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Conventional and twin row spacing in different population densities for maize (*Zea mays* L.)

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The increase in maize yield is directly related to management practices, especially the manipulation of spatial arrangement of plants. This work aimed, evaluated the effect of conventional and twin-row spacing in different plant densities for maize, in the crop year 2011/2012. The treatments consisted of combinations between two rows spacing (twin-row spacing (0.2 x 0.7 m) and conventional spacing (0.7 m)) and five plant populations (50,000; 65,000; 80,000; 95,000 and 110,000 plants ha^{-1}). It was evaluated the plant height, insertion height of the first ear, stem diameter, number of rows, number of kernels per ear, weight of 1,000 kernels, ear weight and yield. The use of twin row spacing provided better results for stem diameter, number of rows, number of kernels per ear, weight of 1,000 kernels, ear weight and the average maize yield. The stem diameter, number of kernels per ear, weight of 1,000 kernels and ear weight responded negatively to increased plant density.

Key words: Plant arrangement, yield, agronomic characteristics.

INTRODUCTION

Maize (*Zea mays* L.) is one of the main cereals grown in Brazil, occupying increasingly significant positions on the value of agricultural production, especially in no-tillage system. With the increasing consumption, both for human and animal consumption and currently to meet the energy demand, there is a growing pressure to increase the yield of this kernel. According to the National Food Supply Company (CONAB, 2013), the estimated maize production in the crop year 2012/2013 will be approximately 77.45 million tons, with an average yield of 4,956 kg ha^{-1}, and 3.08% higher than the yield obtained in 2011/2012.

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Among the practices and techniques used to obtain higher maize yield, the choice of spatial arrangement of plants, resulting from the combination of row spacing and the number of plants per meter is one of the most important (Almeida et al., 2000). Recent researches have demonstrated that reducing spacing has contributed to increased yield (Gross et al., 2006; Modolo et al., 2010). Another option of plant arrangement that has been studied mainly in the United States refers to the twin-row or double row system, which is a form of plants distribution that seeks to increase the distance between the plants without affecting the phenotype and increase the yield by providing less competition in the row. Another possible advantage of double lines is to increase the number of plants per unit area without affecting the phytotechnical variables.

In Brazil, there is no record of studies and the utilization of double lines in grain crops, already in the United States, studies with double lines showed no consistent advantages in yield compared to the single-spaced, with same plant densities (Nelson and Smoot, 2009; Balkcom et al., 2011). For being a new form of plant arrangement, still no recommendation from sowing density and optimal spacing, since the optimum arrangement generally presents variation because is linked to the region at the time of sowing, the cropping system, the edaphoclimatic conditions and the genotype choice.

Studies developed by Cox et al. (2006) found that the row spacing (conventional or double row) did not affect plant height in both V_8 stage (vegetative phase with 8 developed leaves) as in the physiological maturity. However, the authors observed that the kernel yield was higher in the arrangement with double rows of maize compared to the arrangement using conventional rows. The authors attributed the results to the more rapid canopy closure, allowing better use of solar radiation and thus increasing the amount of photoassimilates accumulated in the stem. According to Nummer and Hentschke (2006), the rapid initial growth of the plant enables greater interception of solar radiation, and hence competitive advantages and higher photosynthetic rates, resulting in greater accumulation of photoassimilates.

In view of recently morphological changes introduced into maize genotypes, such as lower plant height, lower height of ear insertion, lower sterility of plants, shorter duration of the tasseling-silking subperiod and plants with more erect leaves; it turn necessary to reevaluate the recommendation of the spatial arrangement of plants (plant density, row spacing and row arrangement). Therefore, this study aimed to evaluate the effects of conventional and twin row spacing in different population densities for maize crops.

MATERIALS AND METHODS

The experiment was conducted in Pato Branco, Paraná State - Brazil, under field conditions in the summer crop of 2011/2012, on Hapludox soil according to the Brazilian Agricultural Research Corporation (EMBRAPA, 2006), with loamy texture (77.4% clay, 20.3% sand and 2.3% silt), and the following chemical characteristics (0.0 to 0.2 m), sampled before establishing the experiment: pH in $CaCl_2$ 6.0, 44.25 g dm^{-3} of organic matter, 25.02 mg dm^{-3} of P, and exchangeable cations: 326.49 $cmol_c$ dm^{-3} of K, 5.66 $cmol_c$ dm^{-3} of Ca, 3.72 $cmol_c$ dm^{-3} of Mg, 3.66 $cmol_c$ dm^{-3} of H+Al. The experimental area is located at 26°16'36" south latitude and 52º41'20" longitude west of Greenwich, with an average altitude of 769 m. The climate in the region is Cfa, according to Köppen climate classification (Caviglione et al., 2000), with average temperature in the coldest month below 18°C and above 22°C in the warmest month, with relatively warm summers, infrequent frosts and trend of concentration of rainfall in the summer months, but with no defined dry season.

The experiment consisted of a 2x5 factorial arrangement in a randomized block design with four replications, totaling 40 experimental units. The treatments involved the combinations of two spacing between the rows (conventional spacing and twin row spacing) and five levels of plant population (50,000; 65,000; 80,000; 95,000 and 110,000 plants ha^{-1}). Spacing adopted for twin rows was 0.20 m between double rows and 0.70 m between rows, that is, 0.2 x 0.7 m, and 0.7 m between rows for conventional spacing.

In the conventional spacing (0.7 m), each plot with 14 m^2 was comprised of four rows of 5 m length, and considered for evaluation only the two central rows. In the twin row spacing (0.2 x 0.7 m), each plot with 18 m^2 consisted of four double rows of 5 m length, and considered for evaluation the two central twin rows.

A single cross (SC) hybrid (P30F36 H) was used with semi-erect leaf architecture, temperate germplasm, early maturity, high proliferative capacity, high defensiveness against major diseases, and high-yield potential. Sowing was held on October 20, 2011 by hand with the use of manual seeder and equidistant pits according to the treatment. Two seeds were sown per pit, and when plants had four fully expanded leaves, the thinning was done in order to adjust the populations in each treatment. Seeds were treated with thiamethoxam systemic insecticide at 210 g a.i. per 100 kg of seed to prevent a possible attack by *Dichelops furcatus* and *Elasmopalpus lignosellus* (Zeller).

As topdressing fertilization was applied 600 kg ha^{-1} of the NPK formula 10-30-11, according to chemical characteristics of the soil and maximum expected yield of 13,000 kg ha^{-1} (SBCS, 2004). For broadcast topdressing, it was used 500 kg ha^{-1} of the formula 45-00-00 (Urea Plus) divided into two equal applications, the first application when plants had 3 fully expanded leaves, and the second, with 6 leaves. Additionally, it was applied 150 kg ha^{-1} of the formula 00-00-56 (KCl). The fertilization in the sowing furrows was performed with a seeder-fertilizer (Vence Tudo, model SA 14600) with a furrow opener mechanism.

During the cultivation, phytotechnical practices were performed according to the needs. In order to keep the crop free from weed competition, at preemergence, it was applied atrazine + simazine at 1,750 g a.i. ha^{-1}. For disease control, it was applied preventatively at pre-flowering a systemic fungicide picoxystrobin + cyproconazole at 80 g + 32 g ha^{-1} a.i.

The flowering was evaluated by the number of days, counted from the emergency, which 50% of the plants presented the inflorescence. In the stages V_6, V_{10} (vegetative phases with 6 and 10 developed leaves, respectively) and pre-flowering, gun-sprinkler irrigation was held with a water depth of about 20 mm and a shift irrigation of two hours, totaling 60 mm.

The following variables were examined: plant height - distance between the ground surface and the end of the male inflorescence; insertion height of the first ear - distance between the ground surface and the ear insertion; stem diameter - determined on the first internode above the plant base; number of rows per ear; number of kernels per ear, weight of 1,000 kernels and kernel yield. The variables plant height; height of the first ear and stem diameter

Table 1. Summary of analysis of variance for plant height (PH), first ear height (FEH), stem diameter (SD), 1,000 grain kernels (GK), ear weight (EW), number of rows (NR), number of grains per ear (NGE), and yield (YIE) of maize crop.

Sources of variation	GL	PH(m)	FEH(m)	SD(mm)	GK(g)	EW(g)	NR	NGE	YIELD(kg ha^{-1})
Conventional	---	2.34^{a}	1.41^{a}	23.00^{b}	358.05^{b}	152.85^{b}	17.5^{b}	577.70^{b}	11,975.40^{b}
Twin-row	---	2.34^{a}	1.42^{a}	24.00^{a}	370.65^{a}	164.85^{a}	18.1^{a}	640.20^{a}	13,411.70^{a}
Row spacing (E)	1	0.0003^{ns}	0.0003^{ns}	6.4000*	1587.6000**	1440.0000*	3.6000*	39062.5000**	20629576.9000**
Population (P)	4	0.0195^{ns}	0.0037^{ns}	22.7125**	435.0250**	8021.5875**	0.7250^{ns}	5842.7875^{ns}	1530205.5375*
E x P	4	0.0446^{ns}	0.0009^{ns}	2.7125^{ns}	79.8500^{ns}	31.3125^{ns}	0.4750^{ns}	1049.3125^{ns}	1565286.8375^{ns}
Residual	27	0.0218	0.0025	1.4111	89.5815	258.8667	0.7851	2998.1370	820570.9111
C.V (%)	---	6.32	3.52	5.09	2.60	10.13	4.98	8.99	7.14

Means followed by the same letter in the same column are not significantly different by Tukey's test at p<0.05 probability. * Significant at the p<0.05 level; ** Significant at the p<0.01 level; ^{ns}: not significant; CV: Coefficient of variation.

were determined in stage R_6 (physiological maturity), based on a sampling of ten plants collected in the working area of each plot. For the variables number of rows per ear; number of kernels per ear and weight of 1,000 kernels, were collected five ears in each plot at harvest. To quantify, the yield were used in only the two central rows of each experimental unit. Assessments involving weighing of the kernel were corrected to 13% moisture, and the manual maize harvest was performed at 186 days after sowing.

Data were subjected to the F-test of the analysis of variance. For row spacing, means were compared by Tukey test at p<0.05 probability. The effect of plant population was subjected to analysis of variance and regression. Models were chosen based upon the significance of the F-test at p<0.05 probability and on the coefficient of determination. Statistical analysis of data was performed using the software Sisvar for Windows 4.0 (Ferreira, 2000).

RESULTS AND DISCUSSION

The effect of spacing and plant population did not influence the time of inflorescence appearance (female flowering), since it occurred at 73 days after emergence (DAE) for all treatments.

Table 1 presents the summary of the analysis of variance and regression for biometric variables and yield components of maize crop. Row spacing had no significant influence on plant height and first ear height, however, influenced on stem diameter, 1,000 grain kernels, ear weight, number of rows, number of grains per ear, and yield. Plant populations influenced significantly only the stem diameter, weight of 1,000 kernels and ear weight. No significant interactions were detected between treatments.

The lack of effect of reducing row spacing on plant height and first ear height was probably because it had not increased expressively the intraspecific competition. Cox et al. (2006) analyzed a hybrid maize in double row (0.18 x 0.76 m) and conventional (0.76 m) spacing and observed that the spacing had no significant effect on plant height, in both V_8 stage as at physiological maturity, a result that agrees with the present work.

Demétrio et al. (2008) also observed no changes in plant height with reduced row spacing from 0.8 to 0.4 m, for early maturing hybrids (P30F80 and P30K73). However, Alvarez et al. (2006) observed an increase in plant height with reduced row spacing of 0.9 to 0.45 m from 0.9 to 0.7 m, respectively. The twin-row spacing provided a higher mean value of stem diameter (4.3%) compared with the conventional spacing (Table 1). This is probably due to the better interception of solar radiation in the crop canopy at early and before flowering stages. In the twin-row spacing, there is a more equidistant plant distribution, which provided the more rapid closure of the spacing by the plant canopy, thus using better the incident radiation and increasing the growth rate of maize plants at early stages (Nummer Filho and Hentschke, 2006), precisely when the stem diameter is defined (Fancelli and Dourado, 2004). The lowest value of stem diameter found in conventional spacing can be because plants are closer inside the row, enhancing the competition for nutrient, water and space.

There was a reduction in the stem diameter with increased density of plants (Figure 1), indicating that as it increases the population from 50,000 to 110,000 plants ha^{-1}, the stem diameter reduces approximately 20%. This effect is related to competition for resources and mainly by translocation of photoassimilates during kernel filling, especially at sites of high consumption or restriction of water. This result corroborates the assertion that the increase in population density

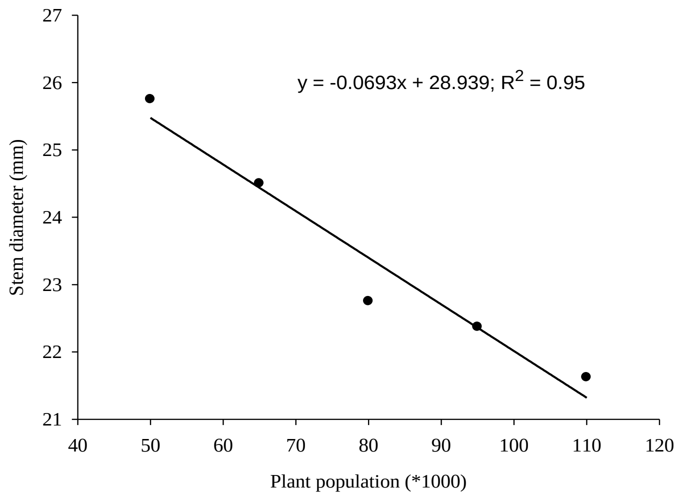

Figure 1. Stem diameter according to increased plant population in maize.

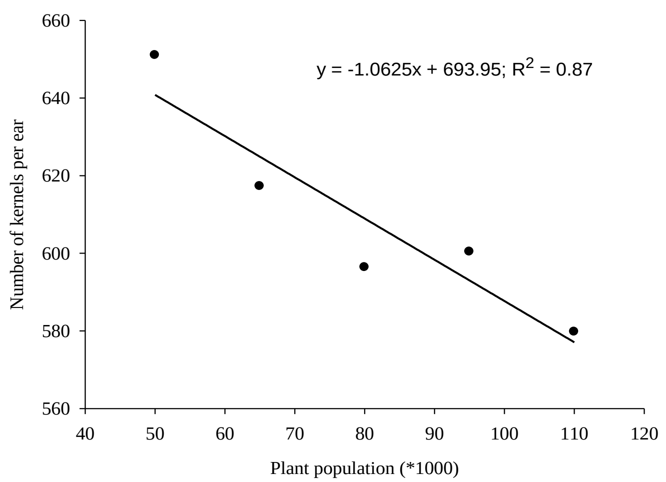

Figure 2. Number of kernels per ear according to increased plant population in maize.

decreases the stem diameter (Gross et al., 2006; Mendes et al., 2011). Only the row spacing influenced the number of rows per ear, with the highest value found in the twin row spacing (Table 1). Possibly, this result is due to the more even distribution of plants in this spacing.

According to Argenta et al. (2001) the reduction of spacing and the equidistant distribution of plants within the area significantly increased the number of rows per ear. However, this result differs from those obtained in studies with different row spacing. For Kappes et al. (2011), the row spacing did not affect the number of rows per ear of five maize hybrids with early and very early maturity when the spacing was reduced from 0.90 to 0.45 m. Piana et al. (2008) evaluated two maize hybrids from simple crossing (DOW 2B587; NB 4217) and four plant densities (55,000; 73,000; 91,000 and 110,000 plants ha^{-1}) and verified no difference in the number of rows per ear when reduced the spacing from 0.90 to 0.45 m.

The twin row spacing resulted in a higher number of kernels per ear (10.8%), compared with the conventional row (Table 1). This may have occurred because of more equidistant distribution of plants, which according to Sangoi (2001) and Argenta et al. (2001) enables the maximization of photosynthetic activity after anthesis, since plants spaced equidistant minimally compete for nutrients, light and other factors, favoring the better ear development.

In Figure 2, it is observed that the reduction on the number of kernels per ear with increased plant population, indicating enhanced competition for photoassimilates, which are necessary for reproductive growth. Similar results were reported by Amaral et al. (2005) who achieved a reduction on the number of kernels per ear with increasing density from 40,000 to 90,000 plants ha^{-1}. With respect to weight of 1,000 kernels, the twin row spacing showed a higher value (3.5%) compared with the conventional spacing (Table 1). This fact can be explained by the more equidistant distribution of plants in twin row spacing. This result corroborates with Nummer and Hentschke (2006) whose argues that the equidistant distribution of plants within the area improves yield components.

The plant population interfered significantly with the weight of 1,000 kernels, with a decreasing linear response to increasing plant density (Figure 3). This result is explained by the production capacity per plant, in general, at low densities, the individual production per plant is high, already at high densities the opposite occurs. According to Amaral et al. (2005) and Demétrio et al. (2008), the increased number of plants per unit area results in lower weight of 1,000 kernels, in other words; densities of 50,000 plants ha^{-1} allow heavier kernels than densities of 90,000 plants ha^{-1}.

Different row spacing significantly influenced the ear weight, and for the twin line spacing, the observed mean was 164.85 g, 7.8% higher than the mean of the conventional spacing (Table 1). The highest ear weight found for twin line spacing is justified by the equidistant distribution of plants and the largest stem diameter resulting from this treatment. The effects of plant population on the ear weight (Figure 4) were similar to those found in the weight of 1,000 kernels, that is, the 120% increase in the population, from 50,000 to 110,000 plants ha^{-1} led to a reduction of 67.3% in ear weight. Borghi et al. (2004) also observed a reduction in the ear weight given the increase in the number of plants when compared three forms of cultivation (conventional, minimum tillage and no-tillage) and three plant densities (55,000; 65,000 and 75,000 plants ha^{-1}) and two forms of fertilization (incorporated and on the surface) to the hybrid P 30F33.

The twin row spacing resulted in 12% increase in the average yield of maize compared with the conventional

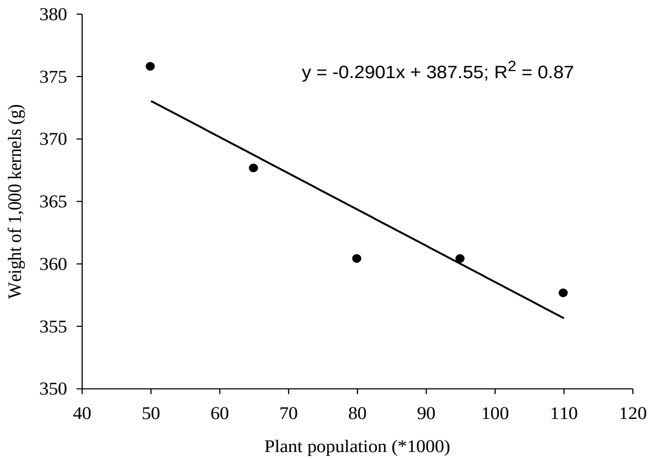

Figure 3. Weight of 1,000 kernels according to increased plant population in maize.

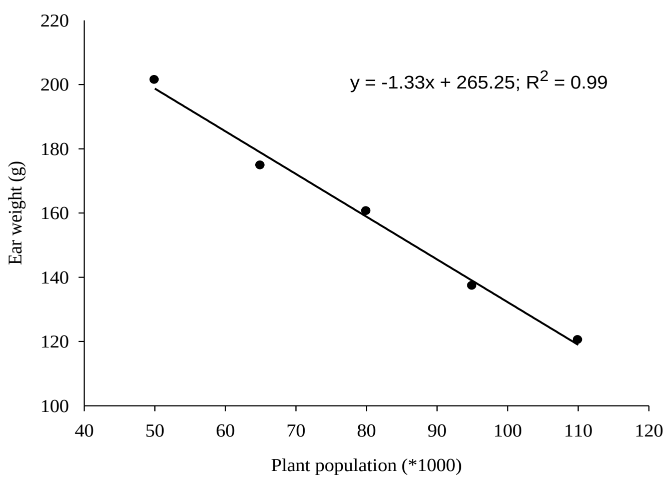

Figure 4. Ear weight according to increased plant population in maize.

spacing (Table 1). The increase in kernel yield in this spacing can be attributed to greater efficiency in radiation interception and decreased competition for light, water and nutrients between plants in the row, due to the more equidistant distribution (Nummer and Hentschke, 2006; Demétrio et al., 2008). Balkcom et al. (2011) also reported yield advantage in maize when used twin row spacing (0.19 x 0.76 m) compared with the conventional row spacing (0.76 m). However, Robles et al. (2012) by assessing three maize hybrids for three consecutive years in twin row spacing (0.20 x 0.76 m) and conventional spacing (0.76 m) at four densities (69,000; 81,000; 93,000 and 105,000 plants ha^{-1}), found that the maize kernel yield with twin row spacing was not significantly higher than conventional spacing for all hybrids and plant density used.

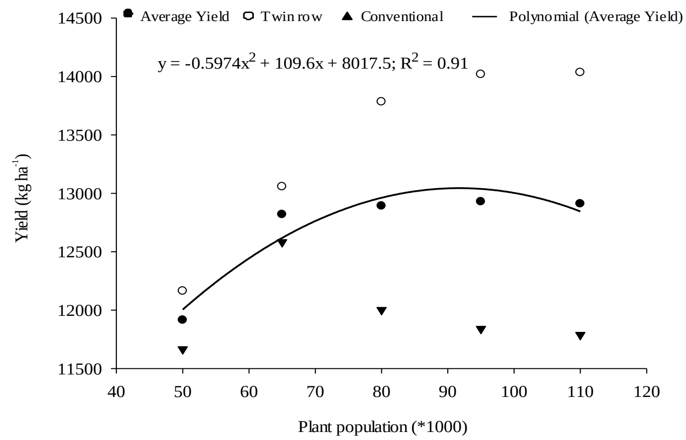

Figure 5. Maize yield according to increased plant population.

The highest yield of 12,950 kg ha^{-1} was found with 91,700 plants ha^{-1} (Figure 5). Recent studies showed positive responses to increased maize yields by increasing plant population, with maximum yield achieved with densities close to 90,000 plants ha^{-1} and decreasing at higher populations, close to 100,000 plants ha^{-1} (Marchão et al., 2005; Nummer and Hentschke, 2006). Although yield showed no significant interaction between treatments (Table 1), there is a distinct behavior at high plant densities between the different spacing. The twin row spacing maintained high yields when adopted plant population above 65,000 plants ha^{-1}. In turn, in the conventional spacing, when the number exceeded 65,000 plants ha^{-1}, the yield decreased. Therefore, the data indicate a trend that in the twin row spacing it would be possible to increase the number of plants per unit area.

The results show that in maize crop, there is a strong relationship between yield and number of harvested ears. This is because the yield components, weight of 1,000 kernels, number of kernels per ear, and ear weight responded linearly, decreasing as the yield responded positively to increased plant population.

Conclusions

The use of twin row spacing provided increment in stem diameter, number of rows per ear, number of kernels per ear, weight of 1,000 kernels, ear weight and average yield of maize crop in relation to conventional row spacing. The stem diameter, number of kernels per ear, weight of 1,000 kernels, and ear weight responded negatively to increased plant density. The density to achieve maximum production is 91,700 kg ha^{-1}, with a tendency to obtain higher yields with larger populations using twin row spacing than with conventional spacing. The hybrid P 30F36H has adaptability to high plant densities and the use of twin row spacing, for the climatic conditions of Pato Branco, Paraná State.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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