was to evaluate the development, yield and its components of a soybean cultivar sown with variation in hole spacing, compared to conventional sowing in rows.

MATERIAL AND METHODS

The work was conducted in the 2017/2018 season in the Regional Jataí of the Universidade Federal de Goiás experimental field located in the municipality of Jataí. The experimental area is located at the coordinates: 17º 55 '32'' S and 51º 42' 32'' W and 685 m altitude. The region climate, presents two well-defined seasons, dry (April-September) and rainy (October-March). Figure 1 shows the meteorological data measured during the period the experiment was conducted. The experimental area soil was classified as a Soil Taxonomy (oxisol), with contents of 490, 100 and 410 g dm^{-3} of clay, silt and sand, respectively.The soil attributes in the 0–20 cm layer were: pH ($CaCl_2$): 5.0; Ca^{2+}: 2.5 $cmol_c$ dm^{-3}; Mg^{2+}: 1.2 $cmol_c$ dm^{-3}; Al^{3+}: 0.2 $cmol_c$ dm^{-3}; H+Al: 3.9 $cmol_c$ dm^{-3}; K^+: 0.097 $cmol_c$ dm^{-3}; P (Mehlich 1): 23 mg dm^{-3}; Cu: 3.2 mg dm^{-3}; Fe: 7 mg dm^{-3}; Mn: 1.8 mg dm^{-3}; Zn: 0.6 mg dm^{-3}; organic matter : 43.0 g dm^{-3}; CTC: 7.03 $cmol_c$ dm^{-3} e V (%): 49.

A randomized block design was used, with 6 treatments and four replications (Table 1). The cultivar choosen was M7739 RR IPRO, which presents a 7.7 maturation group, a semi-determined growth habit, precocity, high yield potential, high stability, wide geographical adaptation and excellent branching (Agro Bayer Brasil, 2021).

The experimental unit consisted of five lines, spaced 0.45 m, 10 m long. For data collection, the three central lines of 6 m in length were used.

Soybean sowing was carried out on November 6, 2017, using a tractor sowing machine equipped with a horizontal disk suitable for group sowing, in which, for each hole four seeds are distributed. The control (T6) was sown in the same day with a traditional horizontal disc row seeder. All treatments received the dose of 444 kg ha^{-1} of the NPK formula 02-20-18 superfically apllied before soybean seeding. No lime was applied.

For weed control, dissication was done with 3.5 L ha^{-1} of the herbicide Glifosato Atanor® 48 (356 g L^{-1} Glyphosate acid equivalent) ten days before sowing and two post emergency applications, the first 14 days after emergency (DAE) with 2.5 L ha^{-1} of herbicide Glifosato Atanor® 48 and the second 21 DAE with 0.5 L ha^{-1} of Gallant® (Haloxifop-P-methyl 124.7 g L^{-1}). Three insecticide application: 0.15 L ha^{-1} of Jackpot® 50 EC (Lambda-Cyhalothrin 50 g L^{-1}) 14 DAE; 0.2 L ha^{-1} of Intrepid® 240 SC (Methoxyfenozide 240 g L^{-1}) + 0.13 L ha^{-1} of Mustang 350 EC (Zeta-Cypermethrin 350 g L^{-1}) 31 DAE and 0.4 L ha^{-1} of Talismã® (Bifenthrin 50 g L^{-1} e Carbosulfan 150 g L^{-1}) 54 DAE. Two fungicide application: Aproach® prima (Picoxystrobin 200 g L^{-1} e Ciproconazole 80 g L^{-1}), dose of 0.3 L ha^{-1} 31 DAE and 0.24 L ha^{-1} of Ópera® (Pyraclostrobin 133 g L^{-1} e Epoxiconazole 50 g L^{-1}) 54 DAE. 0.5 L ha^{-1} of adjuvant Nimbus® (mineral oil 428 g L^{-1}) in insecticide and fungicide applications.

The percentage of area covered by leaves was obtained through the processing of images captured by a camera positioned one and a half meters above the ground. Three images were obtained from each plot, with a resolution of 5 MPixels, 42 days after emergence (DAE). Image processing was performed using the software SisCob (Jorge & Silva, 2009). For this, pixels representing each of the classes to be evaluated (soil, straw and soybean leaves) were sampled. The spectral values of each class in several images were used to reduce processing errors. These values were used by the software to classify each pixel of the images. After processing, the percentage of leaves in each image was obtained, averaging the three images to represent the value of the plot.

To obtain the intercepted radiation and the leaf area index (LAI), a Accupar LP-80 ceptometer was used, which takes simultaneous readings, below and above the canopy, of the photosynthetically active radiation by means of a sensor bar and a external sensor. The equipment calculates the radiation intercepted by difference and the LAI using internal equations. In each plot, three readings were taken with the ceptometer and the average represented the plot value at 42 DAE.

At the crop cycle end, the plants from the useful area were harvested and 10 of them were randomly separated, to evaluate the number of pods per plant, number of branches per plant, grains per pod, height of the first pod and height of plants. All plants were threshed and the grain moisture determined. Yield in kilograms per hectare and the mass of a thousand grains, in grams, was calculated correcting the grain mass for the moisture of 13%.

The data obtained were subjected to variance analysis and the comparison of means by Dunnett's test. The effect of hole spacing was evaluated using regression analysis choosing the curves by means of coefficients significance. The software R (R Core Team, 2020) and the packages Multcomp (Hothorn *et al*., 2008) and ExpDes.pt (Ferreira *et al*., 2018) were used.

RESULTS AND DISCUSSION

It was observed that at 42 DAE the soybean sown in the hole spacing (HS) of 33.33 and 44.44 cm, did not differ from the control sown in line for the variable covered area by leaves (Table 2). However, in HS 22.22, 26.67 and 66.67 cm, the two smaller spacing promoted a larger covered area by leaves, while the larger HS resulted in smaller values of this variable when compared to the control. These results are directly related to the population, since the reduced HS promotes higher number of plants per hectare. Werner *et al*. (2018) also observed that the increase in sowing density provides greater soil coverage by plants, which can favor the management of weeds and the use of light, water and nutrients. The early shading of the area by the rapid closing of the plant canopy is important for its contribution to the chemical control of weeds (Correia & Durigan, 2010). On the present work, the HS of 44.44 cm promoted a soil cover similar to that observed on the control, indicating that the group seeding could be beneficial related to the items cited above, since the population is 25% lower compared to the control. Heiffig *et al*. (2006) observed that with greater spacing between soybean rows there was less soil coverage, which provided greater emergence, development and growth of weeds, which, if not managed, could lead to reductions in agricultural yield. The authors also argued that, on the other hand, this rapid closing between the lines creates conditions of less air circulation and greater humidity, which can favor the incidence of diseases.

It was found that the intercepted radiation was influenced by HS, with 22.22 cm presenting high intercepted radiation when the HS of 44.44 and 66.67 cm showing lower values when compared to the control. The HS of 26.67 cm did not differ to the control, showing that the grouping seeding method allowed similar use of light, even with a lower number of plants per hectare. This result may be attributed to the soybean plants morphology changes due to the grouped arrangement. Souza *et al.* (2010), Tourino *et al.* (2002) and Balbinot Junior *et al.* (2014) observed a reduction in ramifications with

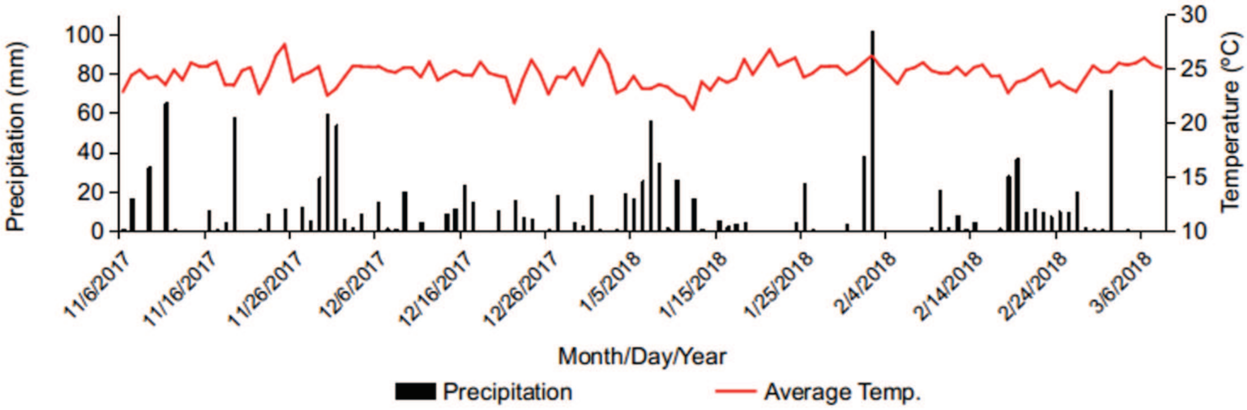

Figure 1: Precipitation (mm) and average temperature (ºC) of the experimental area from November 2017 to March 2018.

Table 1: Treatments used to evaluate hole spacing in soybean crop and percentage of recommended population (% population), number of holes per meter (holes m^{-1}), hole spacing (HS) and number of plants per hectare (plants ha^{-1}), Jataí -GO, 2018

Trat	Population (%)	holes m^{-1}	HS (cm)	plants ha^{-1}
1	50	1.50	66.67	133,332
2	75	2.25	44.44	199,998
3	100	3.00	33.33	266,664
4	125	3.75	26.67	333,330
5	150	4.50	22.22	399,996
6	Line sowing			266,664

reductions in spacing and/or increasing the population. In turn, Zanon *et al.* (2015) observed that the leaf area index of the branches can reach 31% for cultivars with determined growth habit, or 20.2% for that with an indeterminate habit. Petter *et al.* (2016) points out that there is a greater photosynthetically active radiation interception in the highest crop densities up to 45 days after emergence, with no significant difference after this period. The authors point out that in their work it was evident the plants ability in the intermediate densities to compensate the radiation interception.

At 42 DAE, significant differences were noticed for all HS in relation to the control for the leaf area index, except for the HS of 33.33 cm that have the same population of the control.The HS of 22.22 and 26.67 cm promoted a higher leaf area index, when the HS of 44.44 and 66.67 cm presented lower values compared to the control. Similarly, Heiffig *et al*. (2006) studying the soybean crop closure and leaf area index in different spatial arrangements, showed that the highest LAI were observed in the largest population treatments.

Considering the intercepted radiation and LAI, the hole sowing did not promote gains, as there was no difference between the control and the 33.33 cm HS, which is the same population in a different arrangement. In other words, the "boundary effect" was not observed in LAI at this stage, since the lower populations showed lower results. Silva (2018) found that the plant population were more determinant to the LAI than the soybean plants arrangement. But in terms of intercepted radiation it could be said that some gain occured, since the population of 199,998 plants per hectare achieved similar results to the 266,664 population. Light interception is an important component for the expression of the maximum productive potential of soybean especially since it is a C3 type metabolism plant, less efficient in the use of light (Casaroli *et al*., 2007), since solar radiation is one of the most limiting factors for plant growth and development (Taiz & Zieger, 2006).

It was found that the HS influenced the number of pods per plant, number of branches per plant, first pod height insertion, plant height, a thousand grains mass and yield (Table 3).

The treatments with HS of 44.44 and 66.67 cm, were higher compared to the control considering the number of pods and branches per plant, while for the smaller spacing (22.22 cm) the result of the number of pods was lower (Table 3). These results demonstrate the adaptive behavior of this soybean variety that can compensate lower populations increasing the yield components. Tourino *et al.* (2002) also observed an increase in lateral ramifications with an spacing between row increase in, attributing this effect to a compensation in the reduction of spacing between plants in the planting line. On the other hand, Gibbert *et al*. (2018) did not observe a reduction in the number of branches when testing the cultivars Nidera 5909 and BMX Poder RR, with 8, 10, 12 and 14 plants per meter in the 0.45 m spacing between lines. The conflicting results probably indicate diversity of response of cultivars to the spatial arrangement.

For the first pod height insertion, only the spacing of 66.67 cm differed from the control, with a lower height (Table 3). However, this reduction was not enough to impair mechanized harvesting, since Menezes *et al*. (2018) recommend a minimum height of around 10 cm for this operation in the soybean crop. The increase in plant height provided by the 22.22 cm HS is due to the fact that with the smaller HS there is a greater number of plants per hectare, which tends to promote the plants' etiolation according to Andrade *et al*. (2016).

Analyzing the mass of a thousand grains and yield, a significant difference of HS of 22.22 cm in relation to the control was observed. The smallest HS provided greater thousand grain mass (5.82%) and yield (11.25%) compared to the control. Markos *et al.* (2011) verified positive correlation between yield and a hundred grain mass in different soybean spatial arrangements, what reforce the significance of this work results.

Table 2: Covered area by leaves (CAL), intercepted radiation (IntRad) and leaf area index (LAI) as a function of the hole spacing (HS) and control sown in line with soybean crop at 42 DAE. Jataí, GO 2018

HS(cm)	CAL (%)	IntRad (%)	LAI
22.22	93.52 b	92.65 b	3.97 b
26.67	88.83 b	87.68 a	3.46 b
33.33	85.30 a	83.63 a	2.98 a
44.44	70.31 a	67.33 b	1.90 b
66.67	47.46 b	55.63 b	1.39 b
Line (control)	77.86 a	80.75a	2.77 a
CV %	5.16	7.22	12.51

The means followed by letter (a) in the column are equal and those followed by (b) are different from the control according to the Dunnett test ($p < 0.05$). CV - Coefficient of variation.

Similar to that observed in the leaves coverage, light interception and LAI, there was no yield difference and in its components for the grouped arrangement or in line when the population was the same. On the other hand, the largest HS, 66.67 and 44.44 cm, composed of 50% (133,332 plants ha^{-1}) and 75% (199,998 plants ha^{-1}) of the recommended population, respectively, improved the performance of cultivar 7739 RR IPRO in relation to the number of pods per plants and branches per plant, not differing from the control in terms of yield. It is important to note that the largest HS, due to the smaller amount of plants ha^{-1}, can promote a production costs reduction, as it does not differ from the control in yield, using 50 and 75% of the recommended population for the cultivar 7739 RR IPRO.

Tourino *et al*. (2002) studyied the effects of spacing, density and sowing uniformity in the soybean yield and agronomic characteristics, and found the highest grain production per plant, with the reduction of the number of plants in the rows, maintaining the yield levels. The authors achieved savings of more than 100% in seeds, with a reduction in density from 22 to 10 plants m^{-1}. Silva *et al.* (2015) e Martins *et al.* (2020) emphasize that the planting density increase can make the soybean production costs higher.

Results of the regression adjustment for the variables with significant results are shown on Figure 2.

For all the presented equations, the regression parameters were significant at 5% level. To the variables studied, linear models were adjusted, except LAI (Figure 2C) and plant height (Figure 2G) where quadratic models were choosen.

The behavior of light interception (Figure 2B) and the area covered by leaves (Figure 2A) were similar, both with a decreasing linear model, in agreement with Heiffig *et al.* (2006) results. For the LAI, with a quadratic model, the minimum in the adjusted equation occurs in the 65.7 cm hole spacing. The LAI is of relevant physiological significance for the soybean crop, especially from the grain filling beginning, as the plant's demand for water, nutrients and photoassimilates is intensified, which are directed to grains in formation to meet the growing accumulation of matter drought and oil and protein biosynthesis in grains (Heiffig *et al*., 2006). Therefore, the maximum soybean yield is determined by optimizing the plant's capacity to solar radiation interception and or accumulation of dry matter during the vegetative and reproductive stages (Wells , 1991)

The increase in HS promotes a linear increase in the number of branches and pods per plant (Figures 2E and F), with an increase of 1.11 pods for every centimeter of increase in HS, possibly due to the great light availability to each plant. This are similar to the results obtained by Tourino *et al*. (2002) that observed a number of pods reduction with the increase in plant density. According to Jiang & Egli (1993), the number of pods is determined primarily by the number of branches and consequently by the number of knots and flowers. Thus, with the lowest light incidence in each plant with the population increase, there is a reduction in the number of branches and pods per plant (Mauad *et al*., 2010; Silva, 2018). The results obteinad by Silva (2018) and Ludwig *et al.* (2011) showed a reduction in the number of pods per plant, as the population increases. However, the first ones found that from the population of 440 thousand plants ha^{-1}, the reduction in pods stabilizes, showing a potential for yield gains in higher plant densities.

The first pod height (Figure 2F) and the plant height (Figure 2G) also decreased, according to quadratic models, with the increase in HS. Silva (2018) did not observe significant differences for plant height and lodging between spatial arrangements in line or equidistant, but only the population influenced these variables. Casaroli *et al.* (2007) consider that when not sufficient incidence of radiation occurs, there is a reduction in photoassimilates synthesis and dry matter production since soyean is a C3 metabolism plant with low efficiency in the use of light. This situation can cause plant

Table 3: Number of pods per plant (PPP), number of branches per plant (BPP), grains per pod (GPP), first pod height insertion (FPH), plants heights (PH), a thousand grains mass (M1000) and yield (Yield), as a function of the hole spacing and line sown control in the soybean crop. Jataí, GO 2018.

HS(cm)	PPP	BPP	GPP	FPH (cm)	PH (cm)	M1000 (g)	Yield (kg ha^{-1})
22.22	45.23 b	6.32 a	2.01	17.45 a	70.79 b	200.15 b	4892.08 b
26.67	48.90 a	6.12 a	2.03	15.81 a	67.67 a	198.08 a	4474.16 a
33.33	66.00 a	7.40 a	2.04	14.40 a	64.93 a	197.39 a	4663.90 a
44.44	75.83 b	8.02 b	2.04	14.22 a	57.59 a	194.79 a	4343.88 a
66.67	94.40 b	8.90 b	2.08	12.31 b	51.29 b	197.29 a	4203.16 a
Line (control)	57.18 a	6.17 a	2.00	15.43 a	62.93 a	189.14 a	4397.10 a
CV%	7.37	10.76	3.67	7.65	4.33	2.38	4.12

The means followed by letter (a) in the column are equal and those followed by (b) are different from the control according to the Dunnett test ($p < 0.05$). CV - Coefficient of variation.

etiolation an in some situations, lodging can be noticed, The results of the present work showed that the grouped arrangement was not able to improve the light incidence in plants to the point of minimizing the effects of population increase.

According to Dalchiavon & Carvalho (2012) the number of pods per plant and the grain mass were directly correlated with soybean yield, proving to be the best components to estimate it. However, in this work, the greater branching and the greater number of pods in lower populations were not enough to compensate yield reduction, since it was observed a linear decrease in the last cited variable with hole spacing increase and consequent population reduction. Heiffig *et al*. (2006) noted a proportional growth in yield with the plant population increase. Cruz *et al*. (2016) reported that the yield increase as the plant population increases, and this fact is related to two factors: the number of pods per plant and the grain mass. Rahman & Hossain (2011) and Markos *et al*. (2011) observed better results of grain yield in higher populations. At higher levels of population, it is expected that the increase in yield can be significant, however, one should always consider favoring the lodging of plants (Silva, 2018)

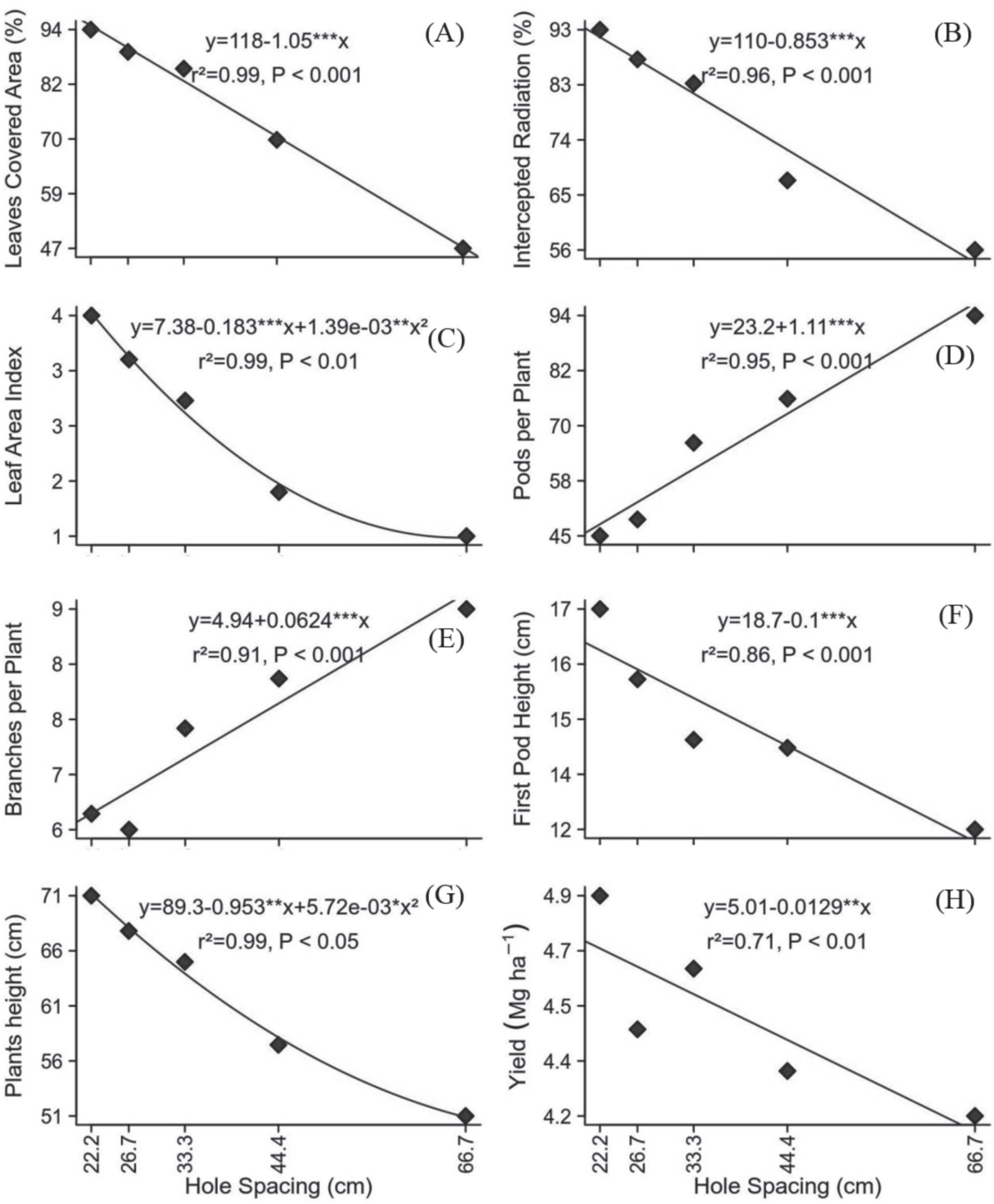

Figure 2: Covered area by leaves (A), percentage of intercepted radiation (B), leaf area index (C), number of pods per plant (D), number of branches per plant (E), First pod height (F), Plant height (G) and yield (H). Regression coefficients significance: * = p < 0,05; **= p < 0.01; *** = p < 0,001. The Regression P value is presented below the equation. All variables as a function of hole spacing. Jataí - GO, 2018.

Therefore, the results show that grouped soybean sowing was efficient in increasing the yield morphological components in reduced population. The largest hole spacing can reduce seed production costs, not differing from the control in yield.

CONCLUSIONS

The cultivar 7739 RR IPRO responds to hill drop sowing, obtaining even in lower populations, yields similar to line sowing.

The highest yield in grouped sowing with the cultivar 7739 RR IPRO are obtained in the largest populations, with a linear decrease with the increase in hole spacing.

Increasing hole spacing provides an increase in the number of pods and branches and the reduction in soil cover by leaves, light interception, plant height and height of the first pod.

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