e-ISSN: 2177-5133
www.comunicatascientiae.com

Comunicata Scientiae 7(2): 197-203, 2016

DOI: 10.14295/CS.v7i2.847

Article

Corn agronomic characteristics according to crop year, spacing and plant population densities

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Abstract

The present study aimed to evaluate the influence of row spacing, plant density, crop year and yield in crop agronomic parameters in a 'Cerrado' area in Brazil. The experiments were conducted during the 2010/2011 and 2011/2012 crop years, at an experimental Farm of the IF Goiás Campus Ceres, located in the city of Ceres, Goiás, Brazil. The experiment was conducted in a complete randomized block design in a 2x3x2 factorial (two crop years: 2010/2011 and 2011/2012, three population densities: 60,000, 70,000 and 80,000 plants ha^{-1} and two spacing: 0.50 and 0.80 m) with four repetitions, totaling 48 plots. The observed values for plant height and cob height were higher for the 2011/2012 season with values of 2.56 and 1.26 m, respectively. The cob diameter was higher for the 2011/2012 crop year with a value of 51.92 mm. The yield was higher for the 2010/2011 harvest. Increasing plant population and reducing row spacing can lead to an increase on the grain yield due to better spatial distribution of plants per area, fact observed mainly during the 2010/2011 crop year. Corn maintains high productivity with spacing of 0.50 and 0.80m. Increases in plant density can lead to increase on yield. Increasing plant population reduced the corn stem diameter.

Keywords: spatial arrangement, yield, *Zea mays* L.

Características agronômicas da cultura do milho em dois ciclos de cultivo sob diferentes densidades populacionais e espaçamento entre linhas

Resumo

Com a presente pesquisa objetivou-se avaliar os parâmetros agronômicos da cultura do milho cultivado em diferentes espaçamento entre linhas, densidade de plantas e anos de cultivo no Cerrado. Os experimentos foram conduzidos nas safras agrícolas de 2010/2011 e 2011/2012, nas dependências da Fazenda Experimental do IF Goiano Campus Ceres, localizado no município de Ceres, Goiás. O delineamento experimental utilizado foi de blocos completos casualizados em esquema fatorial 2x3x2 (dois anos safras 2010/2011 e 2011/2012, três densidades populacionais 60.000, 70.000 e 80.000 plantas ha^{-1} e dois espaçamentos 0,50 e 0,80 m) com quatro repetições totalizando 48 parcelas. A altura de planta e de espiga foram superiores na safra 2011/2012 com valores de 2,56 e 1,26 m, respectivamente. O diâmetro da espiga foi maior na safra 2011/2012 com valor de 51,92 mm. A produtividade foi superior na safra 2010/2011. As populações de 70 e 80 mil plantas ha^{-1} e a redução do espaçamento incrementaram a produtividade de grãos devido melhor distribuição espacial das plantas por área principalmente no ano safra 2010/2011. A cultura do milho mantém altas produtividades para os espaçamentos de 0,50 e 0,80 m. O aumento da população de plantas reduziu o diâmetro do colmo da planta de milho.

Palavras-chave: arranjo espacial, produtividade, *Zea mays* L.

Received: 26 July 2014
Accepted: 28 April 2016

Introduction

In Brazil the corn grain yield (*Zea mays* L.) is considered low, achieving 5.3 tons ha^{-1} (CONAB, 2015) and in countries like USA and France, the crop can achieve yield of 8 to 9 tons ha^{-1} (USDA, 2014). This lower yield is related to variables such as soil fertility, spatial arrangement of the plants and use of inadequate genotypes and management practices.

To achieve high grain yield is necessary to adequate the management practices to the environment available resources, allowing better conditions for the plant development. Between the management strategies that can be used, the plant density plays an important role (Serpa et al., 2012)

The plant arrangement is an important strategy of plant management because it can lead to an increase in solar radiation interception, better use of water and nutrients use and higher yield (Sangoi et al., 2005). The increase in the sowing density with a concomitant reduction in spacing needs an increase in nutrients absorption by the plants, since more plants will have to compete for water, light and nutrients at the same space.

The appearance of new corn genotypes increased the demand for studies determining the better plant spatial arrangement because of the morphologic and genetic variations, since this crop is very sensitive to these variations due to its lower capacity to emit fertile tillers, limited prolificacy, low leaf plasticity and its monoic flower structure, where the male and female inflorescences competes for photoassimilates under stress conditions (Sangoi et al., 2011).

The modern hybrids have lower size, better leaf architecture and lower plant mass. Thus, these hybrids exert lower shading indexes and are able to capture better the sunlight (Cruz et al., 2006). Because of that, modern hybrids can tolerate a higher plant density when compared to older hybrids. The trend is to split lines and increase plant density. Between the forms to manipulate the plant arrangement, the plant density is the variable that affects most the grain productivity, since small changes on the number of plants lead to relative bigger changes on the final yield (Silva et al., 2008).

Some growers have been adopting, with success, populations of 72000 plants ha^{-1} and spacing of 0.40m between lines (Fancelli & Dourado Neto, 2004).

Thus, it is necessary to evaluate the management practices and recommendations for the crop, such as the plant arrangement.

The present study aim to evaluate the corn agronomic characteristics under different spacing between lines, plant densities and crop year in a 'cerrado' region.

Material e Methods

The experiments were conducted in an experimental farm of the Federal Institute of Goias, Ceres campus, on the municipality of Ceres, Go, with S 15º 21' 03'' of latitude and longitude of W 49º 35' 37'' and 564 m of altitude. According to Koppen classification, the climate of the region is classified as Aw. The variation on rainfall and average temperature were registered during the two studied crop years (Figure 1).

The soil of the experimental area is classified as a red dystrophic oxysol (Embrapa, 2006), and the chemical analysis of the 0-0.2m layer indicated the following values: Ca= 2.4 ($cmol_c\ dm^{-3}$); Mg= 1.3 ($cmol_c\ dm^{-3}$); Al= 0.0 ($cmol_c\ dm^{-3}$); H= 3.5 ($cmol_c\ dm^{-3}$); P= 5.6 ($mg\ dm^{-3}$); K= 101.0 ($mg\ dm^{-3}$); pH= 5.0 ($CaCl_2$); bases saturation (V%)= 51.8% and organic matter= 1.5 g kg^{-1}. A management dissection was realized seven days before sowing, with 3 L ha^{-1} of glyphosate for both crop years.

The experiment was installed in a no-tillage system area during the both crop years, on November 18, 2010 and November 18, 2011. The cultivar used was P30F35H whose seeds were industrially treated with Thiamethoxam + fipronil. Sowing was done manually by distributing eight seeds per meter, and 12 days after germination the thinning was carried out, leaving the pre-established population of plants for each treatment.

The sowing fertilization consisted of 20 kg ha^{-1} of nitrogen, 150 kg ha^{-1} of phosphorus and 80 kg ha^{-1} of potassium, whose formula was 04-30-16. The topdressing consisted of two applications, the first was performed when the plants have four unfolded leaves, with the application of 40 kg ha^{-1} of N and 40 kg ha^{-1} of potassium (20-00-20). The second application was carried out when the plants presented the sixth leaf, using 70 kg ha^{-1} of N (urea). At this stage, atrazine was also applied in post-emergence at a dose of 3 L ha^{-1}.

The experiment was conducted in a complete randomized block design in a 2x3x2 factorial, with four repetitions. The treatments consisted of two crop years, (2010/2011 and 2011/2012), three plant population densities (60,000 plants ha^{-1}, 70,000 plants ha^{-1} and 80,000 plants ha^{-1}) and two spaces between rows (0.50 and 0.80 m). Each plot consisted of four rows with five meters in length and for the data collection, the two central lines were used, and 0.50 m around the edges was not considered.

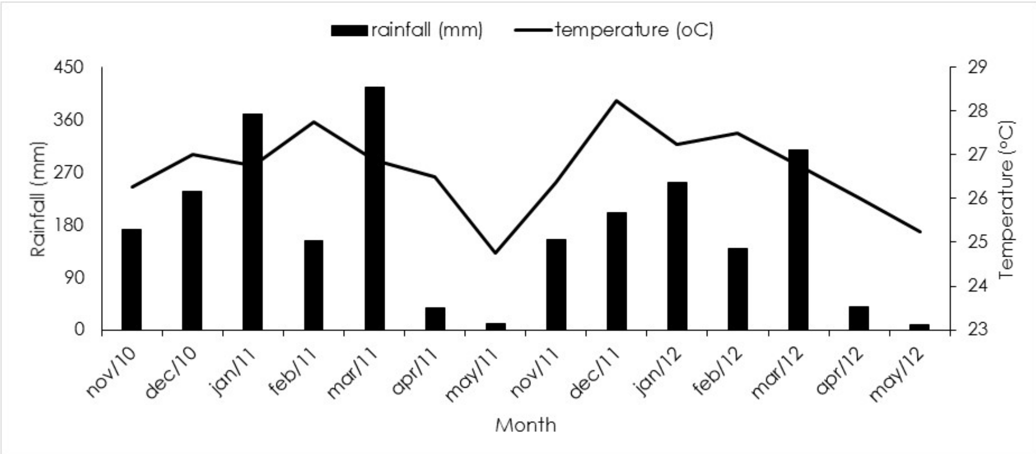

Figure 1. Montly values for rainfall and temperature during the experimental period, in Ceres, GO. Source: Meteorological Station of IF Goiano, Ceres Campus.

The evaluated variables were: height of the first cob; plant height (from the ground to the flag leaf); stem diameter according to the methodology of Demetrius et al. (2008); diameter of the cob and cob length, both measured with a digital caliper; number of grain rows; number of grains per row, thousand grain weight and yield (kg ha^{-1}). The harvest of the corn was performed manually for both experiments, at 130 days after emergence and the grain moisture was adjusted to 13%.

Data were submitted to analysis of variance and compared by the Scott Knott´s test at 5% of significance level. Analyses were performed using the R software (R Development Core Team, 2014) and the easyanova package (Arnhold 2013).

Results and discussion

No interaction was observed between the factors for the evaluated characteristics, but for yield an interaction was observed between the plant population x year and spacing x year (Table 1). Calonego et al. (2011), studying spacings of 0.45m and 0.90m and three plant populations (45, 60 and 75 000 plants ha^{-1}), did not observed significant interaction between spacing x plant population influencing agronomic components and grain yield.

The variables plant height, cob insertion height and stem diameter were not affected by an increase in spacing between lines from 0.50 to 0.80m and by the changes in the plant population (Table 2). These values corroborated with the results obtained by other authors, in which the reduction of the spacing between the lines did not influenced plant height and cob insertion (Demetrius et al, 2008; Calonego et al, 2011; Gilo et al, 2011).

The plant height and cob insertion height were different for the evaluated crop years (2010/2011 and 2011/2012), with average values of 2.56 and 2.40 m for plant height and 1.26 and 1.17 m for cob insertion height, respectively.

The diameter of the cob was higher for the 2011/2012 crop year, with an average of 51.92 mm, while in the 2010/2011 crop year, this variable presented an average of 51.17 mm. Stem diameter was not different between the crop years, with values from 20.31 to 20.65 mm (Table 2). However, for this variable, an effect of the plant population was observed, in which

Table 1. Mean squares for population (P), spacing (S) and year (Y) sources of variation and the interactions for the agronomic and productive variables of the corn crop. Ceres, Go, Brazil.

Characteristics	Source of variation						
	P	S	Year	P x Y	P x S	S x Y	P x S x Y
Plant height	0.0225ns	0.03307ns	0.2977**	0.0054ns	0.01283ns	0.00403ns	0.00054ns
Cob height	0.0138ns	0.01021ns	0.0936**	0.0007ns	0.00084ns	0.00270ns	0.00270ns
Stem diameter	6.4363**	0.9130ns	1.4077ns	0.4765ns	0.6500ns	2.3585ns	0.3022ns
Cob diameter	0.0375 ns	1.7480 ns	6.8252**	0.2256 ns	0.3940 ns	0.3888 ns	1.0408 ns
Cob length	34.196 ns	118.41 ns	21.534 ns	51.271 ns	238.396 ns	11.242 ns	5.591 ns
Number of rows	0.8958 ns	0.1302 ns	0.13021 ns	0.1458 ns	0.77083 ns	0.25521 ns	0.77083 ns
Grain per rows	9.7206 ns	0.2133 ns	4.5633 ns	0.7352 ns	0.9915 ns	0.1633 ns	6.1540 ns
Thousand grain mass	0.6153 ns	4.8775**	143555**	682 ns	1387 ns	3417 ns	0.0502 ns
Yield	13083**	290821 ns	297380**	26174**	475738ns	148908**	769338 ns

** significant at 5%. ns non-singnificant.

Table 2. Mean values for the biometric parameters: cob height, stem diameter and cob diameter in Ceres, Go, Brazil.

Spacing (m)	Plant height (m)	Com height (m)	Stem diameter (mm)	Cob diameter (mm)
0.50	2.46 a	1.20 a	20.34 a	51.35 a
0.80	2.51 a	1.23 a	20.62 a	51.74 a
Population (thousand plants ha^{-1})				
60	2.44 a	1.18 a	21.16 a	51.58 a
70	2.50 a	1.23 a	20.36 b	51.49 a
80	2.51 a	1.23 a	19.92 b	51.56 a
Year				
2010/2011	2.56 a	1.26 a	20.65 a	51.17 b
2011/2012	2.40 b	1.17 b	20.31 a	51.92 a
CV (%)	5.70	6.90	4.31	2.30

Means followed by the same letter in the column are different according to Scott Knott´s test at 5% of probability.

the population of 60 000 plants ha^{-1} resulted in a higher mean (21.16 mm), differing from the stem diameter of plants from other populations, with 70 and 80 thousand plants ha^{-1}, which presented average values of 20.36 and 19.92 mm, respectively. It is expected that an increase in plant population can lead to a reduction in stem diameter, due to the competition among plants for resources such as water, nutrients and light.

Demetrius et al. (2008) observed no differences for stem diameter with a variation in spacing, but observed a reduction of this variable with an increase of plant population. Calonego et al. (2011) observed that the plant population of 75,000 plants ha^{-1} promoted a reduction in the stem diameter. The increase in plant population can also lead to morphological and physiological changes in plants, higher plant height, higher height of the cob insertion and lower stem diameter, enabling greater lodging and reduced yield.

Lima et al. (2012) observed no differences for plant height, cob diameter, cob length and number of grain per rows when studying three plant populations (50,000 plants ha^{-1}, 55,000 plants ha^{-1} and 60,000 plants ha^{-1}). Silva et al. (2008) observed higher plants for larger populations, due to the increased competition between plants for light, water and nutrients. When there was a reduction in spacing, these authors observed a reduction in plant size due to the better plant distribution.

The cob length, number of rows per cob and the number of grains per row did not differed between the different spacing, plant populations and years (Table 3). The number of rows per cob has a strong genetic control, so it is little influenced by external factors. The data corroborate to the observed by Marchão et al. (2005), which concluded that the number of grain rows per cob was not influenced by an increase in plant population density.

The thousand grain mass was influenced by the change in spacing and agricultural years (Table 3). This characteristic is greatly influenced by environmental factors such as water limitation and severe reduction in growth. This component was crucial to the highest yields obtained in the first crop year, regardless the spacing and plant population (Table 4).

The variable grain yield was influenced by the interaction between spacing x year and between plant population x year (Table 4). For the first crop year, the highest yield were obtained for populations of 70,000 and 80,000 plants ha^{-1}, with values of 10,922 and 11,796 kg ha^{-1} of grain, respectively, differing from the productivity of 9,118 kg ha^{-1} of grain obtained by the population 60,000 plants ha^{-1}. The corn production is significantly influenced by plant density, where the number of cob per area is the main factor for this increase. For the second crop year, the population of 70,000 plants ha^{-1} resulted in a yield of 6253 kg grains ha^{-1}, differing from populations of 60 and 80 thousand plants ha^{-1} that produced 5045 and 5606 kg ha^{-1} of grains, respectively (Table 4).

Table 3. Agronomic variables: cob length, grain rows per cob, number of grains per row and thousand grain mass.

Spacing (m)	Cob length (mm)	Grain rows (cob^{-1})	Grains (rows^{-1})	Thousand grain mass (g)
0.50	131.37 a	16.58 a	33.85 a	263.65 a
0.80	134.51 a	16.69 a	33.98 a	248.54 b
Population (thousand plants ha^{-1})				
60	133.71 a	16.91 a	33.46 a	259.06 a
70	133.85 a	16.47 a	34.81 a	258.63 a
80	131.25 a	16.53 a	33.47 a	250.75 a
Year				
2010/2011	132.27 a	16.69 a	33.60 a	310.83 a
2011/2012	133.61 a	16.58 a	34.22 a	201.46 b
CV (%)	7.40	4.50	8.52	9.31

Means followed by the same letter in the column are not different according to Scott Knott´s test at 5% of probability.

Table 4. Corn yield (kg ha^{-1}) according to plant population and spacing between rows for the 2010/2011 and 2011/2012 crop years. Ceres, Go, Brazil.

Crop year	Plant population (thousand ha^{-1})			Spacings (m)	
	60	70	80	0.50	0.80
2010/2011	9,118 aB	10,922 aA	11,796 aA	10,923 aA	10,301 Aa
2011/2012	5,045 bB	6,253 bA	5,606 bB	6,437 bA	4,831 bB

Means followed by the same lowercase in the columns and uppercase in lines are not different according to Scott Knott´s test at 5% of probability.

The yield from the first crop year was higher than for all plant populations with values ranging from 9,118 to 11,796 kg of grains ha^{-1}, while in the second crop year the yield ranged from 5045 to 6253 kg of grains ha^{-1} (Table 4).

The lower yield during the 2011/2012 harvest (Table 4) may have occurred due to hybrid stability, that reduced productivity for this season, as the rainfall and temperature were satisfactory for the crop development (Figure 1). Another factor that contributes for the reduced yield during the second crop year was the corn leafhopper infestation (*Dalbulus maidis*). At harvest, there was the presence of various plants with cobs at the same insertion point, making them unproductive. According to Magalhães et al. (2005), leafhoppers attack can transmit phytoplasma or spiroplasma for the plants, causing several changes in plant development and the spread of abnormal cobs due to the hormonal unbalance of the plants.

An interaction between crop year and spacing on yield means was observed. During the first crop year, the yield was the same for both studied spaces, with values ranging from 10,923 to 10,301 kg ha^{-1} (Table 4). For the second crop year, the observed yield when the spacing of 0.50m was used was 6,437 kg ha^{-1}, significantly different from 4.831 kg ha^{-1}, observed for plants submitted to the spacing of 0.80 m (Table 4). Sharratt & McWillians (2005) observed an increase in corn yield with reduction in spacing from 0.76 to 0.57 and 0.38m between rows, with a population of 75 000 plants ha^{-1}.

The increase in plant population and the reduction in the spacing resulted in an increased grain yield due to the better spatial distribution of plants in the area, mainly in the 2010/2011 crop year (Table 4).

The highest yield related to an increase in the plant population is due to an increase of harvested cobs ha^{-1}. Silva et al. (2008) reported an increase in yield with an increase in plant population of the hybrid 30K75 from 40 to 80 000 plants ha^{-1}, whose yield reached 6,239 and 8,703 kg ha^{-1}, respectively. With the spacing of 0.60 m between lines, Silva et al. (2012) achieved an increase of 11% in yield with an increase of plant density from 78 to 100 thousand plants ha^{-1}.

Sangoi et al. (2012) found no difference between two consecutive crop years (2009/2010 and 2010/2011), by reducing the spacing from 0.80 to 0.40 m between rows. In this present research, no difference on yield with a reduction of the spacing was observed during the first season.

According to Stacciarini et al. (2010), a reduction in the spacing between plant rows (0.90 to 0.45 m) and an increase in population density (from 60,000 to 90,000 plants ha^{-1}) resulted in higher yield for the hybrid 30K75, without changing their agronomic characteristics, such as plant height, cob insertion height, thousand grain weight, number of grains per cob, number of grains per row and cob percentage.

Conclusion

The density of 70 thousand plants ha^{-1} lead to a yield increase.

The increase in plant population decreases the stem diameter.

The reduction on the space between rows increased the thousand grain mass.

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