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Grain yield performance of corn in different plant arrangements

Desempenho produtivo do milho em diferentes arranjos de plantas

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ABSTRACT - Sowing arrangements composed of double-row spacing in corn can favor the interception of solar radiation by the canopy and, consequently, the yield performance of the crop. However, it is possible that the microclimate provided by this spacing, especially at high plant densities, favors the occurrence of leaf diseases. Thus, the objective was to evaluate the effect of 0.45 m and double-row spacing arrangements on the severity of foliar diseases and yield performance of corn grown in the first and second -crop seasons. Two independent experiments were conducted (with and without the fungicide fluxapyroxad + pyraclostrobin) in the first and second-crop seasons in a randomized block design arranged in a split-plot scheme with four repetitions. The plots consisted of spacing (0.45 m) and double-row (0.30 × 0.60 m), and the subplots, four plant densities (59,200, 74,000, 81,400, and 96,200 plants ha^{-1}). In the plant density factor, in the second-crop season, there is a decrease in the severity of white spot as plant density is increased. Also, for the plant density factor, in the first-crop season, there may be a significant yield increase as the plant density is increased.

Keywords: *Zea mays* L. Inter-row spacing. Plant density. Leaf disease severity.

RESUMO - Arranjos de plantas compostos pelo espaçamento fileira dupla no milho podem favorecer a interceptação da radiação solar pelo dossel e, consequentemente, o desempenho produtivo da lavoura. Entretanto, é possível que o microclima proporcionado por este espaçamento, sobretudo em altas densidades de plantas, favoreça a ocorrência de doenças foliares. Assim, objetivou-se avaliar o efeito de arranjos compostos pelos espaçamentos de 0,45 m e fileira dupla sobre a severidade de doenças foliares e o desempenho produtivo do milho cultivado em 1ª e 2ª safra. Foram conduzidos dois experimentos independentes (com e sem o fungicida fluxapiroxade + piraclostrobina) na 1ª e 2ª safra, em delineamento em blocos ao acaso com parcelas subdivididas, com quatro repetições. As parcelas consistiram nos espaçamentos (0,45 m) e fileira dupla (0,30 × 0,60 m), e as subparcelas, quatro densidades de plantas (59.200, 74.000, 81.400 e 96.200 plantas ha^{-1}). No fator densidade de plantas, na 2ª safra, há decréscimo na severidade da mancha branca conforme adensamento de plantas. Ainda, também para o fator densidade, na 1ª safra, pode haver incremento significativo na produtividade em função do adensamento de plantas.

Palavras-chave: *Zea mays* L. Espaçamento entrelinhas. Densidade de plantas. Severidade de doenças foliares.

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INTRODUCTION

The adjustment of plant arrangement in corn cultivation considers variations in plant density and inter-row spacing (GALVÃO et al., 2014), and also spatial and temporal distribution of plants in the row (NOVAK; RANSOM, 2018), being a technique employed in the search for better yield performance, since it allows to allocate the maximum amount of plants per area, increasing the interception of photosynthetically active radiation, one of the determinants of grain yield (LU et al., 2017).

Arrangements that employ 0.45 m spacing have been common in corn cultivation, but alternative arrangements are still being sought, such as those composed of double-row spacing. In the double-row configuration, two rows are spaced closer together and are alternated by wider spacing, which can provide greater interception of solar radiation (NOVACEK et al., 2013), especially in second-crop season conditions where light intensity is reduced and especially in higher plant density, since greater competition for the light within the canopy is seen (YANG et al., 2019).

The increase in plant density in arrangements employing double-row spacing may trigger changes in air circulation, temperature, and relative humidity, conditioning a favorable microclimate for developing pathogens that cause leaf diseases, which would cancel the positive effect of a particular arrangement. However, this occurrence can be mitigated by applying fungicides (BRITO et al., 2013).

Studies such as those by Silva et al. (2012) and Kappes, Andrade, and Arf (2013) evaluated the development of leaf diseases in different plant arrangements, however, none focused on double-row spacing. Thus, the present study aimed to evaluate the effect of 0.45 m and double-row spacing arrangements on the severity of foliar diseases and the yield performance of corn grown in the first and second-crop seasons.

MATERIAL AND METHODS

Two independent experiments were conducted in the first and two in the second-crop seasons (one with and one without fungicide application in each crop season). Two were conducted in the first-crop season of 2019/2020 on Nitossolo Vermelho, at 23°20'27” S and 51°12'48” W, with an altitude of 572 m. The other two experiments were conducted in the second-crop season of 2020, on Latossolo Vermelho, at 23°40'04" S, 51°10'03” W, with an altitude of 650 m. The meteorological data of the sites are shown in Figures 1A and 1B. For the first-crop season, the values of accumulated precipitation and average temperatures (maximum, average, and minimum) were: 702 mm, 29.9°C, 24.9°C, and 19.9°C, respectively. For the second-crop season, 545 mm, 27.3°C, 20.9°C, and 14.5°C, respectively.

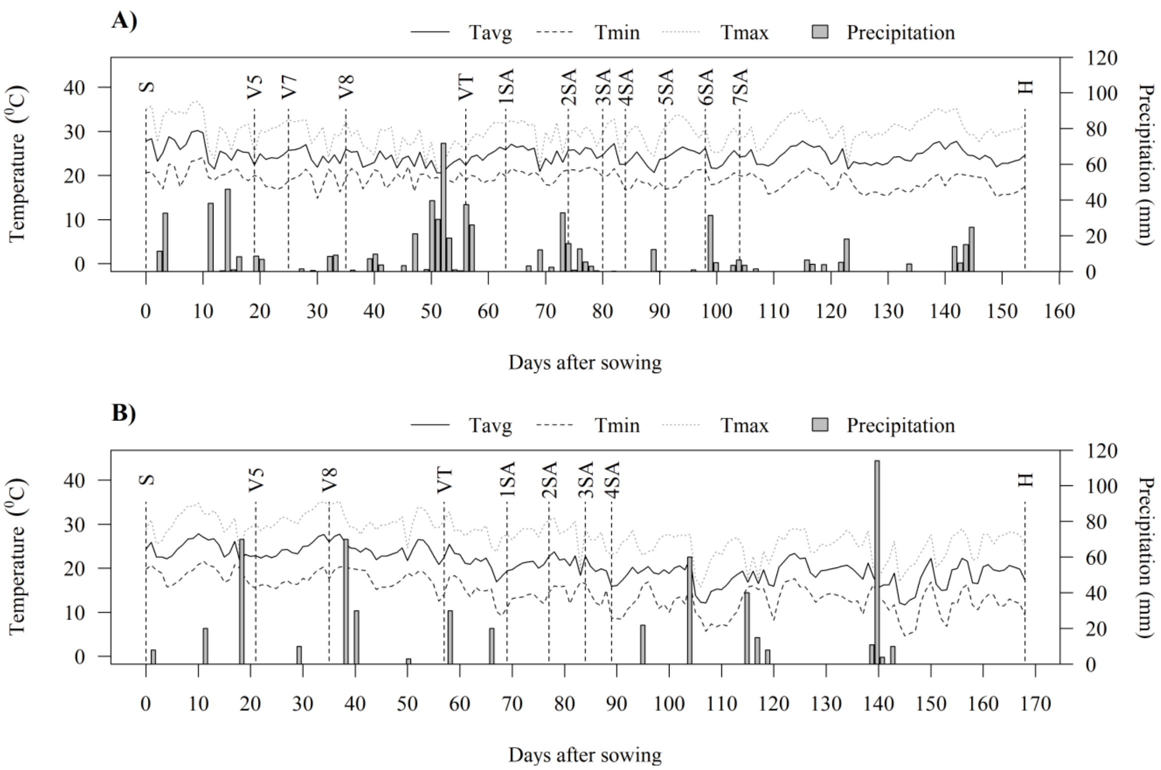

Figure 1. Daily precipitation and average, maximum, and minimum temperatures for the first (A) and second (B) crop seasons. S: sowing; V5, V7, V8: five, seven, and eight fully developed leaves, respectively; VT: tasselling; 1SA, 2SA, 3SA, 4SA, 5SA, 6SA, 7SA: first, second, third, fourth, fifth, sixth, and seventh leaf disease severity assessment, respectively; H: harvest.

The chemical characteristics of the soil at a 0-20 cm soil depth determined before the installation of the experiments were: first-crop season - $pH_{(CaCl2)}$ = 5.25; H+Al = 4.75 $cmol_c$ dm^{-3}; Al^{+3} = 0 $cmol_c$ dm^{-3}; Ca^{+2} = 3.77 $cmol_c$ dm^{-3}; Mg^{+2} = 1.30 $cmol_c$ dm^{-3}; K^+ = 0.65 $cmol_c$ dm^{-3}; P = 18.66 mg dm^{-3}; $CEC_{(pH7.0)}$ = 10.47 $cmol_c dm^{-3}$; $CEC_{(effective)}$ = 5.72 $cmol_c$ dm^{-3}; OM = 3.20%; Second-crop season - $pH_{(CaCl2)}$ = 4.90; H+Al = 5.20 $cmol_c$ dm^{-3}; Al^{+3} = 0 $cmol_c$ dm^{-3}; Ca^{+2} = 8.13 $cmol_c$ dm^{-3}; Mg^{+2} = 2.66 $cmol_c$ dm^{-3}; K^+ = 0.71 $cmol_c$ dm^{-3}; P = 7.49 mg dm^{-3}; $CEC_{(pH7.0)}$ = 16.72 $cmol_c dm^{-3}$; $CEC_{(effective)}$ = 11.53 $cmol_c$ dm^{-3}; OM = 3.21%.

The experimental design was a randomized block design arranged in the split-plots scheme with four repetitions. The plots consisted of two inter-row spacings (0.45 m and double-row 0.30 × 0.60 m), and the subplots consisted of four plant densities (59,200, 74,000, 81,400, and 96,200 plants ha^{-1}). The subplots comprised six 5 m long rows, with the evaluations occurring in the two central rows, discounting 1.0 m from the ends, totaling 2.7 m^2.

The corn hybrids used in the first and second-crop seasons were P3380H and LG36600 AgrisureViptera 3, respectively. The sowings of the first and second-crop seasons were performed on 10/26/2019 and 02/08/2020, respectively, in an area previously occupied by wheat. For the 0.45 m spacing, sowing was performed with the seeder in its original configuration. For double-row spacing (0.30 × 0.60 m), sowing was performed with a seeder at a spacing of 0.90 m, and then, with the help of a reference marker (wooden ruler of five meters), positioned 0.30 m parallel to each furrow, the other furrows were opened manually. The same reference marker was developed as a template so that the seeds were evenly distributed, also manually. The sowings were all performed based on the highest plant density, with the number of seeds already corrected previously according to the germination test. The lowest densities were obtained by thinning at the growth stage of five fully developed leaves (V5), when the initial plant stand was recorded.

The base fertilization used was adjusted according to soil analysis and following technical recommendations (PAULETTI; MOTTA, 2017), which consisted of 436 kg ha^{-1} of the NPK formulation 04-14-08 for the first-crop season, and 451 kg ha^{-1} of the same NPK formulation for the second-crop season. In the first-crop season, the topdressing fertilization was performed twice, at the V5 growth stage, after thinning, and at V7 growth stage, applying 90 kg of N ha^{-1} at each stage, totaling 180 kg of N ha^{-1}. For the second-crop season, it was applied at the V5 growth stage, after thinning, in the amount of 130 kg of N ha^{-1}. The source used in both experiments was ammonium sulfate (21% N).

The management of pests and weeds was carried out according to observations made during crop development. At the V8 growth stage, the commercial fungicide Orkestra® SC was applied in the control experiment, composed of a mixture of the active ingredients fluxapyroxad (167 g L^{-1}) and pyraclostrobin (333 g L^{-1}) at a dose of 300 mL of the commercial product per hectare. A 20 L capacity electric backpack sprayer was used, with its flow rate adjusted to 166 L ha^{-1}, equipped with a four-tip spray bar.

Immediately after silking growth stage, phytometric evaluations were performed, including leaf area index (LAI), stem diameter (SD), ear insertion height (EIH), and plant height (PH), the last three of which were taken from the same plant. Following this, assessments of leaf disease severity were initiated.

To estimate the leaf area index (LAI), the leaf area of ten plants (five random plants in each central row) of each subplot useful area was estimated. For this, the length (L) from the base to the tip of the leaf and the greatest width (W) of all photosynthetically active leaves were measured. The leaf area (A), expressed in cm^2, was estimated using the expression: $A = L \times W \times 0.75$. The sum of the areas of all the plant leaves was used to determine the leaf area per plant. The leaf area index corresponded to the leaf area per plant divided by the soil surface occupied by it at each inter-row spacing combination (SANGOI et al., 2019).

Stem diameter (SD) was determined by measuring in millimeters the largest and smallest diameter in the central part of the second or first elongated internode using a digital caliper, and then calculating the average of the measures. The ear insertion height (EIH) and plant height (PH) was determined by measuring the distance in centimeters between the soil surface and the top ear insertion node and between the soil surface and the base of the tassel, respectively. The measurements were performed on ten plants (five random plants in each central row) in each subplot useful area.

Assessments of leaf disease severity, being naturally occurring diseases, were carried out weekly, for seven weeks for the first-crop season, and four weeks for the second-crop season, respectively. It was considered for assessment, the ear leaf of four plants, randomly taken in each assessment (MOTERLE; SANTOS, 2019) in each subplot useful area, two in each of the two central rows. The following diseases were evaluated: turcicum leaf blight (*Exserohilum turcicum*), gray leaf spot (*Cercospora zeae-maydis*), white spot (*Pantoea ananatis* and/or *Phaeosphaeria maydis*), and southern rust (*Puccinia polysora*). Severity scores were taken according to the following diagrammatic scales: turcicum blight (VIEIRA et al., 2014), gray leaf spot, white spot, and southern rust (CAPUCHO et al., 2010). From the severity scores obtained in the plant evaluations, the evolution of each disease was determined by calculating the area under the disease progress curve (AUDPC) according to the formula below proposed by Shaner and Finney (1977):

$$\mathrm{AUDPC} = \sum_{i=1}^{n} (\mathrm{Y_i} + \mathrm{Y}_{i+1}/2)\ (\mathrm{t_{i+1}}\text{-}\mathrm{t_i})$$

where: [Y_i and Y_{i+1}] - severity values observed in two consecutive assessments; [t_{i+1} and t_i] - interval between two assessments; [n] - total number of assessments.

For the second-crop season, it was necessary to quantify the incidence of the stunt disease complex, according to Costa et al., (2019), performed 89 days after sowing, and the percentage of lodging at harvest, right after quantifying the final plant stand (Table 1). Plants with less than 45° of inclination about the ground were considered lodged, and then the percentage was calculated.

Table 1. Desired (DS), initial (IS), and final (FS) plant stand in the first and second-crop seasons.

Crop seasons	First-crop season			Second-crop season		
DS	IS	FS	FS/DS	IS	FS	FS/DS
plants ha^{-1}	-----------plants ha^{-1}-----------		(%)	-----------plants ha^{-1}-----------		(%)
59,200	59,200	59,000	99	59,200	58,100	98
74,000	74,000	73,600	99	73,800	73,300	99
81,400	81,200	80,700	99	81,200	80,000	98
96,200	94,600	93,200	96	93,900	92,000	95

Subsequently, the ears were harvested manually, when the average moisture content was close to 140 and 180 g of water per kilogram of grain, for the first and second-crop seasons, respectively. The water content in the grains was obtained by a Gehaka digital capacitance meter (G600). The harvested ears were quantified, and the number of ears per plant was determined with this value. Productive ears were considered as those that presented more than 15 formed grains.

From the harvested ears, ten were randomly separated for the determination of the diameter (ED) and length (EL) of ears; 1000-grain weight (1000W) expressed in grams, determined from eight repetitions of one hundred grains; and yield (YLD) expressed in kg ha^{-1}, determined from the mass of grains of all ears harvested in the useful area of the subplots, which were threshed manually. The last two had their moisture content corrected to 130 g of water per kilogram of grain.

Besides the measurements mentioned above, the mass of grains per ear (MGE) was evaluated, determined by weighing the grains from the ten ears from which the yield components were measured, and averaging them, which was later used to calculate the number of grains per ear; the number of grains per ear (NGE), determined by the ratio between the mass of grains per ear, and the mass of one thousand grains; and number of grains per square meter (NG m^{-2}), determined by multiplying the number of grains per ear by the number of ears per hectare, which resulted from multiplying the number of ears per plant by the final plant stand obtained, dividing the result by ten thousand.

The data were tested for the assumptions of normality of errors and homogeneity of variances by the Shapiro-Wilk and Bartlett tests, respectively ($p>0.05$). Subsequently, they were submitted to the joint analysis of variance considering the mixed model in which block within fungicide and block within density were considered random effects, and the other effects were considered fixed effects. Interactions with the fungicide factor and the isolated fungicide were not considered in the interpretation since there is no valid error term, thus, it was only used for the need to analyze the results together or not. Wald's F test ($p<0.05$) analyzed the variation sources in the model. If significant, the means were compared by the Tukey test, following the emmeans package procedure (LENTH, 2018). When there was an interaction effect with density or an isolated effect, the linear or quadratic regression model was adjusted ($p<0.05$). Pearson correlation was performed between the yield components. R software (R CORE TEAM, 2020) was used for all analyses.

RESULTS AND DISCUSSION

There was no interaction between the factors analyzed for the first-crop season, and isolated significance was obtained only for the plant density factor. For the second-crop season, there was an interaction between the number of ears per plant with spacing and density; isolated significance between the stem diameter and spacing; and the remaining significances, also isolated, for plant density (Table 2).

Stem diameter fitted quadratic equations for both crop seasons, according to the increasing plant density, with a minimum point outside the range studied for the first-crop season and close to 88,100 plants ha^{-1} for the second-crop season (Figures 2A and 2B). The behavior of reduction in the stem diameter according to the increase in plant density is based on the increase in intra-specific competition for light; physiological changes of hormonal origin, auxin in particular, which does not oxidize due to the greater shading, stimulating cell elongation; and alteration in the perception of photomorphogenic light (red and far-red) by the phytochrome, leading to an increase in the red/far-red ratio, which regulates the partitioning of photoassimilates and morphological adaptation. These factors together cause the vertical growth of the stem to predominate to the detriment of its diameter (SANGOI, 2001).

For the second-crop season, stem diameter was greater at double-row spacing (17.66 mm) compared to 0.45 m (16.95 mm), so there was a significant difference at densities of 74,000 and 96,200 plants ha^{-1} (Figure 3). There was a quadratic adjustment for both spacings according to the increasing plant density, with minimum points near 91,100 plants ha^{-1} for the 0.45 m spacing and 85,200 plants ha^{-1} for the double-row spacing. The larger stem diameter at double-row spacing may be linked to the higher interception of photosynthetically active radiation by the crop canopy around the vegetative stage of eight to nine leaves, as reported by Robles, Ciampitti, and Vyn (2012) and Novacek et al. (2013). Such an increase may have favored the photosynthetic efficiency of the plants, thus directing surplus photoassimilates to stem growth in diameter. The same authors also observed a greater stem diameter with double-row spacing.

For ear insertion height, there was a quadratic adjustment for both crop seasons according to the increasing plant density, with maximum and minimum points outside the range studied for the first and second-crop seasons, respectively (Figures 4A and 4B). The physiological explanations for the reduction in stem diameter go along with those that explain the increase in ear insertion height at higher densities. Courbier and Pierik (2019) point out that under such conditions, the greater intraspecific competition for light leads to the so-called etiolation effect, whereby plants increase their chances of growing above the canopy and avoiding shading, which justifies the greater ear insertion height.

Table 2. Summary of analysis of variance (p-value): stem diameter (SD); ear insertion height (EIH); plant height (PH); leaf area index (LAI); area under the disease progress curve: southern rust (AUDPC-S), turcicum leaf blight (AUDPC-T), gray leaf spot (AUDPC-G), white spot (AUDPC-W); stunt incidence (STI); plant lodging (LODG); number of ears per plant (EP); ear length (EL); ear diameter (ED); 1000-grain weight (1000W); number of grains per ear (NGE); number of grains per square meter (NG m^{-2}); and grain yield (YLD). Spacing (S); plant density (D).

Crop season	Variable	S	D	S × D
First-crop season	SD	0.72	2.9.10^{-11***}	0.08
	EIH	0.66	2.6.10^{-02*}	0.22
	PH	0.41	0.48	0.54
	LAI	0.09	2.10^{-16***}	0.71
	AUDPC-S	0.24	0.08	0.90
	EP	0.18	2.9.10^{-04***}	0.74
	EL	0.49	5.3.10^{-09***}	0.79
	ED	1.00	4.2.10^{-05***}	0.55
	1000W	0.99	5.4.10^{-07***}	0.28
	NGE	0.75	4.8.10$^{-05\ ***}$	0.67
	NG m^{-2}	0.07	1.4.10^{-11***}	0.08
	YLD	0.14	1.7.10^{-07***}	0.12
Second-crop season	SD	3.8.10^{-02*}	3.2.10^{-05***}	0.54
	EIH	0.86	5.3.10^{-03**}	0.69
	PH	0.49	0.05	0.52
	LAI	0.38	<2.10^{-16***}	0.08
	AUDPC-T	0.94	0.49	0.38
	AUDPC-G	0.27	0.81	0.38
	AUDPC-W	0.39	7.3.10^{-03**}	0.47
	STI	0.26	0.51	0.56
	LODG	0.09	0.12	0.38
	EP	0.28	2.3.10^{-09***}	3.5.10^{-02*}
	EL	0.96	2.2.10^{-02*}	0.66
	ED	0.43	0.97	0.79
	1000W	0.27	0.68	0.63
	NGE	0.92	0.10	0.40
	NG m^{-2}	0.82	0.11	0.13
	YLD	0.33	0.63	0.94

*: significant at 5% probability (p<0.05); **: significant at 1% probability (p<0.01); ***: significant at 0.1% probability (p<0.001).

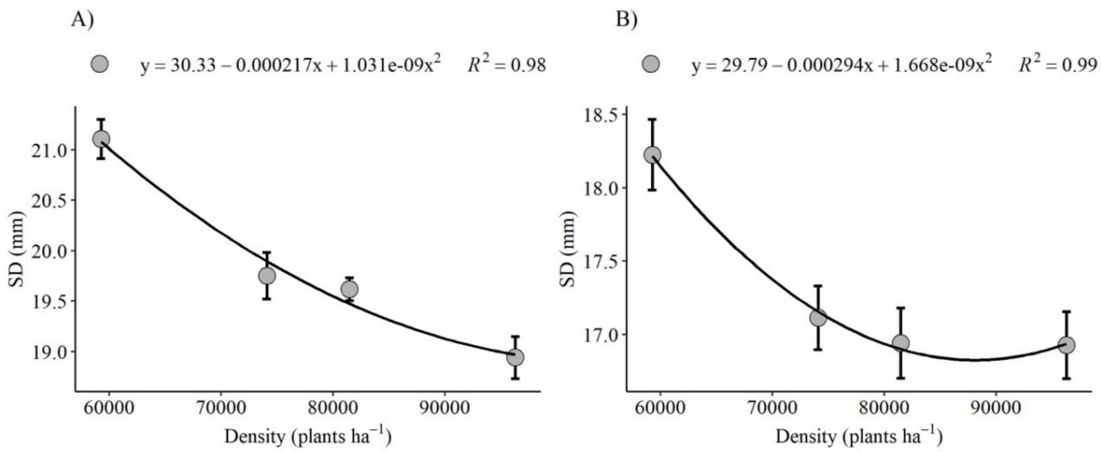

Figure 2. Stem diameter (SD) according to the plant density: (A) first and (B) second-crop seasons.

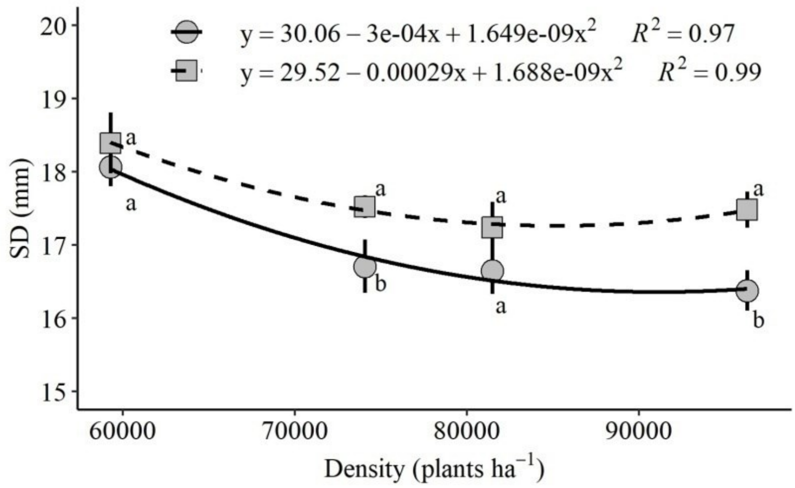

Figure 3. Stem diameter (SD) according to 0.45 m and double-row spacings.

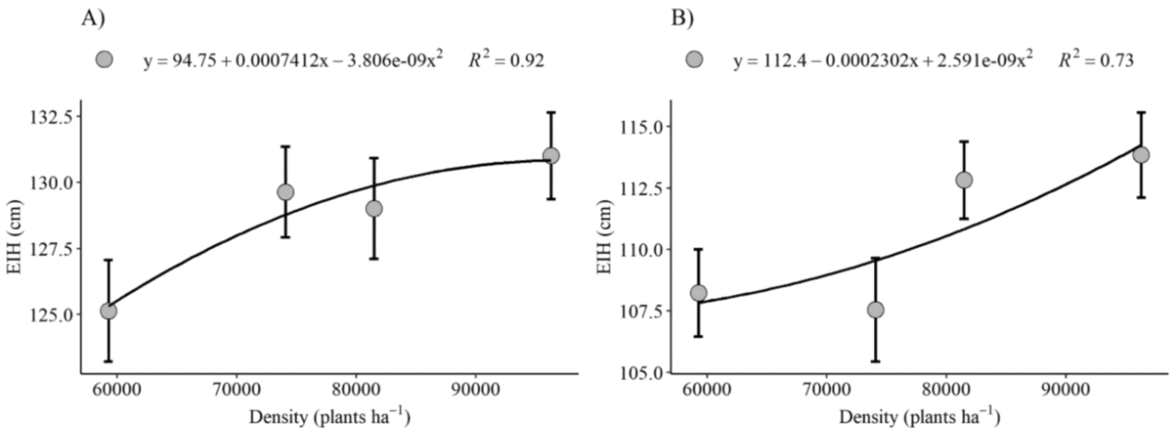

Figure 4. Ear insertion height (EIH) according to the plant density: (A) first and (B) second-crop seasons.

Corroborating with the results obtained for stem diameter and ear insertion height, Fromme, Spivey, and Grichar (2019) working with increasing densities, from 43,000 to 117,000 plants ha^{-1}, also observed the same pattern of response according to plant density increasing. Xue et al. (2017) point out that this growth pattern can have negative implications, as with a high center of gravity and smaller stem diameter, plants become more prone to events such as breakage and lodging. Thus, it is essential to maintain stem health to maintain their resistance under higher plant density conditions, as they become more susceptible to rots.

There was a quadratic fit for leaf area according to the increasing plant density in both crop seasons, Figures 5A and 5B, with minimum points outside the range studied. The observed pattern of increase is since, under high plant density, the crop canopy per unit area covers a greater amount of soil. Bernhard and Below (2020), when increasing the density from 94,000 to 139,000 plants ha^{-1}, observed an increase in leaf area index from 5.8 to 7.3.

The area under the progress curve of the white spot in the second-crop season (Figure 6) fitted the quadratic equation according to the increase in plant density, with a minimum point outside the range studied. The severity values of the spot were within the range of 0.3 to 1.6% at the end of the fourth evaluation, at 89 days after sowing. Miller et al. (2016) point out that frequent precipitation is among the factors that favor the development of the disease, which did not occur during the period of evaluations, from 69 to 89 days after sowing (Figure 1B), which probably influenced its low severity. Also, considering that the pathogen is disseminated by wind (CARVALHO; PEREIRA; CAMARGO, 2016), it is speculated that the reduced air circulation within the canopy due to the higher plant densities and open leaf architecture pattern of the hybrid in question may have influenced its lower dissemination. Silva et al. (2012) and Kappes, Andrade, and Arf (2013) observed similar behavior when evaluating grey leaf spot and tropical rust, respectively.

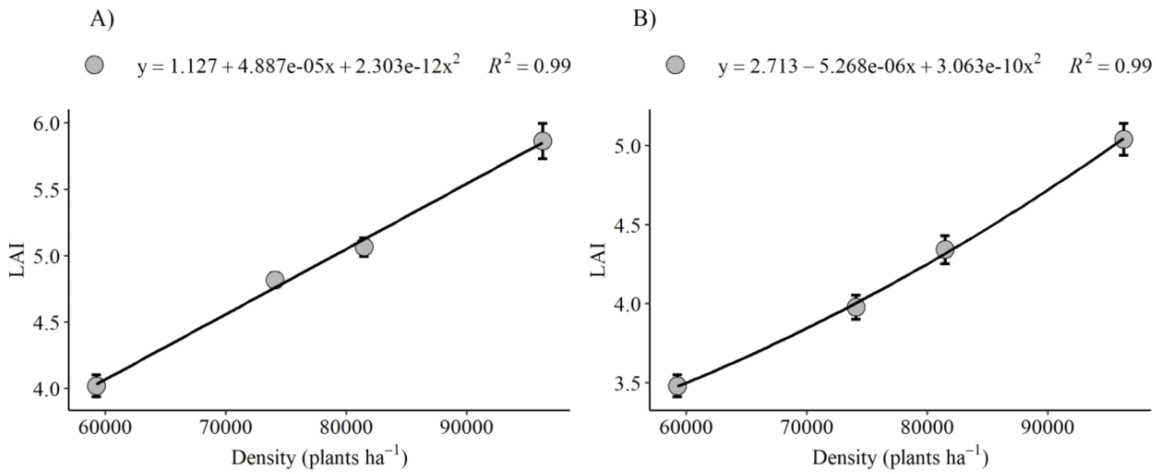

Figure 5. Leaf area index (LAI) according to the plant density: (A) first and (B) second-crop seasons.

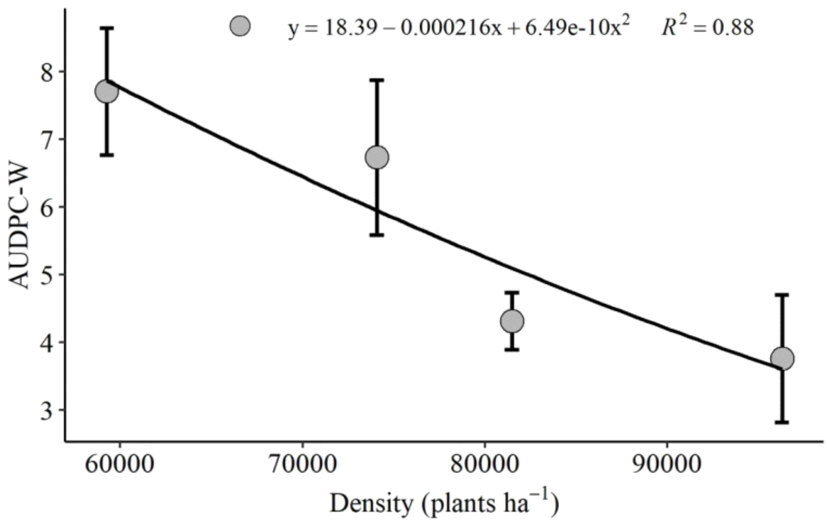

Figure 6. Area under the progress curve of white spot (AUDPC-W) according to the plant density.

The number of ears per plant in the first-crop season fitted the quadratic equation, according to the increase in plant density, with a minimum point outside the range studied (Figure 7A). In the second-crop season, the number of ears per plant was greater in double-row spacing (1.45) than in 0.45 m spacing (1.24) at a density of 59,200 plants ha^{-1} (Figure 7B). Also, in the second-crop season, there was a quadratic adjustment for both spacings according to the increase in plant density, with minimum points near 94,000 and 93,100 plants ha^{-1}, for the double-row and 0.45 m spacings, respectively (Figure 7B). The greater number of ears per plant in the double-row spacing, at the density of 59,200 plants ha^{-1}, can be justified by, besides a possible greater interception of solar radiation, a higher incidence of the corn stunt complex in the same arrangement. The average incidence rates for the 0.45 m and double-row spacings were 36.30 and 41.18%, respectively. There was no statistical difference among the four densities; however, at the density of 59,200 plants ha^{-1}, the incidence values obtained were 36.82 and 49.53% for 0.45 m and double-row spacings, respectively. Despite the absence of significance, it is suspected that this difference may have been the reason for the higher number of ears per plant since among the physiological responses of corn plants attacked by the stunt complex, the production of multiple ears stands out (JONES; MEDINA, 2020).

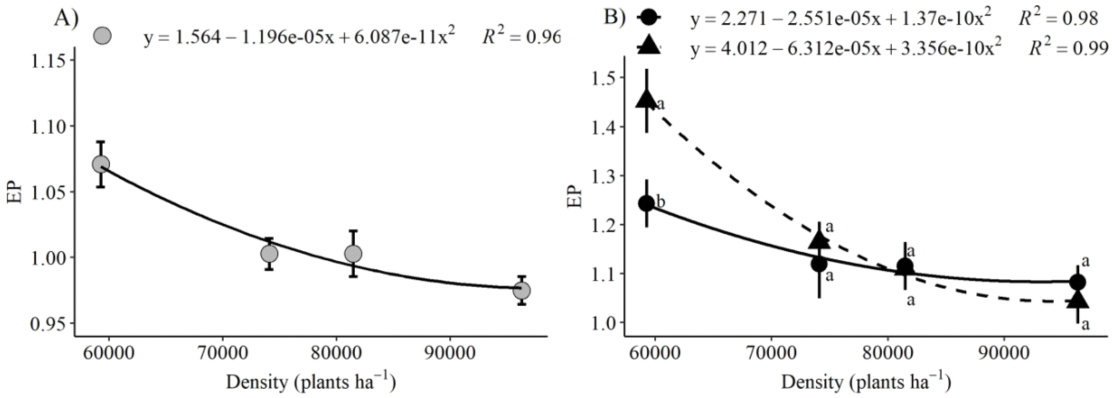

Figure 7. Number of ears per plant (EP) according to the plant density: (A) first and (B) second-crop seasons.

In general, in the absence of interactions, Sangoi (2001) points out that the factors responsible for reduced prolificacy are associated with competition between the ear and other plant organs for photoassimilates and in response to the hormonal balance of the auxin in specific. Large amounts of auxins are directed to the tassel stimulating its cell division, growth, and dry mass accumulation, once its primordium is transformed into a reproductive structure. High light intensity oxidizes and inactivates auxins, breaking apical dominance. Under high plant density conditions, less light falls on the point of tassel growth compared to low densities, and therefore there is less inactivation of auxins, which remain in higher concentration, thus promoting apical dominance and consequently favoring lower ear formation.

The ear characteristics at the first-crop season, Figures 8A, 8C, and 8D, fitted quadratic equations according to the increasing plant density. For ear length, Figure 8A, the maximum point was near 61,000 plants ha^{-1}; for ear diameter, Figure 8C, there was a tendency to decrease; for the number of grains per ear, Figure 8D, the maximum point was near 65,700 plants ha^{-1}. In the second-crop season, Figure 8B, there was a quadratic adjustment for ear length, with a minimum point outside the studied range. Ventura and Dalchiavon (2018) also observed an ear length and diameter reduction in response to increased intraspecific competition. Reduction in the number of grains per ear was also observed by Zhang et al. (2018), who point out that such a result may stem from the low formation of floral primordia, reduced pollination due to asynchrony in flowering, and also high grain abortion rate after fertilization.

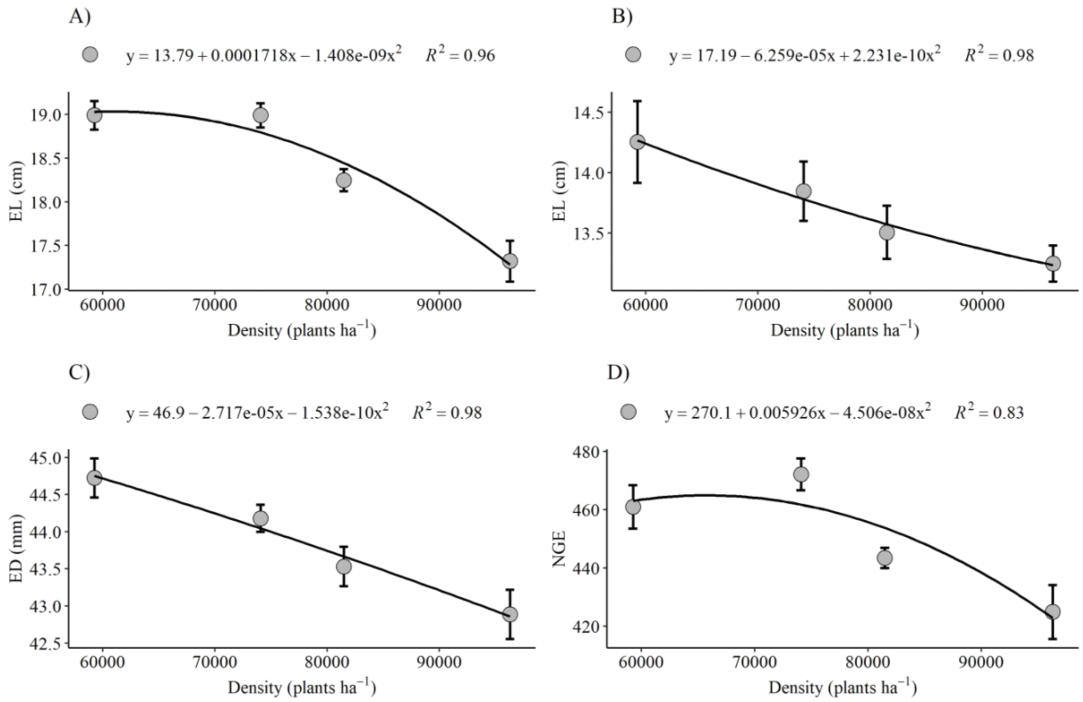

Figure 8. Ear length (EL), ear diameter (ED), and number of grains per ear (NGE) according to the plant density: (A) first, (B) second, (C) first, (D) first-crop seasons.

The 1000-grain weight in the first-crop season, Figure 9A, fitted the quadratic equation according to the increase in plant density, with a minimum point outside the studied range. The lower development of the ears is partially justified by the reduction of ear development and grains of shorter length (TESTA; REYNERI, BLANDINO, 2016). Furthermore, based on the results of other authors, Haegele, Becker, and Below (2014) discuss this same behavior, stating that the shading provided by high plant density promotes a reduced photosynthetic rate, consequently reducing individual grain weight. It also indicates that hybrids with more stable grain weight in response to competitive conditions may be the most suitable for cultivation with higher plant densities.

The number of grains per square meter in the first-crop season, Figure 9B, fitted the quadratic equation according to the increase in plant density, with a maximum point outside the studied range. According to Haegele, Becker, and Below (2014), an increase in the number of grains per unit area is expected, since it is influenced by the number of plants per area, and consequently, the number of ears per area.

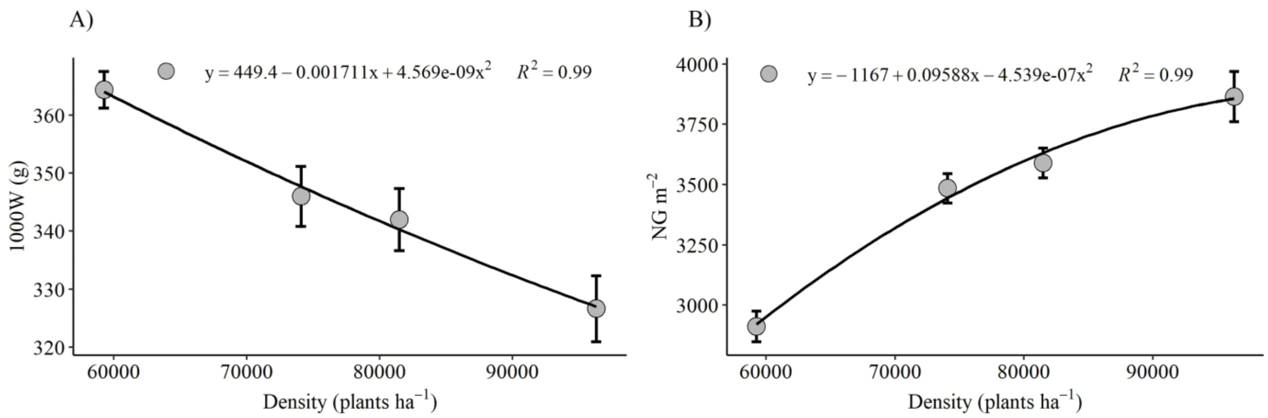

Figure 9. 1000-grain weight (1000W) and number of grains per square meter (NG m^{-2}) according to the plant density: (A) and (B), first-crop season.

The grain yield in the first-crop season, Figure 10, fitted the quadratic equation, according to the increase in plant density, with a maximum point near 89,000 plants ha^{-1}, at which 12,609 kg ha^{-1} was obtained. In a study conducted by Pricinotto et al. (2019) under first-crop conditions, with density ranging from 40,000 to 120,000 plants ha^{-1}, the yield was maximized with 93,400 plants ha^{-1}, an amount close to that of the present study, in which they reached 11,858 kg ha^{-1}. The same authors point out that under ideal edaphoclimatic conditions and appropriate management, it is possible to increase plant density and increase grain yield, thus better exploring the interaction between genotype and environment.

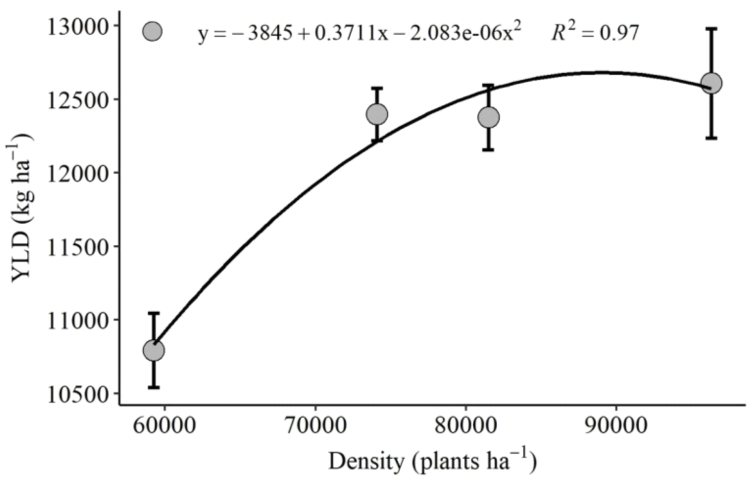

Figure 10. Grain yield (YLD) according to the plant density.

Based on the results obtained, it was possible to observe that the increase in intra-specific competition according to the higher plant densities suppressed the grain yield per individual so that the number of ears per plant, the number of grains per ear, and the 1000-grain weight reduced, however, the number of grains per square meter increased. Thus, understanding the relationship between the yield components in grain yield formation in high plant-density corn crops allows more assertive decisions to be made during crop planning.

When performing the correlation between grain yield and yield components 1000-grain weight and number of grains per square meter (Table 3), it was possible to observe that there was a high correlation in the first-crop season between the number of grains per square meter and grain yield (0.75), on the other hand, there was a negative correlation between 1000-grain weight and grain yield (-0.02). Such a result indicates that the number of grains per unit area was more important than grain mass for grain yield. The results obtained are in agreement with those of Ruffo et al. (2015), in which the authors point out that effort to reduce yield gaps should continue to focus on maximizing the number of ovules per ear and reducing the grain abortion rate to increase the number of grains per unit area.

Table 3. Pearson correlation coefficient between the grain yield components 1000-grain weight (1000W) and number of grains per square meter (NG m^{-2}) with grain yield (YLD).

Grain yield components	YLD
1000W	-0.02 ^{ns}
NG m^{-2}	0.75 **

^{ns}: not significant; **: significant at 1% (p<0.01).

To the adopted inter-row spacing, it was possible to observe that the 0.45 m and double-row spacings were similar for diseases and grain yield. Thus, based on the data from this research, this configuration is not a justifiable alternative to be adopted by producers. On the other hand, in the inter-row spacing of 0.45 m, more studies with plant density involving management practices that aim to reduce the physiological stress provided may contribute to a greater base of information.

It was observed under first-crop season conditions that the practice of adopting high plant densities is interesting as a strategy for obtaining high yields, however, studies are needed to search for the maximum point for each cultivar in each growing environment. For the second-crop season, increasing the number of plants per area did not prove advantageous, presenting only a numerical increase in grain yield, resulting largely from the smaller quantity and irregular distribution of precipitations. In second-crop conditions, factors other than the increase in plant density could provide better results.

CONCLUSIONS

In the plant density factor, in the second-crop season, there is a decrease in the severity of white spot as plant density is increased. Also, for the plant density factor, in the first-crop season, there may be a significant increase in grain yield as plant density is increased.

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