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Agronomic characteristics of corn grown in different population arrangements

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ABSTRACT: The objective of this study was to determine the response of different population arrangements on the agronomic performance of corn. The experiment was carried out in Instituto Federal de Educação, Ciência e Tecnologia de Mato Grosso (IFMT), Campo Novo do Parecis. The experimental design was a complete randomized block in a 5 x 2 factorial scheme, with five populations of single hybrid DKB 390 VT PRO3 (50,000, 60,000, 70,000, 80,000 and 90,000 plants ha^{-1}) and two row spacings (0.45 and 0.90 m) with four replications. The experiment evaluated the vegetative and reproductive characteristics of corn. Data were submitted to analysis of variance and regression analysis. The raise in corn plant population increases the fresh mass and the dry mass while reducing the mass of a thousand grains (80,000 plants ha^{-1}), length and diameter of the ears and number of rows per corn ear. The reduced row spacing (0.45 m) and the population of 50,000 ha^{-1} plants presented the best results for reproductive characteristics, with lower variation in behavior among the populations evaluated in the experiment.
Keywords: agronomic performance, plant population, spacing between plants, *Zea mays*.

Características agronômicas de milho cultivado em diferentes arranjos populacionais

RESUMO: Objetivou-se determinar a resposta de diferentes arranjos populacionais sobre o desempenho agronômico do milho. O experimento foi realizado no Instituto Federal de Educação, Ciência e Tecnologia de Mato Grosso (IFMT),Campo Novo do Parecis O delineamento experimental foi o de blocos casualizados, em esquema fatorial 5 x 2, sendo cinco populações do híbrido simples DKB 390 VT PRO3 (50.000; 60.000; 70.000; 80.000 e 90.000 plantas ha^{-1}) e dois espaçamentos entre linhas (0,45 e 0,90 m), com quatro repetições. Foram avaliadas características vegetativas e reprodutivas do milho. Os dados obtidos foram submetidos à análise de variância e análise de regressão. O aumento na população de plantas do milho incrementa a massa verde e a massa seca ao mesmo tempo em que reduz a massa de mil grãos (80.000 plantas ha^{-1}), comprimento e diâmetro de espigas e número de fileiras por espiga de milho. O reduzido espaçamento entre linhas (0,45 m) e a população de 50.000 plantas ha^{-1} apresentaram os melhores resultados para as características reprodutivas, com menor variação de comportamento entre as populações avaliadas.
Palavras-chave: desempenho agronômico, espaçamento entre plantas, população de plantas, *Zea mays*.

1. INTRODUCTION

Corn is one of the main cereals grown in Brazil, with a significant rise in its production, related to human consumption, energy demand and particularly to animal diets (OSÓRIO et al., 2015). The management of the spatial arrangement of plants by the alteration in spacing and plant density in the row has been pointed out as one of the most important management practices for corn grain yield maximization by optimizing the use of production factors, such as water, light and nutrients (FARINELLI et al., 2012; SILVA et al., 2014).

The best population arrangement is the one that provides optimal use of water, nutrient and light, resulting in the greatest crop yield. One of the objectives of modifying the plant arrangement by reducing the distance between rows is to shorten the time needed by the crop to intercept the maximum incident solar radiation and thereby increase the amount of energy captured per unit area and time. The photosynthetically active radiation and the availability of water and nutrients are the factors that are strongly influenced by the population and the arrangement of plants in the field. The development of new genotypes and management techniques for corn cultivation has motivated the execution of several studies to determine the best spatial arrangement of corn plants in different regions and in favorable environments (CALONEGO et al., 2011; SILVA et al., 2014).

Choosing the best arrangement that directs the ideal density in corn sowing is of extreme importance since this is a very sensitive grass to the variations of the stand. The positive effect of the reduction in row spacing on grain yield is most clearly manifested when high densities (around 80,000 ha^{-1} plants) are used as, until recently, corn was traditionally sown in a spacing between rows of 0.80 and 0.90 and a population around 50,000 plants ha^{-1}, which makes it necessary to evaluate new varieties of corn at different plant spacings and densities seeing that a large number of the new genotypes available on the market are more productive, smaller and with a more upright leaf architecture, in relation to older materials.

For this reason, it is important to conduct studies whose objective is the achievement of the best population of plants and spacings that will provide greater efficiency in the absorption of light, water and nutrients, improvement in crop management practices and a greater productivity to the crop of corn, as well as the understanding on the behavior of genetic materials in different regions (VALLE et al., 2013; SILVA et al., 2014). Therefore, the objective of this study was to determine the response of different population arrangements on corn agronomic performance.

2. MATERIAL AND METHODS

This study was conducted from November/2016 to April/2017 in the experimental area at Instituto Federal de Educação, Ciência e Tecnologia de Mato Grosso (IFMT) *Campus* Campo Novo do Parecis at the geographic coordinates 13º40'31"S and 57º53'31"W, 572 meters above sea level. According to the Brazilian Soil Classification System, recommended by Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA (EMPRAPA, 2013), the local soil is a typical dystrophic Red Latosol. According to soil chemical analysis, its initial fertility characterization for the 0-0.20 m layer showed the following values: pH ($CaCl_2$) = 4.97; OM = 27.02 g dm^{-3}; K^+ = 0.05 $cmol_c$ dm^{-3}; Ca^{+2} = 2.17 $cmol_c dm^{-3}$, Mg^{+2} = 0.85 $cmol_c dm^{-3}$; H^+ = 4.61; H+Al = 4.61 $cmol_c$ dm^{-3}; P = 7.47 mg dm^{-3}; Cu = 1.03 mg dm^{-3}; Zn = 4.19 mg dm^{-3}; Fe = 189.53 mg dm^{-3}; Mn = 15.76 mg dm^{-3} and V = 39.98%.

According to the classification of Köppen, the climate in Campo Novo do Parecis is Aw, tropical climate with dry winter and rainy summer, with average temperature of 23.7° C and average annual rainfall of 1945 mm. The dry and rainy seasons are well defined; the dry season occurs from May to September and the rain season is from October to April (DALLACORT et al., 2011). Rainfall and average temperatures that occurred during the experimental period are shown in Figure 1. Their average values were: 30.4; 23.9 and 20.4°C for the maximum, medium and minimum temperatures, respectively, as well as a rainfall of 1813.1 mm, which perfectly meets the water demand of the crop, since it requires an accumulated rainfall of 450 to 800 mm, regularly distributed over its cycle (BERGAMASCHI; MATZENAUER, 2014).

Simple corn hybrid (DKB 390 VT PRO3) was mechanically sown on November 18, 2016, as a summer crop, and the harvest was carried out on April 15, 2017. The hybrid is an early cycle and plant size ranging from 2.08 to 2.60 meters, ear insertion height between 1.06 and 1.52 meters, orange and semi-dent grains, excellent root system and good Stay Green feature.

Base fertilization was performed according to the chemical analysis of the soil, aiming to meet 30 kg of N, 100 kg of P_2O_5 and 60 kg of K_2O per ha^{-1}, according to the recommendation for the crop, applied in the furrow at sowing. Topdressing fertilization was carried out by applying 130 kg ha^{-1} N and 60 kg ha^{-1} K_2O in broadcast, split at the stages of four (V4) and eight true leaves (V8), for an estimated yield of 10000 kg ha^{-1} (SOUSA; LOBATO, 2004).

Cultural practices were performed according to the need of the crop, with application of herbicides with glyphosate (620 g L^{-1}) at the dose of 2.0 L ha^{-1} in post emergence. Pest control was performed by applying physiological, contact and ingestion insecticides by alternating the principal active (141 g L^{-1}) + lambda cyhalothrin (106 g L^{-1}) at the dose of 0.2 L ha^{-1}, according to the area monitoring and level of economic damage.

Fungicide applications were firstly carried out in a preventive way, using systemic fungicides based on triazoles, estrubilurins and carboxamides at the stages of six and nine true leaves (V6 and V9) and at the pre-tasseling (VT) stage. The fungicides used were, as follows: pyraclostrobin 260 g L^{-1} (26.0% m/v) + epoxiconazole 160 g L^{-1} (16.0% m/v) at a dose of 0.4 L ha^{-1}; azoxystrobin 200 g L^{-1} (20% m/v) + ciproconazole 80 g L^{-1} (8% m/v) at a dose of 0.3 L ha^{-1}; (16.0% w/v) at the dose of 0.4 L ha^{-1} and mancozeb 750 g kg^{-1} (26.0% m/v) + epoxiconazole 160 g L^{-1} 75% m / m), 1.5 kg ha^{-1}.

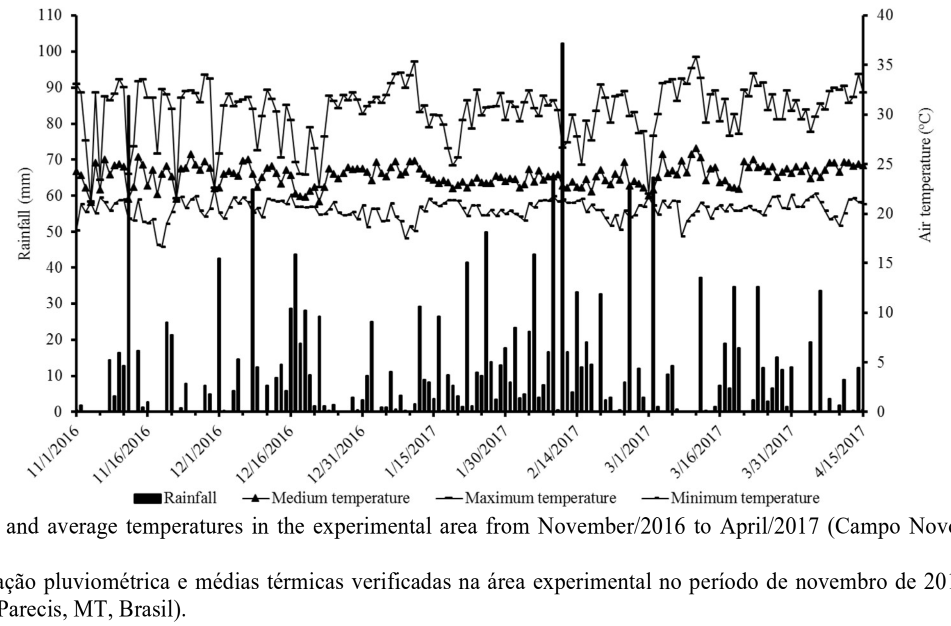

Figure 1. Rainfall and average temperatures in the experimental area from November/2016 to April/2017 (Campo Novo do Parecis, MT, Brazil).

Figura 1. Precipitação pluviométrica e médias térmicas verificadas na área experimental no período de novembro de 2016 a abril de 2017 (Campo Novo do Parecis, MT, Brasil).

The experimental design was a randomized block in a 5 x 2 factorial scheme, with five populations (50,000; 60,000; 70,000; 80,000 and 90,000 plants ha^{-1}) and two spacings between rows (0.45 and 0.90 m), with four replicates. The experimental plot consisted of six sowing rows with seven meters in length and the useful area was the four central rows with five meters in length.

The agronomic characteristics evaluated in 5 plants per plot were, as follows: plant height (PH, m), measured from the base of the plant stem to the flag leaf, using a metric scale at the milk stage (R3); stem diameter (SD, mm), measured with a digital caliper at 5 cm from ground level at R3; ear insertion height (EIH, m), measured from the ground level to the base of the ear using a metric line at the R3 stage; fresh mass (MFM, t ha^{-1}), measured by collecting and weighing five continuous plants in a row at the flowering (R1); dry mass (MDM, t ha^{-1}) assessed by drying of the plants used to obtain fresh mass and dried in a forced air circulation oven (105°C); ear diameter (ED, cm), evaluated with the aid of a digital caliper, measuring the middle third of the ear at physiological maturity (R6); length of the ear (EL, cm), obtained with the aid of a graduated ruler at R6; number of grain rows per ear (NGRE), determined by counting grain rows; mass of one thousand grains (MTG, g), obtained by counting and weighing 1000 grains, after ear threshing; grain yield (GY, kg ha^{-1}), determined by weighing the mass obtained in the useful area, after threshing of the ears contained therein, extrapolated to ha^{-1}, correcting grain moisture to 13% (wet basis), according to adaptation of Dalchiavon et al. (2011).

Data were submitted to analysis of variance (F test) followed by regression analysis ($p < 0.05$), according to procedures of Ferreira (2011), using the correlation coefficient (r) for linear regressions and coefficient of determination (R^2) for quadratic regressions

3. RESULTS

The overall means (OM) and the coefficients of variation (CV) for plant height (PH), ear insertion height (EIH), stem diameter (SD), fresh mass (MFM), dry mass (MDM), ear length (EL), ear diameter (ED), number of grain rows (NGR), mass of one thousand grains (MTG) and grain yield (GY) are given in Table 1, and it is possible to verify that data variability (CV) were between low (up to 10%), medium (between 10 and 20%) and high (between 20 and 30%), according to the magnitude defined by PIMENTEL-GOMES; GARCIA (2002). No effect, either alone or in the interaction, was found for PH and EIH (Table 1).

The variables SD, MFM and MDM had no effect for spacing between rows, corroborating with the data of Gilo et al. (2011) and Nascimento et al. (2012); however, they had an effect on the plant population (Table 1). Thus, decreasing (SD) and increasing (MFM and MDM) linear equations were modeled as plant population increased (Figure 2).

In relation to SD, their values varied between 23.02 and 19.46 mm when plant populations increased from 50,000 to 90,000 plants ha^{-1}, respectively, indicating that the increment in the independent variable negatively affects plant growth rates in competition for light, water and nutrients (Figure 2a). For MFM and MDM the observed linear increases varied between 40.85 and 62.60 ha^{-1} and 5.72 and 8.40 ha^{-1}, when plant populations varied between 50,000 and 90,000 plants ha^{-1}, respectively (Figures 2bc).

Ear length and ear diameter were influenced by both spacing and plant population (Table 1), whose average values were greater for the 0.90 m spacing (Table 2). The competition between plants clearly showed a linear reduction in EL and ED characteristics (Figures 2d and 2e), that is, for the populations of 50,000 and 90,000 ha^{-1} plants, the values of El and ED decreased from 16.15 to 14.15 cm and from 5.33 cm to 5.13 cm, respectively.

The variables NGR and MTG showed interaction among the evaluated factors (Table 1). For the NGR, only the populations of 50,000 and 90,000 plants ha^{-1} showed differences for the spacing between rows, so it was evidenced that for the smallest plant populations (50,000 plants ha^{-1}), the largest row spacings (0.90 m) contribute to a higher NGR value, whereas for larger plant populations (90,000 plants ha^{1}), the effect is opposite, that is, reduced spacings are desirable (0.45 m), (Table 3).

On the other hand, for the 0.90 m spacing between rows, it was possible to model a decreasing linear regression for the NGR (Figure 2f), so that oscillations between 50,000 and 90,000 plants ha^{-1} reflected values between 17.02 and 15.82, respectively.

Table 1. F values and statistical significance for the characteristics analyzed in corn grown in different population arrangements. Campo Novo do Parecis-MT, 2017.
Tabela 1. Valores de F e significância estatística para as características analisadas em milho cultivado em diferentes arranjos populacionais. Campo Novo do Parecis-MT, 2017.

Characteristics	Sources of variation			CV (%)	OM
	Spacing (E)	Population (P)	E x P		
PH (m)	1.16 ns	0.64 ns	0.55 ns	7.55	2.26
EIH (m)	2.93 ns	0.65 ns	1.37 ns	10.07	1.37
SD (mm)	0.58 ns	3.56*	0.93 ns	10.33	21.05
MFM (t ha^{-1})	0.23 ns	6.09**	1.12 ns	21.47	50.05
MDM (t ha^{-1})	0.18 ns	4.97**	0.97 ns	22.13	7.08
EL (cm)	30.04**	12.21**	1.14 ns	4.84	15.02
ED (cm)	19.70**	6.30**	2.57 ns	1.94	5.24
NGR	1.09 ns	1.6 ns	3.0*	4.51	16.12
MTG (g)	9.83**	10.10**	4.73**	4.4	321.62
GY (kg ha^{-1})	11.12**	0.34 ns	0.78 ns	11.53	11141.9

[1] PH= plant height, EIH = ear insertion height, SD = stem diameter, MFM = mater fresh mass, MDM = mater dry mass, EL = ear length, ED = ear diameter, NGR = number of grain rows, MTG = mass of one Thousand grains and GY = grain yield; [2]ns, ** and * are not significant and significant at 1 and 5%, respectively; [3]CV = Coefficient of variation; [4] OM = overall mean.

Table 2. Average values for ear length (EL), ear diameter (ED) and grain yield (GY) in corn grown in different population arrangements. Campo Novo do Parecis-MT, 2017.
Tabela 2. Valores médios para comprimento de espigas (CE), diâmetro de espigas (DE) e produtividade de grãos (PRG) em milho cultivado em diferentes arranjos populacionais. Campo Novo do Parecis-MT, 2017.

Characteristic	Spacing (m)	
	0.45	0.90
Ear length (cm)	14.39 b	15.65 a
Ear diameter (cm)	5.17 b	5.32 a
Grain yield (kg ha^{-1})	11819.31 a	10464.51 b

*Equal lower-case letters are not different from each other by the F test (p<0.05).

For MTG, a statistical difference was observed for spacing between rows only for the population of 50,000 plants ha^{-1} (Table 3), where the 0.90 m spacing allowed a larger MTG, 15% lager than the 0.45 m spacing. For both 0.45 m and 0.90 m spacings, MTG was quadratically influenced by the plant population, so that the minimum sites were set at 73625 and 86666 plants ha^{-1}, respectively, when MTGs were 301.70 and 277.66 g (Figure 2g). It is also observed that for populations of up to 80,000 plants ha^{-1}, the 0.90 m spacing was advantageous, while smaller spacing (0.45 m) is more recommended for the cultivation of high technology corn, with populations greater than 80,000 plants ha^{-1}.

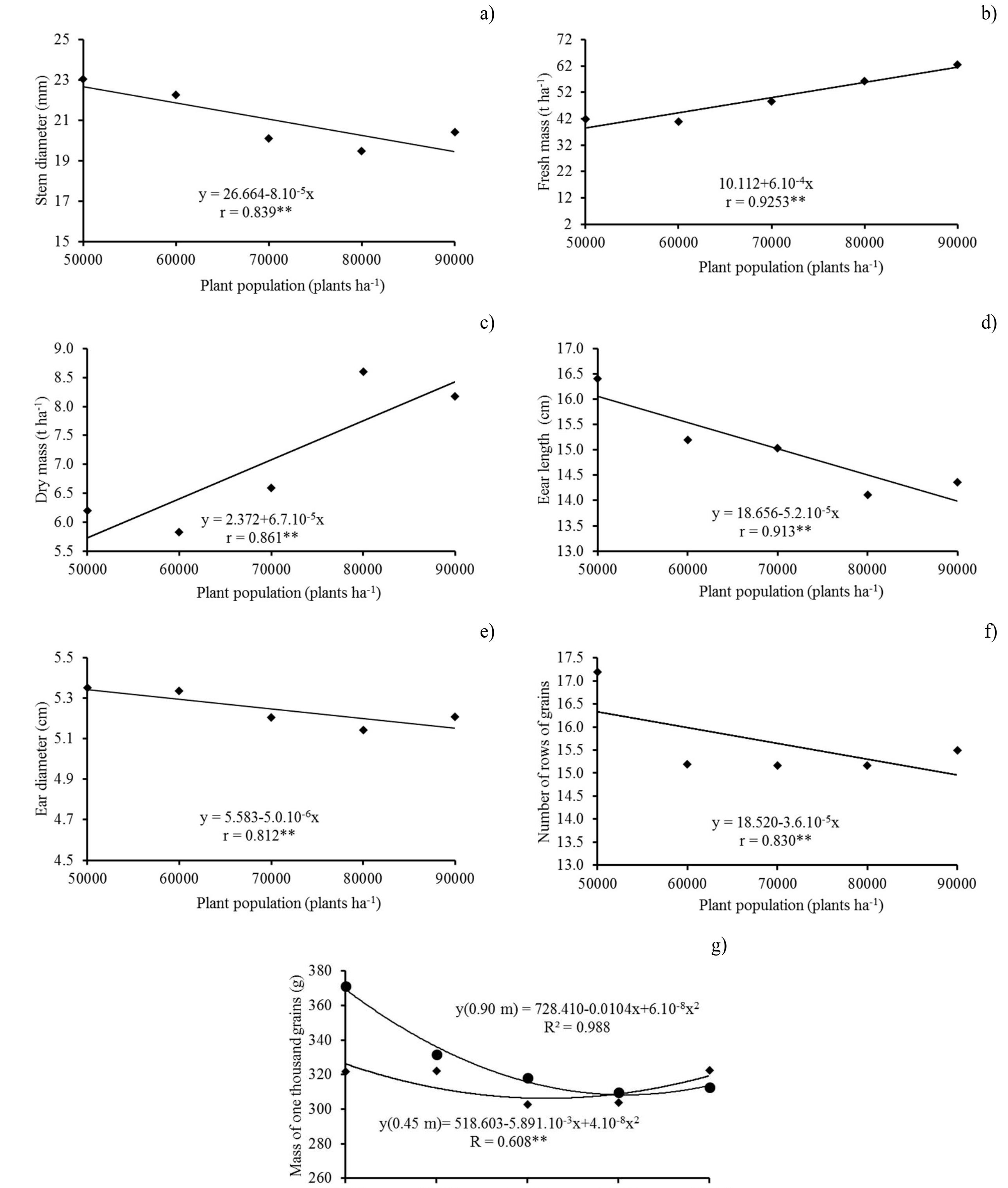

Figure 2. Stem diameter (a), fresh mass (b), dry mass (c), ear length (d), ear diameter (e) and number of rows of grains (f) according to the population of plants and mass of one thousand grains for the unfolding of plant population in the spacings between rows of 0.45 m (g) and 0.90 m (h) in corn crop. Campo Novo do Parecis (MT), 2017.
Figura 2. Diâmetro do caule (a), massa verde (b), massa seca (c), comprimento de espigas (d), diâmetro de espigas (e) e número de fileiras de grãos (f) em função da população de plantas e para a massa de mil grãos para o desdobramento da população de plantas nos espaçamentos entre linhas de 0,45 m (g) e 0,90 m (h) na cultura do milho. Campo Novo do Parecis (MT), 2017.

Grain yield showed a significant difference only for the spacings under study (Tables 1 and 2), where the 0.45 m spacing between rows provided the largest productivity, with an increase of 11.5% in relation to the 0.90 m spacing between rows. When GY was related with PH and SD, a raise in the values of these characteristics can be seen in larger r spacings between rows, which is directly related to the growth of plants and accumulation of total biological mass (MFM), not necessarily that of grains, differently to what happens in smaller row spacings, where plants concentrate more energy for GY, which was also reported by Kappes et al. (2011) and Silva et al. (2014).

Table 3. Unfolding for the spacing between rows within each plant population for the number of grain rows (NGR) and mass of one thousand grains (MTG) in corn grown under different population arrangements. Campo Novo do Parecis - MT, 2017.
Tabela 3. Desdobramento para os espaçamentos entre linhas dentro de cada população de plantas para as características número de fileira de grãos (NFG) e massa de mil grãos (MMG) em milho cultivado em diferentes arranjos populacionais. Campo Novo do Parecis - MT, 2017.

Spacing (m)	Plant population (plants ha^{-1})				
	50,000	60,000	70,000	80,000	90,000
	Number of grain rows				
0.45	16.10 b	16.10 a	16.01 a	16.10 a	16.90 a
0.90	17.20 a	15.90 a	15.70 a	15.70 a	15.50 b
	Mass of one thousand grains (g)				
0.45	321.80 b	322.25 a	302.75 a	303.70 a	322.52 a
0.90	371.05 a	331.77 a	318.10 a	309.50 a	312.75 a

Distinct letters are different from each other by the F test (p<0.05).

4. DISCUSSION

As in the present study (Table 1), neither Gilo et al. (2011) nor Nascimento et al. (2012) obtained significant difference for PH for the 0.45 and 0.90 m spacings for different populations in an experiment of performance of corn hybrids in Cerrado Sul Matogrossense.

Besides interfering directly with crop management, plant height has a significant relationship with plant lodging and when combined with the plant population, it determines quantitative and qualitative values of MFM, MDM and EIH since smaller spacings between plants in the same area provide greater competition for water, nutrients and luminosity, directly interfering in the morphological and reproductive aspects of the plants. For that reason, it is important in the selection of the best arrangement of plants, seeking to minimize these effects, as reported by Lana et al. (2009), who because of a better distribution of plants, observed a better efficiency in light interception and a better use of water and nutrients, influencing the development of plants, such as stem lengthening, and on the length and width of the leaves.

The values for the EIH (Table 1) were higher than those found by Vieira et al. (2016), which were between 0.83 and 1.12 m. They also stated that a more uniform EIH results in a better harvest performance and allows the intercropping with other crops. In addition, climatic conditions (humidity, light and temperature) may influence plant growth and consequently, the length of the ears.

For SD, the results corroborate with Foloni et al. (2014), since they presented a decreasing linear equation model attributable to the population increase. In large populations, plants direct their resources for a faster growth in order to avoid shading, increasing the possibility of growth above the canopy, but with reductions in the stem diameter and the leaf area (TAIZ and ZEIGER, 2017

Regarding MFM, in a study carried out in the northeastern semi-arid region with corn hybrids for silage, Vieira et al. (2016) obtained results similar to this study, with values ranging from 39.71 and 56.53 t ha^{-1}, attributed mainly to the influence of the cycle and size of the plant. On the other hand, the values for MDM in that study were between 15.31 and 22.87 t ha^{-1}.

The greater average values for CE and DE at the 0.90 m spacing (Table 2) disagreed with the behavior reported by Nascimento et al. (2012) and Silva et al. (2014), who observed that the 0.45 m spacing provided the largest values. However, according to data achieved by Brachtvogel et al. (2009), who stated the occurrence of intraspecific competition for water, light and nutrients, reflecting on the morphometric development of the ear, observed an isolated effect for the plant population upon the EL characteristic, but this phenomenon was explained by a quadratic regression model, while in the present study, the linear model was the appropriate one.

These authors also observed an interaction between the evaluated factors (spacing between sowing rows and plant population) for the ED characteristic, demonstrating the existence of different behaviors, which is related to the populations within each arrangement, as well as Valle et al. who also observed the reduction in the averages of EL and ED as plant population increased, ratifying the narrow relationship between cause (plant population) and effect (EL and ED).

In relation to NGR, Brachtvogel et al. (2009) also observed a linear reduction as the plant population increased; however, without any interaction between the evaluated factors.

The largest plant population (90,000 plants ha^{-1}) for intensifying intraspecific competition for light also caused a reduction in the number of grain rows per ear in the study of Kappes et al. (2011), adjusting to a negative linear equation.

The largest MTG values were also achieved at 0.90 m spacing in a study carried out by Silva et al. (2014). Similar to the present study, Brachtvogel et al. (2009) also verified the effect of the plant populations on MTG, which better fit the quadratic polynomial regression model. In addition, these authors reported the importance of intraspecific competition, where the rise in plant population reduces the available resources, with consequences to the plant that produces smaller ears and with smaller and lighter grains, resulting in lower productivity. Kappes et al. (2011), in a study carried out in Selvíria (MS), also verified that the plant population linearly and negatively affected MTG, demonstrating that the increase in the plant population changes the rate and length of the grain filling period. Nevertheless, the influence of the spacings (0.45 and 0.90 m) was not observed on the characteristic in question.

Regarding GY, Kappes et al. (2011) and Silva et al. (2014) also reported larger yields by 15 and 17% favoring the reduced spacings (0.45 m), as well as they attributed the increase in PH and SD values to larger spacings between rows due to the relation with total biological mass accumulation (MFM), not necessarily of grains, differently from what happens in smaller spacings between rows, a fact verified in this study.

When GY is related with PH and SD, it can be observed the increase in their values in larger spacings between rows, which is directly related to the growth of plants and accumulation of total biological mass (MFM), not necessarily to of grains, differently to what happens in smaller row spacings, where plants concentrate more energy for GY, which was also reported by Kappes et al. (2011) and Silva et al. (2014).

The high grain yield achieved in this study (Table 2) occurred mainly due to thermal and water availability during the experimental period (Figure 1), fully meeting corn crop requirements, as observed by Bergamaschi; Matzenauer (2014).

5. CONCLUSIONS

In comparison to the 0.90 m row spacing, the 0.45 m row spacing combined with any population provides a greater corn grain yield.

6. ACKNOWLEDGEMENTS

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