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Development and yield of maize (*Zea mays*) under plant densities using single and twin-row spacing

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Among the main factors that influence higher maize yield are the use of more productive materials, plant arrangement more suitable to the cultivar, reduced spacing between rows and/or higher population density. In this context, the objective of this work was to evaluate the development and yield of maize under different plant densities using single and twin-row spacing configurations. The work was developed in the 2012/2013 harvest year, using a randomized block design, with four replications in a 5 x 5 factorial design, featuring five inter-row spacing arrangements (twin-rows: 0.4 x 0.2, 0.5 x 0.2, 0.6 x 0.2, 0.7 x 0.2 m; and conventional spacing between rows as control: 0.7 m) and five sowing densities (50,000; 65,000; 80,000; 95,000 and 110,000 plants ha^{-1}). The study evaluated plant height and first ear insertion height, stem diameter, number of row per ear, 1,000-kernel weight and yield. The t-test (p = 0.05) was used to evaluate the effects of twin-row spacing arrangements and the contrast between twin-rows and control (single-row). Whenever the interaction between twin-row spacing arrangements and plant population was significant, the data were submitted to Response-Surface Methodology. As population density increased, there were reductions in stem diameter, number of rows per ear, 1,000-kernel weight and yield. The greatest plant heights, first ear insertion heights and yields were obtained in conventional spacing. Kernel yield responded negatively to plant density increase.

Key words: Crowding, plant arrangement, production system.

INTRODUCTION

In recent years, the status of maize (*Zea mays* L.) has risen among farmers, going from a rotation crop to becoming an agricultural commodity. With growing worldwide demand for both human and animal

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consumption as well as to meet energy needs, there is growing pressure to increase the grain yield of this crop. According to data from National Food Supply Company (CONAB, 2014), the estimated 2013/2014 maize harvest will in total approximately be 78.2 million tons, with average yield of 4,996 kg ha^{-1}. The choice of row spacing and the proper number of plants in a given area are of utmost importance among the different management practices, as they determine the best possible use of abiotic factors such as water, light and nutrients so that the crop can express its full physiological potential (Penariol et al., 2003).

Considering the built of modern hybrids-featuring shorter plant and ear height, slighter leaf angle, higher yield capacity, reduced number of leaves, more erect leaves and smaller leaf area, minimizing competition for light- decreasing spacing may be an adequate practice (Argenta et al., 2001). The use of reduced spacing brings several advantages, one of which is the increased distance between each plant in the same row, resulting in a more equidistant arrangement of individuals in the crop area, reducing plant competition for water, light and nutrients (Porter et al., 1997).

Higher plant density is one of the easiest and most efficient ways to increase the interception of an incident solar radiation by maize plants. However, very high densities can reduce photosynthesis and the efficiency of photoassimilate conversion in grain production (Marchão et al., 2006). As a result, female sterility increases, and the number of kernels per ear and grain yield are compromised (Marchão et al., 2006; Pereira et al., 2008).

Another option for plant arrangement is the twin-row system, which is used to improve the configuration between plants, allowing for higher population density without compromising kernel yield. In this type of configuration, plants are arranged equidistant from one another, allowing for better land use, as well as lower plant competition for water, light and nutrients, both in the rows and between them (Balem et al., 2014).

Studies on twin-row systems in maize crops are recent, and the results are still inconsistent. While some results indicate higher kernel yield using twin-row systems (Gozubenli et al., 2004; Cox et al., 2006; Balem et al., 2014), others did not show any yield advantages when compared to single-row spacing (Robles et al., 2012; Novacek et al., 2013; Haegele et al., 2014).

Since this is a new form of plant arrangement, there is no sowing density or ideal spacing recommendation, considering that the ideal arrangement usually varies and is closely linked to differences in region, sowing season, crop system, edaphoclimatic conditions and choice of genotype. Thus, this study aimed to evaluate the effects of single and twin-row spacing under different population densities for maize crops.

MATERIALS AND METHODS

The experiment was carried out during the 2012/2013 harvest on Oxisol, in São João, Paraná State - Brazil, (Soil Survey Staff, 2014), with loamy texture (76.5% clay, 8.0% sand and 15.5% silt), featuring the chemical profile shown in Table 1. The experimental area is located at 25°52'32" S and 52°47'58" W, with mean elevation of 620 m. The predominant climate in the region according to the Köppen classification is Cfa (temperate humid), with average temperatures below 18°C in the coldest month of the year and above 22°C in the warmest, featuring relatively hot summers, frequent frosts and well-distributed rainfall throughout the year. During the experiment, accumulated precipitation was 1,060 mm and mean temperature ranged from 18 to 23°C (SIMEPAR, 2013).

The experiment consisted of a 5 x 5 factorial arrangement in a randomized block design with four replications. The treatments resulted from the combination of five inter-row spacing configurations (four in twin-rows: 0.4 x 0.2, 0.5 x 0.2, 0.6 x 0.2, 0.7 x 0.2 m; one single spacing between rows: 0.7 m) and five sowing densities (50,000, 65,000, 80,000, 95,000, 110,000 plants ha^{-1}). Experimental units consisted of four single-rows in the conventional spacing configuration and four twin-rows in twin-row spacing, 5.0 m long. Evaluations and data collection were carried out over a useful plot of 3.0 m long and consisting of two single or twin central rows, according to the treatment.

Hybrid SUPERIS® was chosen for the study, characterized by early growth, high-yield potential, excellent leaf health, good rooting and stem quality, high kernel quality and stability (SYNGENTA, 2013). This material is considered a high investment hybrid, recommended for regular and off-season sowing. The hybrid features VIPTERA® technology, offered control of *Elasmopalpus lignosellus*, *Spodoptera frugiperda*, *Diatraea saccharalis*, *Helicoverpa zea* and *Agrotis ipsilon*. Sowing took place on September 27, 2012, done manually using jab planters, to an average depth of 5.0 cm. An extra 15% of seeds were sown, and when plants reached four expanded leaves, they were thinned to achieve the final stand for each treatment.

Basic fertilization consisted of 450 kg ha^{-1} of 12-32-18 (N-P-K) formula, according to the chemical profile of the soil and maximum expected yield of 11,650 kg ha^{-1} (SBCS, 2004). Nitrogen fertilizer (27% N) was used for nitrogen side dressing, applying 350 kg ha^{-1} divided into two applications – one at V4 and the other at the V6 stage (Vn: vegetative phase with n developed leaves).

Weed control consisted of atrazine at a dose of 4.2 L ha^{-1}, when the crop was at stage V4. Pest control consisted of 0.4 L ha^{-1} of beta-cyfluthrin at stage V4. A second application was carried out at stage V8, using the same insecticide and dose as before.

The following evaluations were carried out according to methodology proposed by Balem et al. (2014):

plant height - distance between the soil surface and the tip of the male inflorescence; height of the first ear insertion-distance between the soil surface and the first ear insertion; stem diameter-determined at the first internode above the plant collar; number of rows per ear; 1,000-kernel weight; and kernel yield. Plant height, height of first ear insertion and stem diameter were determined at phenological stage R5 (dent stage), based on a sample of 10 plants collected in each useful plot. For other evaluations, 10 ears were collected from each plot. The evaluations involving kernel weight were corrected for 13% moisture with manual harvesting.

Data were subjected to analysis of variance using Genes software to evaluate the effects of inter-row spacing and plant density factors, as well as the interaction between them (Cruz, 2006). To evaluate the effects of twin-row spacing and the contrast between twin-rows and control (single-row), means were compared through t-test (p = 0.05). Whenever the interaction between twin-rows and plant population was significant, the data were submitted to Response-Surface Methodology. Where the interaction between the contrast of twin-rows and control (single-row) and plant population was significant, polynomial regression was carried out. Models were chosen based on the significance of the coefficients of

Table 1. Chemical profile of the soil at the 0 to 0.2 m deep layer, sample before the experiment was established.

pH	MO	P	H+Al	K	Ca	Mg	V
$CaCl_2$	g dm^{-3}	mg dm^{-3}		$cmol_c$ dm^{-3}			(%)
4.9	40.21	1.32	5.35	109.48	3.82	2.84	56.47

Table 2. Sources of variation, degrees of freedom (DF) and mean square of characters plant height (PH), height of first ear insertion (FEI), stem diameter (SD), number of rows per ear (NRE), 1,000-kernel weight (KW) and yield (Y) according to inter-row spacing configurations and plant populations.

Sources of variation	DF	PH (m)	EIH (m)	SD (mm)	NRE	KW (g)	Y (t ha-1)
Block	3	0.0263	0.0130	1.94	2.45	267.66	0.905
Spacing (S)	4	0.0295**	0.0144**	0.28 ^{ns}	0.35 ^{ns}	91.24 ^{ns}	0.929**
Twin-Row (TR)	3	0.0192**	0.0121**	0.37 ^{ns}	0.34 ^{ns}	114.45 ^{ns}	0.978**
Crtl (C) vs	1	0.0605**	0.0213**	0.02 ^{ns}	0.39 ^{ns}	21.62 ^{ns}	0.781**
Population (P)	4	0.0025 ^{ns}	0.0119**	58.29**	1.35**	2189.48**	0.591**
TR x P	12	0.0093**	0.0076**	0.48 ^{ns}	1.06**	132.06 ^{ns}	0.397 ^{ns}
(C vs TR) x P	4	0.0030 ^{ns}	0.0021 ^{ns}	0.35 ^{ns}	0.22 ^{ns}	144.43 ^{ns}	0.257 ^{ns}
Error	72	0.0080	0.0050	0.78	0.55	331.71	0.552
Overall mean	---	2.24	1.09	20.01	15.42	357.40	7.25
Twin-rows	---	2.23 b	1.30 b	20.00 a	18.70 a	357.63 a	7.21 b
Single-rows	---	2.29 a	1.33 a	20.04 a	18.54 a	356.47 a	7.43 a
CV (%)	---	3.99	10.35	4.42	5.91	5.09	10.25

Means followed by the same lower-case letter are not significantly different by the t-test (p = 0.05). ** and * significant (p <0.01) and significant (p <0.05), respectively, by F test; ^{ns}: not significant (p>0.05); CV: coefficient of variation.

the fitted regression equation, tested by F test (p = 0.05), as well as the values of the coefficient of determination (R^2).

RESULTS AND DISCUSSION

Mean values and the synthesis of the analysis of variance in the parameters of initial development of maize crops are presented in Table 2, demonstrating that the tallest plant heights were obtained in single spacing (control). This result may be attributed to how the plants are arranged in both spacing configurations. In single-row sowing, plants area distributed in a non-equidistant manner when compared to twin-row spacing arrangements, thus increasing intraspecific competition in the row, inducing plants to grow in search of light (Sangoi et al., 2010).

According to Argenta et al. (2001) and Alvarez et al. (2006), there is a natural tendency for greater plant heights in situations of intense competition for light. Demétrio et al. (2008), while evaluating two hybrids subjected to three inter-row spacing configurations (0.4, 0.6 and 0.8 m) and four population densities (30,000; 50,000; 70,000 and 90,000 plants ha^{-1}), observed that plant height was not influenced by the reduction in the spacing between rows; this result differs from the data found in this research.

The reduction in inter-row and plant population caused shorter plant heights, and the tallest heights were obtained at 0.7 m inter-row spacing and at populations between 65,000 and 85,000 plants ha^{-1} (Figure 1). This result is justified, because whenever the space between rows is increased, the number of plants in the row necessarily increases along with it, in order to maintain a constant plant population. This increase naturally causes etiolation in plants in search of light. According to Sangoi et al. (2002), plant height will increase at the same rate as the population, due to the combined effect of intraspecific competition for light, resulting in stimulus of the apical dominance of plants.

Dourado Neto et al. (2003), evaluating the performance of three maize hybrids at three densities (30,000; 60,000 and 90,000 plants ha^{-1}) and two inter-row spacing (0.40 and 0.80 m), observed an increase in plant height for all three hybrids, with greater plant density, regardless of spacing. Yet, Farinelli et al. (2012), evaluating the performance of two maize hybrids in three sowing densities (40,000, 60,000 and 80,000 plants ha^{-1}) and three inter-row spacing (0.4, 0.6 and 0.8 m), observed finer plant heights at 0.6 and 0.8 m associated with the two greater sowing densities. According to those authors, this result was due to the natural tendency of increased heights for plants in situations of high population *densities.*

The greatest heights of first ear insertion were obtained

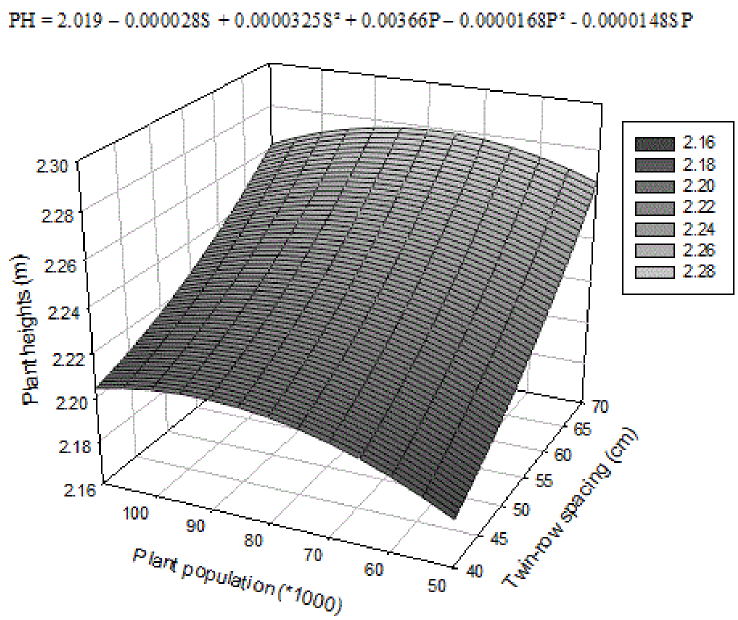

Figure 1. Plant heights (m) of maize crop according to plant population (plants ha^{-1}) and twin-row spacing (cm).

at single-row spacing. This result is attributed to the superior plant heights obtained in this spacing, as taller plants result in greater first ear insertion heights.

The tallest height of first ear insertion observed was 1.34 m, found at inter-row spacing of 70 cm and at a population density of 105,000 plants ha^{-1} (Figure 2). This result may be due to the fact that the number of plant in the row increases whenever inter-row spacing is increased, causing natural blanching of plants in search of light.

The results found herein corroborate those observed by Kappes et al. (2011), which analyzing five maize hybrids, observed that the tallest height of first ear insertion occurred when density was increased from 50,000 to 90,000 plants ha^{-1}. However, the results differ from those obtained by Balem et al. (2014), while evaluating the maize yield in conventional and (0.70 m) and twin-row spacing (0.20 x 0.70 m) and using five plant populations (50,000; 65,000; 80,000; 95,000 and 110,000 plants ha^{-1}), did not observe any increase within plant population increases.

In regard to the number of rows per ear, the highest values were observed at the lowest plant population densities and greatest spaces between rows (Figure 3). Similar data were obtained by Brachtvogel et al. (2009) and Kappes et al. (2011), who observed a reduction in the number of rows per ear as population density increased. However, the decrease in 110,000 to 50,000 plants ha^{-1}, observed by Balem et al. (2014), showed no difference in NRE. These results also differ from those obtained by Marchão et al. (2005), evaluating six maize hybrids at two different locations during the same crop year, an increase of 40,000 to 100,000 plants ha^{-1} showed no influence in NRE.

A population increase up to 64,600 plants ha^{-1} caused a significant increase in 1,000-kernel weight (Figure 4). Similar results were obtained by Farinelli et al. (2012), studying three plant densities (40,000; 60,000 and 80,000 plants ha^{-1}), observed that kernel weight was lower at plant densities above 60,000 plants ha^{-1}. The use of high densities can reduce photosynthesis activity in the crop, as well as photoassimilate conversion efficiency in grain production (Marchão et al., 2006).

Inter-row spacing arrangement significantly influenced maize yield, with conventional spacing showing the highest yield (7.4 t ha^{-1}), approximately 3.0% greater than the yield obtained from twin-row spacing. This result went against expectations, considering that plants are better distributed in twin-row spacing, which would theoretically reduce competition among them, causing yield improvement.

Since this is a new form of plant arrangement, the effects on maize kernel yield are quite varied. Balkcom et al. (2011), while evaluating different hybrids, Pioneer 31N27, Pioneer 31N26, Dekalb DK697 and Dekalb DKC 69-72, at low density (40,000 to 44,000 plants ha^{-1}), average density (59,000 to 64,000 plants ha^{-1}) and high density (79,000 to 84,000 plants ha^{-1}) in twin-row (0.19 x 0.76 m) and conventional spacing (0.76 m), detected that twin-row spacing yielded 16% more than single spacing at the highest plant densities and 10% higher in medium densities, compared to conventional density.

Balem et al. (2014), while working with twin-row (0.2 x 0.7 m) and single spacing (0.7 m) using hybrid 30F53H,

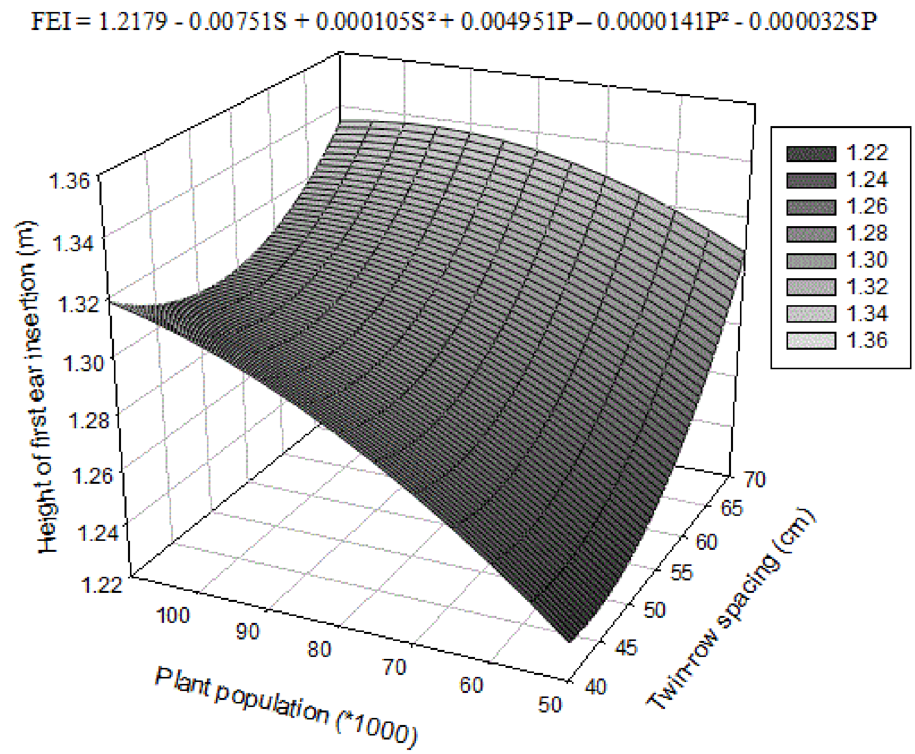

Figure 2. Height of first ear insertion (m) according to plant population (plants ha^{-1}) and twin-row spacing.

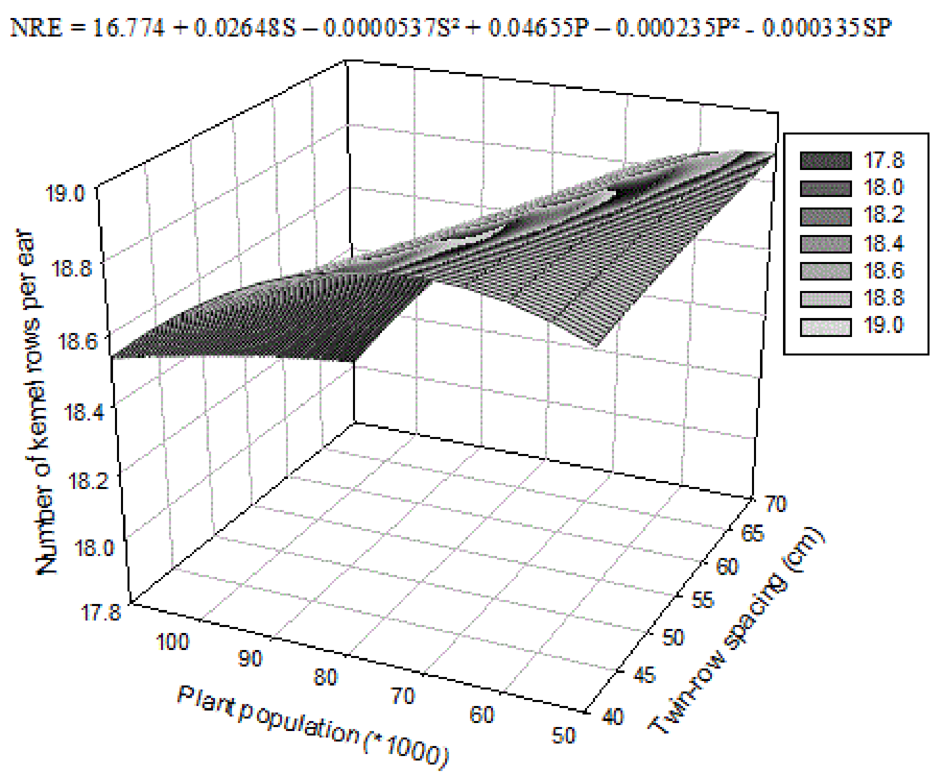

Figure 3. Number of rows per ear of maize according to plant population (plants ha^{-1}) and twin-row spacing (cm).

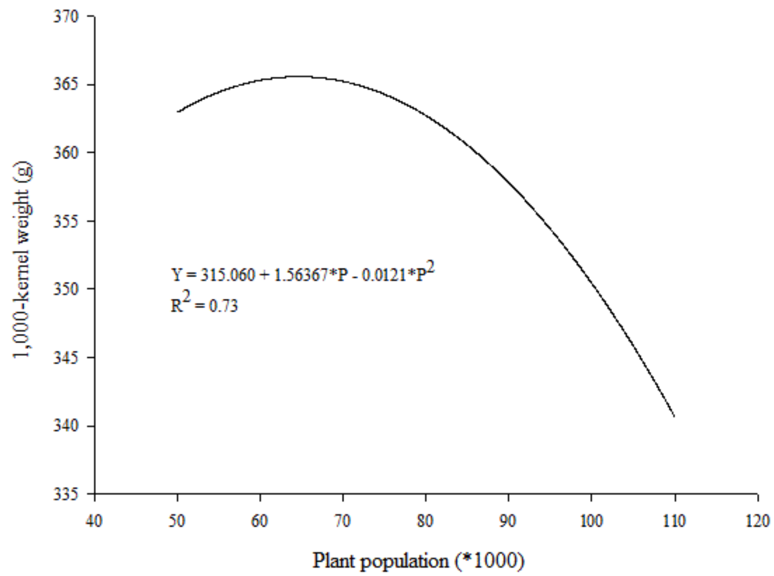

Figure 4. Thousand-kernel weight (g), according to plant population (plants ha^{-1}).

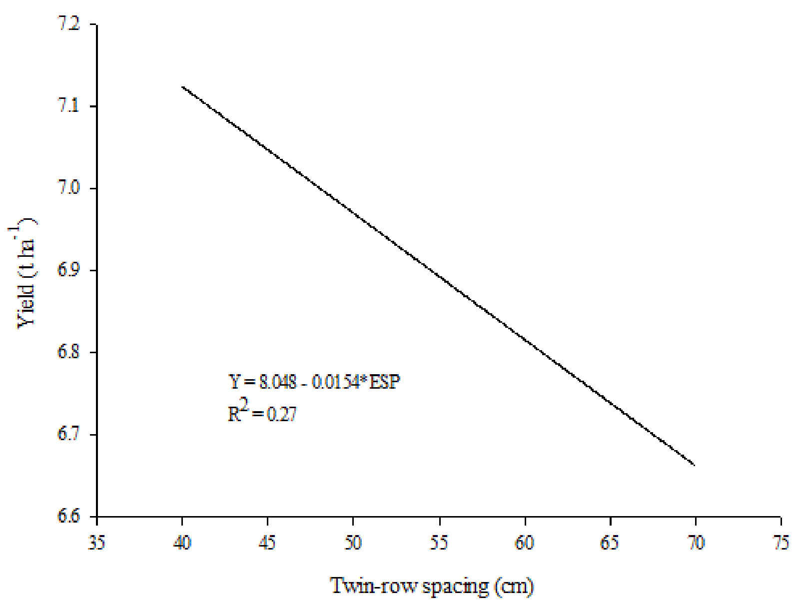

Figure 5. Maize yield (t ha^{-1}), according to twin-row spacing (cm).

also found higher yield in twin-row spacing. However, Robles et al. (2012), while evaluating three maize hybrids for three years, using twin-row (0.20 x 0.76 m) and conventional spacing (0.76 m), at four population densities (69,000; 81,000; 93,000 and 105,000 plants ha^{-1}), detected that maize kernel yield at twin-row spacing was not significantly superior to comparable yields in all hybrids and plant density levels.

Figure 5 shows a linear decrease in maize yield due to the increase of row spacing. This fact is due to the larger number of plants in the row in wider spacing configurations than in closer arrangements; in the latter, the plants are better distributed in the row, favoring root growth and nutrient absorption. Alvarez et al. (2006), studying two maize hybrids, observed a yield increase of 500 kg ha^{-1} when spacing was reduced from 0.9 m to 0.7 m.

Farinelli et al. (2012) observed that decreasing spacing from 0.8 m to 0.4 m increased productivity of tested hybrids, regardless of plant density used (40,000; 60,000 and 80,000 plants ha^{-1}). Modolo et al. (2010) also found an increase in maize yield when spacing was reduced from 0.9 m to 0.45 m.

CONCLUSIONS

With the increase in population density, plant and first insertion heights increased, while stem diameter, number of rows per ear, 1,000-kernel weight and crop yield decreased. Inter-row spacing influenced plant and first insertion heights as well as yield, with the best results found in single spacing. The use of twin-row spacing did not result in any advantages to conventional spacing for the different plant densities.

Conflict of Interest

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

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REFERENCES

Alvarez CGD, Pinho RG, Borges ID (2006). Evaluation of agronomic characteristics and production of forage and grains of corn in differents densities of sowing and row spacings. Ciênc. Agrotec. 30:402-408. http://dx.doi.org/10.1590/S1413-70542006000300003

Argenta G, Silva PRF, Bortolini CG, Forsthofer EL, Manjabosco EA, Beheregaray Neto V (2001). Response of maize single-cross hybrids to reduced row spacing. Pesq. Agropec. Bras. 36:71-78. http://dx.doi.org/10.1590/S0100-204X2001000100009

Balkcom KS, Satterwhite JL, Arriaga FJ, Price AJ, Santen EV (2011). Conventional and glyphosate-resistant maize yields across plant densities in single and twin-row configurations. Field Crops Res. 120:330-337. http://dx.doi.org/10.1016/j.fcr.2010.10.013

Balem Z, Modolo AJ, Trezzi MM, Vargas TO, Baesso MB, Brandelero EM, Trogello E (2014). Conventional and twin-row spacing in different population densities for maize (*Zea mays* L.). Afr. J. Agric. Res. 23:1787-1792. http://dx.doi.org/10,5897/AJAR2014.8714

Brachtvogel EL, Pereira FRS, Cruz SCS, Bicudo SJ (2009). Maize plant densities in conventional and equidistant plant spacing. Cienc. Rural 39:2334-2339. http://dx.doi.org/10.1590/S0103-84782009005000193

CONAB-Companhia Nacional de Abastecimento (2014). Acompanhamento de safra brasileira de grãos, v. 1 – Safra 2013/14, n. 10 - Décimo Levantamento, julho 2014. Brasília: CONAB. P. 89.

Cox WJ, Hanchar JJ, Knoblauch WA, Cherney JH (2006). Growth, yield, quality, and economics of corn silage under different row spacing's. Agron. J. 98:163-167. http://dx.doi.org/10.2134/agronj2005.0133

Cruz CD (2006). Programa GENES: estatística experimental e matrizes. Viçosa: UFV. P. 285.

Demétrio CS, Fornasieri Filho D, Gazetta JO, Cazetta DA (2008). Performance of maize hybrids submitted to different row spacing and population densities. Pesq. Agropec. Bras. 43:1691-1697. http://dx.doi.org/10.1590/S0100-204X2008001200008

Dourado Neto D, Palhares M, Vieira PA, Manfron PA, Medeiros SLP, Romano MR (2003). Distribution and population of plants and maize grain Yield. Revista Brasileira de Milho e Sorgo. 2:63-77.

Farinelli R, Penariol FG, Fornasieri Filho D (2012). Agronomic characteristics and yield of maize cultivars in different row spacing and population densities. Científica 40:21-27. http://dx.doi.org/10.15361/325

Gozubenli H, Kilinc M, Sener O, Konuskan O (2004). Effects of single and twin row planting on yield components in maize. Asian J. Plant Sci. 3:203-206.

Haegele JW, Becker RJ, Henninger AS, Below FE (2014). Row arrangement, phosphorus fertility, and hybrid contributions to managing increased plant density of maize. Agron. J. 106:1838-1846. http://dx.doi.org/10.2134/agronj2013.0382

Kappes C, Andrade JAC, Arf O, Oliveira ÂC, Arf MV, Ferreira JP (2011). Plants spatial arrangement for different maize hybrids. Pesq. Agropec. Trop. 41:348-359. http://dx.doi.org/10.5216/pat.v41i3.9650

Marchão RL, Brasil EM, Duarte JB, Guimarães CM, Gomes JA (2005). Plant density and agronomic traits of maize hybrids in narrow row spacing. Pesqui. Agropecu. Trop. 35:93-101.

Marchão RL, Brasil EM, Ximenes PA (2006). Interceptation of photossintetic active radiation and grain yield of maize under high plant density. Rev. Bras. Milho Sorgo 5:170-181. 2006.

Modolo AJ, Carnieletto R, Kolling EM, Trogello E, Sgarbossa M (2010). Performance of corn hybrids at the Southwest of Paraná under different row spacing. Rev. Ciênc. Agron. 41:435-441. http://dx.doi.org/10.1590/S1806-66902010000300016

Novacek MJ, Mason SC, Galusha TD, Yaseen M (2013). Twin rows minimally impact irrigated maize yield, morphology, and lodging. Agron. J. 105:268-276. http://dx.doi.org/10.2134/agronj2012.0301

Penariol FG, Fornasieri Filho D, Coicev L, Bordin L, Farinelli R (2003). Performance of maize cultivars sown in different row widths and population densities in off-season cultivation. Rev. Bras. Milho Sorgo 2:52-60.

Pereira FRS, Cruz SCS, Albuquerque AW, Santos JR, Da Silva ET (2008). Spatial arrangement of corn plants in a no-tillage system. R. Bras. Eng. Agríc. Ambiental. 12:69-74. http://dx.doi.org/10.1590/S1415-43662008000100010

Porter PM, Hicks DR, Lueschen WE, Ford JH, Warnes DD, Hoverstad TR (1997). Corn response to row width and plant population in the Northern Corn Belt. J. Prod. Agric. 10:209-210. http://dx.doi.org/10.2134/jpa1997.0293

Robles M, Ciampitti I, Vyn TJ (2012). Responses of maize hybrids to twin-row spatial arrangement at multiple plant densities. Agron. J. 104:1747-1756. http://dx.doi.org/10.2134/agronj2012.0231

Sangoi L, Gracietti MA, Rampazzo C, Bianchet P (2002). Response of Brazilian maize hybrids from different eras to changes in plant density. Field Crop Res. 79:39-51. http://dx.doi.org/10.1016/S0378-4290(02)00124-7

Sangoi L, Da Silva PRF, Argenta G, Rambo L (2010). Ecofisiologia da cultura do milho para altos rendimentos. Lages: Graphel, 87p.

SBCS - Sociedade Brasileira de Ciência do Solo. Comissão de Química e Fertilidade do Solo - RS/SC (2004). Manual de adubação e de calagem para os estados do Rio Grande do Sul e de Santa Catarina. 10.ed. Porto Alegre. P. 400.

SIMEPAR-Sistema Meteorológico do Paraná (2013). Available in http://www.simepar.br / Acessed on February 25, 2013.

Soil Survey Staff (2014). Keys to soil taxonomy. 12th edition U.S. Department of Agriculture. Natural Resources Conservation Service, Washington, D.C. P. 372.

SYNGENTA (2013). Available in http://www.syngenta.com / Acessed on February 25, 2013.