ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.19, n.12, p.1172–1177, 2015
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v19n12p1172-1177

Production components of corn as function of seed distribution along the planting row

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Key words:
coefficient of variation
grain yield
non-uniformity
Zea mays

ABSTRACT
High corn yields in high-tech systems are related to proper crop implementation. This study aimed to evaluate the effects of variability in the distribution of seeds along the planting row on corn production components. The study was conducted under Cerrado conditions in the municipality of Urutaí, GO, Brazil. The experimental design was randomized blocks in a 5 x 2 factorial scheme, with four replicates. The effects of five coefficients of variation (0, 20, 40, 60 and 80%) of non-uniformity in the spatial distribution of seeds along the planting row of two corn hybrids (P30F53HX and P3646HX) were evaluated. No interactions were observed for the analysed corn variables. However, as the non-uniformity in seed distribution along the planting row increased, stalk diameter, hundred-grain weight, number of rows per ear, number of kernels per row and ear length decreased. Additionally, linear reductions were observed in corn grain yield with the increase in the coefficient of variation of the spatial distribution of seeds along the planting row. Between the hybrids, the 30F53HX showed higher hundred-grain weight.

Palavras-chave:
coeficiente de variação
rendimento de grãos
desuniformidade
Zea mays

Componentes de produção do milho em função da distribuição de sementes na linha de semeadura

RESUMO
Produtividades elevadas de milho em sistemas com alta tecnologia estão relacionadas à correta implantação da lavoura. Neste trabalho objetivou-se avaliar os efeitos da variabilidade na distribuição de sementes de milho na linha de semeadura sobre os componentes de produção do milho. A pesquisa foi realizada em condições de Cerrado, no município de Urutaí, GO. O delineamento experimental utilizado foi de blocos casualizados em esquema fatorial 5 x 2, com quatro repetições. Avaliaram-se os efeitos de cinco coeficientes de variação (0, 20, 40, 60 e 80%) de desuniformidade na distribuição espacial de sementes na linha de semeadura em dois híbridos de milho (P30F53HX e P3646HX). Não foram observadas interações para as variáveis analisadas no milho; contudo, foram diminuídos, com o aumento da desuniformidade na distribuição das sementes na linha, o diâmetro do colmo, a massa de cem grãos, o número de fileiras por espiga, o número de grãos por fileiras e o comprimento da espiga. Também foram observadas reduções lineares no rendimento de grãos de milho com o aumento do coeficiente de variação na distribuição espacial das sementes na linha de semeadura. Entre os híbridos o 30F53HX apresentou maior massa de cem grãos.

Protocolo 019-2015 – 05/04/2015 • Aprovado em 02/10/2015 • Publicado em 03/11/2015

Introduction

Corn is a traditional crop that occupies significant positions with respect to agricultural production value, cultivated area and produced volume, especially in the South, Southeast and Mid-west regions of Brazil. This crop represents one of the main cereals cultivated worldwide, providing products widely used for human and animal consumption. However, despite its great importance, the gradual evolution of amounts produced and the obtained yields, the production of grains per unit area does not yet translate the genetic potential of the materials recommended for cultivation (Barbosa, 2007).

Some important alterations have occurred in the cultivation of corn in the last decades, such as the increase in plant population, reduction in the spacing between rows and increment in the production potential of the hybrids (Silva et al., 2008). These changes can intensify the effects of non-uniformity in plant distribution along the rows on the agronomic performance of the crop (Sangoi et al., 2012). Theoretically, the higher the plant population and the aimed maximum production, the more negative will be the effect of irregular spatial distribution on the use of resources. Thus, Nielsen (2004) and Doerge et al. (2004), in studies conducted in the United States, observed decreases in corn grain yield caused by the increase in the irregularity of the spatial distribution of plants along the row.

The arrangement of plants can interfere with corn growth and development through variations in population density, spacing between rows and in spatial and temporal distribution of individuals along the row (Argenta et al., 2001; BrachtvogeL et al., 2009). Obtaining high grain yields in corn depends on the duration of the period of interception of incident solar radiation, use efficiency of the radiation intercepted during photosynthesis and adequate distribution of the produced photoassimilates to different plant demands (Argenta et al., 2003; Marchão et al., 2005). Plant density and arrangement have great importance in the interception and efficiency of conversion of the photosynthetically active radiation intercepted by the canopy into grain production. This effect is more significant in corn than in other Poaceae plants because of its morphological, anatomical and physiological characteristics (Sangoi et al., 2001; 2011).

The irregularity in plant spatial distribution along the rows can reduce the use efficiency of water, light and nutrients by plants, increasing the number of dominated plants in the cultivation (Sangoi, 1990; Rizzardi et al., 1994; Schimandeiro et al., 2006). Various factors can affect the uniform arrangement of corn plants, among which the inadequate seed classification with respect to shape, mass and size, the incompatibility between seed size/shape and the discs of sowing machines, inadequate regulation of sowing machine, seed-conducting tubes and the excessive velocity during sowing are the most common causes for the occurrences of non-uniform stands of corn (Trogello et al., 2013). In these cases, there are segments in the rows where plants are very close to each other and long segments without plants.

Thus, plants with late emergence can also show lower growth of shoots and root system and, consequently, lower capacity of quantitative competition for water, light and nutrients. However, variation in intraspecific competition is directly related to plant distribution in the area through the variation of the spacing between rows and between plants in the row (Brachtvogel et al., 2012).

Uniform spatial distribution of seeds along the planting row is one of the most important factors for the adequate stand of plants and, consequently, for good yield. Given the above, this study aimed to evaluate the effects of non-uniformity in plant spatial distribution along the planting row on development and agronomic performance of corn.

Material and Methods

The experiment was conducted during the 2012/2013 crop season, in the experimental area of the Urutaí Campus of the Federal Institute of Goiás, located in the municipality of Urutaí-GO, Brazil (17°28'41" S; 48°11'35" W; 800 m). The experimental area has been cultivated and irrigated by a fixed central pivot system for more than ten years.

The soil in the area is classified as dystrophic Red Latosol of clayey texture (EMBRAPA, 2006), which was originally under Cerrado vegetation. Soil analysis in the layer of 0-0.2 m showed the following physical-chemical attributes: pH in water of 5.7; K, Ca, Mg, H + Al of 0.0, 30.0, 2.0, 7.0, 0.0, 4.0 and 2.6 $cmol_c\ dm^{-3}$, respectively; P of 53 mg dm^{-3}; organic matter of 1.2 dag kg^{-1}; S, Zn, B, Cu, Fe, Mn and Mo of 5.6, 5.6, 0.12, 1.8, 47.3, 27.0 and 0.07 mg dm^{-3}, respectively; and granulometry of 45, 16 and 39 dag kg^{-1} of clay, silt and sand, respectively.

The prevailing climate in the region is humid tropical, typical of areas with occurrence of Cerrado vegetation, with thermal oscillation from 15 °C (June and July) to 33 °C (October to April), mean annual temperature around 23 °C and annual rainfall between 1000 and 1500 mm (Costa, 2005). The meteorological data observed during the experiment are shown in Figure 1.

The experiment was set in a randomized block design, in a 5 x 2 factorial scheme, with four replicates. The treatments consisted of five levels of non-uniformity in the spatial distribution of corn seeds along the planting row, equivalent to 0, 20, 40, 60 and 80% of the coefficient of variation (CV), and two corn hybrids, Pioneer P30F53HX and Pioneer P3646HX.

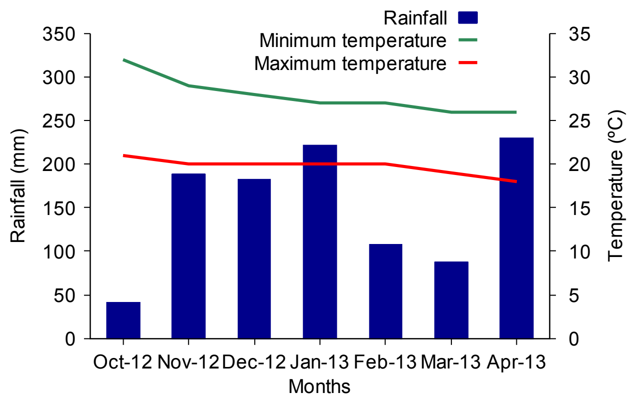

Figure 1 . Data of maximum temperature, minimum temperature and rainfall during the experimental period from October 2012 to April 2013

The experimental plots comprised six 6.0-m-long rows with spacing of 0.50 m between rows, totaling an area of 18 m^2 (3.0 x 6.0 m). For data collection, only the two central rows (evaluation area) were used, disregarding 0.50 m on each side.

Soil preparation consisted of one disc harrowing and one leveling harrowing. Basal fertilization, at sowing, was performed using a seeder/fertilizer machine (Jumil 2900) and was determined based on soil physical-chemical attributes and on the recommendations proposed by Raij et al. (1996) for an expected yield of 12 Mg ha^{-1}. 400 kg ha^{-1} of the 08-28-18 formulation (+ 2.95% of S and 0.3% of Zn) were applied. After incorporating the fertilizer, seeding as manually performed using wooden rulers marked with the distances between plants to place the seeds, according the treatments.

Seeding was performed on November 9, 2012. 3.5 corn seeds per linear meter were planted at the depth of 5 cm, by placing two seeds in each pre-established point in the row, according to the desired spatial variability, equivalent to 0, 20, 40, 60 and 80% of the coefficient of variation (Figure 2). For the determination of the coefficient of variation, five linear meters were measured and the distances between plants were added. Then, the coefficient of variation was calculated by the division of the mean standard error. Thus, the treatment with CV of 10% was equivalent to the uniform distribution of 3.5 plants per linear meter in the planting row.

Immediately after emergence, thinning was performed in the VE stage on the scale of Ritchie et al. (1993), leaving only one plant per point and the final density of 70,000 plants ha^{-1}. Cultural practices were performed according to crop needs (Barbosa, 2007). Top-dressing fertilization was performed 25 days after sowing (DAS), in the V5 development stage, by applying 130 kg ha^{-1} of N, in the form of urea, on the soil surface beside each plant.

Weed control was performed through two applications of the herbicides atrazine + nicosulfuron, in the doses of 1100 and 32 g ha^{-1}, respectively, in the corn stages of V3 and V6. The control was complemented by two manual weedings until the complete closure of the canopy. Corn harvest was manually performed on April 3 2013, at 145 DAS.

The evaluated variables were stalk diameter (SD), ear length (EL), number of rows per ear (NRE), number of kernels per row (NKR), hundred-grain weight (HGW) and grain yield (GY). SD was measured at a height of 5 cm from the soil surface, using a digital caliper. The evaluations were performed one day before harvesting. EL was determined after harvesting and before threshing the grains; ten corn ears were randomly collected in each plot and measured, without the husk, from the base to the tip, using a ruler.

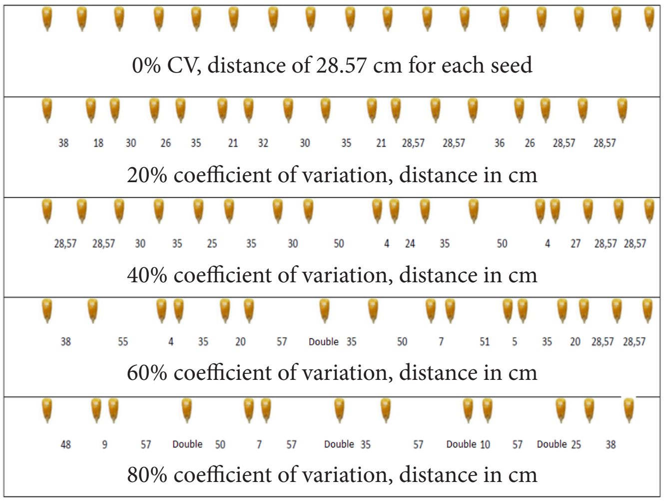

Figure 2 . Seed distribution scheme used in the wooden ruler at sowing

GY was obtained from the threshing and weighing of grains from ears collected in the evaluation area of the plots. Then, it was converted to kg ha^{-1} and the humidity was standardized at 13%, on wet basis. Grain humidity was obtained by the indirect, non-destructive, electrical method, using a portable humidity meter (G800 – Gehaka®), which provides direct readings on a digital display. After threshing the corn ears collected in the evaluation areas of the plots, HGW was measured. A subsample of a hundred grains was randomly collected in each plot, weighed on a precision scale (0.01 g) and subjected to water content determination, allowing the estimation of corrected HGW.

The results were subjected to analysis of variance and, when significant effects were observed, the means were subjected to regression analysis as a function of the tested coefficients of variation. Significance levels of 0.05 and/or 0.01 were adopted.

Results and Discussion

There was no significant effect of the interaction between Corn hybrids x Coefficient of variation on the evaluated crop characteristics (Table 1). However, the treatments showed isolated effects: the variables SD, EL, NRE, NKR, HGW and GY were affected by the coefficients of variation and only HGW was influenced by corn hybrids. The hybrid 30F53HX showed higher HGW compared with P3646HX (Table 1). The effects of non-uniform spatial distribution of seeds along the planting row were explained by simple linear models for the variables SD, EL, NRE, NKR, HGW and GY (Table 2).

Table 1. Stalk diameter (SD), ear length (EL), number of rows per ear (NRE), number of kernels per row (NKR), hundred-grain weight (HGW) and grain yield (GY) of two corn hybrids subjected to increasing levels of non-uniformity in the spatial distribution of seeds along the planting row

Treatments	Mean squares					
	SD	EL	NRE	NKR	HGW	GY
Hybrids (H)	0.88^{ns}	0.02^{ns}	2.53^{ns}	0.37^{ns}	7.13^{*}	0.41^{ns}
Non-uniformity (CV)	23.68^{**}	1.77^{**}	14.47^{**}	4.63^{**}	15.33^{**}	20.22^{**}
H x CV	0.78^{ns}	0.10^{ns}	1.25^{ns}	0.70^{ns}	0.45^{ns}	0.13^{ns}
Hybrids	(mm)	(cm)	(n°)		(g)	(kg ha^{-1})
30F53HX	19.84	15.79	16.95	34.40	35.39 a[1/]	10,541.00
P3646HX	20.19	15.96	16.24	32.72	34.14 b	10,395.00
Non-uniformity CV (%)						
0	22.74	16.27	16.81	33.92	37.27	11,762.50
20	21.29	16.16	16.35	33.28	36.33	11,332.50
40	19.75	16.01	16.07	32.86	34.22	10,465.00
60	18.78	15.91	15.85	32.11	33.84	9,840.00
80	17.52	15.33	15.70	30.63	32.14	8,940.00
CV %	5.96	4.84	2.03	5.10	4.25	6.62

^{ns}Not significant ($p \geq 0.05$), **Significant at 0.01 probability level ($p < 0.01$), *Significant at 0.05 probability level ($0.01 \leq p < 0.05$); [1/]Means followed by different letters in the columns differ at 0.05 probability level by the ANOVA F test

Table 2. Adjusted equations and determination coefficients of the evaluated variables as a function of non-uniformity in the spatial distribution of corn seeds along the planting row

Variables	Adjusted equations	Determination coefficients
Stalk diameter (SD)	SD = 22.606 -0.0648CV	$r^2 = 0.994^{**}$
Ear length (EL)	EL = 16.362 -0.0106CV	$r^2 = 0.848^{**}$
Number of rows per ear (NRE)	NRE = 16.70 -0.0136CV	$r^2 = 0.955^{**}$
Number of kernels per row (NKR)	NKR = 34.11 -0.0388CV	$r^2 = 0.941^{**}$
Hundred-grain weight (HGW)	HGW = 37.31 -0.0638CV	$r^2 = 0.969^{**}$
Grain yield (GY)	GY = 11.896 -35.688CV	$r^2 = 0.989^{**}$

**Significant with $p \leq 0.01$

The adjusted equation of SD showed that, as CV increased, plants produced thinner stalks compared with uniformly distributed plants (CV 0%), in the proportion of 0.065 mm per unit variation (Table 2). Plants equidistantly spaced have higher efficiency of assimilation of the productive resources (water, light and nutrients), since the intraspecific competition becomes minimal. Conversely, in irregularly spaced crop systems, certain individuals stand out over the others in the same population and, consequently, the frequency of plants dominated by the higher intensity of intraspecific competition tends to increase, hampering the agronomic performance of the crop (Sangoi et al., 2012). Stalk diameter is important in the mechanical harvest, avoiding plant breaking and lodging due to thinner stalks (Kappes et al., 2011).

For ear length, each unit variation in seed distribution along the row promoted a reduction of 0.011 cm (Table 2), which is probably related to the reduction in SD, since plants with thinner stalks have lower reserve capacity and, as a result, the transport of nutrients to the ears is hampered (Soratto et al., 2010). In addition, EL is defined at an early stage, when corn plants have twelve fully expanded leaves (V12). Thus, according to Fancelli & Dourado Neto (2004), any adversity that occurs in this stage, as a combined effect of the intraspecific competition, can result in EL reduction, causing a consequent decrease in grain yield.

As observed for EL, NRE showed reduction of 0.014 per unit variation in seed distribution along the row (Table 2). The linear reduction of this characteristic as a function of the non-uniformity of seed distribution is due to the disarrangement of plants, in which the increase in the frequency of gaps and doubles along the planting row intensified the intraspecific competition, triggering the formation of smaller ears with lower number of rows (Calonego et al., 2011). Likewise, NKR was negatively influenced (NKR = 34.11 – 0.0388*CV) by the increase in the variability of seed distribution along the planting row (Table 2). This result is associated with the ear length (EL), which, due to the intraspecific competition established in the beginning of the vegetative stage, resulted in lower values for these variables.

Unlike the other production components, HGW is the last one to be defined and is determined by the duration of the effective period of filling and growth rate of grains (Wang et al., 1999). According to the adjusted equation HGW = 37.31 – 0.0638*CV (Table 2), irregular plant distribution along the row intensified the competition between corn plants in such a way that the environmental resources became limiting for the crop and the stress conditions induced by the intraspecific competition altered the rates and the duration of the grain-filling period, resulting in lighter grains, approximately 0.064 g (hundred grains) per unit variation, thus hampering the final crop yield. It should be pointed out that plants subjected to the highest levels of spatial non-uniformity showed the lowest values of yield components and that the adjusted linear models showed irreversible damages on plants. Therefore, it is not sufficient to establish the desired population; the spacing between plants in the row becomes essential to obtain high grain yields (Sangoi et al., 2011; 2012).

The decrease in grain yield occurred linearly at the intensity of 35.69 kg ha^{-1} per unit variation in seed distribution along the planting row (Table 2, Figure 3). Thus, there were decreases of 2,822.50, 1,922.50, 1,297.50 and 430.00 kg ha^{-1} of grains for the CV values of 80, 60, 40 and 20%, respectively (Figure 3). The highest yields observed in more uniform, or with minimum variation, sowings resulted from the better use of solar radiation interception and acquisition of resources like water and soil nutrients, as well as from the decrease in the competition between plants along the row (Argenta et al., 2001). These results agree with those reported by Nielsen (2004) and Doerge et al. (2004) in the United States, who observed decreases in corn grain yield caused by the increase in non-uniformity of spatial distribution of plants along the row.

Likewise, Sangoi et al. (2012) evaluated five levels (0, 25, 50, 75 and 100%) of variability in plant spatial distribution along the row and two spacings between rows (0.40 and 0.80 m), in Lages-SC, and observed a decrease in grain yield with the increase in spatial non-uniformity between plants along the row, with higher reduction in the smallest spacing. However, different results were reported by Lauer & Rankin (2004) in the United States, by Liu et al. (2004) in Canada and by Rizzardi et al. (1994) in Brazil, who did not observe decreases in grain yield caused by the irregularity of plant spatial distribution.

The discrepancy in the results described in the literature referring to the real effects of non-uniform distribution of plants along the row on crop performance can be associated with the methodology adopted to simulate the spatial variability (Sangoi et al., 2012). According to Nielsen (2004), not only the methodology used, but also the existing

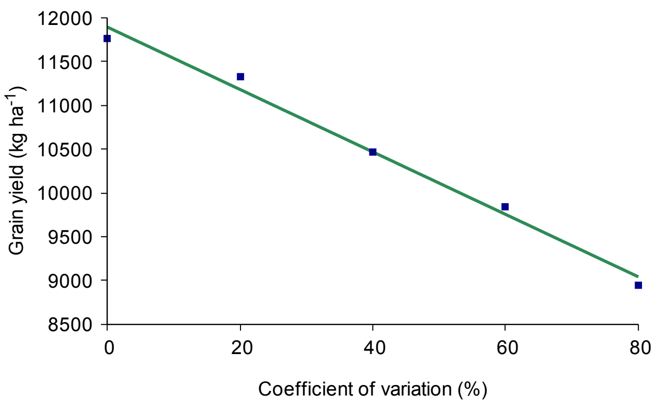

Figure 3 . Grain yield as a function of increasing levels of irregularity in the spatial distribution of corn plants along the row

differences related to climate, soil type in the corn-producing regions, spacings, plant population and the tested hybrids are factors that contribute to explaining the contrasting effects of spatial variability in the distribution of plants along the row on the agronomic performance of corn.

In the present study, for every 10% of variability measured by the CV, there were losses of approximately 282 kg ha^{-1} of grains (Table 2; Figure 2), which are substantially different from the results reported by Sangoi et al. (2012). These authors observed grain yield loss of 73.5 kg ha^{-1} in corn plants subjected to a 10% increase in the variability of plant distribution along the furrow, in a study conducted in Santa Catarina, Brazil. In studies conducted by Pioneer® in Brazil, the acceptable CV for corn was up to 25% and, for each 10%, even obtaining the desired plant population, there was a reduction in yield of approximately 128 kg ha^{-1} (Horn, 2011). Nevertheless, the yield losses observed in this study can be associated with edaphoclimatic conditions of the Cerrado, which intensified the damages caused by the irregular distribution of plants along the row, since most studies on this subject were conducted in the South region of the country.

Conclusions

1. The values of stalk diameter, ear length, number of rows per ear, number of kernels per row, hundred-grain weight and grain yield decrease with the increase in spatial non-uniformity of corn seeds along the planting row.

2. Under Cerrado conditions, loss of 282 kg ha^{-1} was observed for each 10% of variability measured by the coefficient of variation.

3. The establishment of crops with higher spatial uniformity along the planting row allows adequate occupation of the physical space, minimizing intraspecific competition between plants.

Literature Cited

Argenta, G.; Sangoi, L.; Silva, P. R. F.; Rampazzo, C.; Gracietti, L. C.; Strieder, M. L.; Forsthofer, E. L.; Suhre, E. Potencial de rendimento de grãos de milho em dois ambientes e cinco sistemas de produção. Scientia Agraria, v.4, p.27-34, 2003. http://dx.doi.org/10.5380/rsa.v4i1.1062

Argenta, G.; Silva, P. R. F.; Bortolini, C. G.; Forsthofer, E. L.; Maniabosco, E. A.; Beheregaray Neto, V. Resposta de híbridos simples à redução do espaçamento entre linhas. Pesquisa Agropecuária Brasileira, v.16, p.71-78, 2001. http://dx.doi.org/10.1590/S0100-204X2001000100009

Barbosa, C. A. Manual da cultura do milho (*Zea mays*). Viçosa; Minas Gerais: Agro Juris, 2007.123p.

Brachtvogel, E. L.; Pereira, F. R. S.; Cruz, S. C. S.; Abreu, M. L.; Bicudo, S. J. População arranjo de plantas uniforme e a competição intraespecífica em milho. Revista Trópica–Ciências Agrárias e Biológicas. v.6, p.75-80, 2012.

Brachtvogel, E. L.; Pereira, F. R. S.; Cruz, S. C. S.; Bicudo, S. J. Densidades populacionais de milho em arranjos espaciais convencional e equidistante entre plantas. Ciência Rural, v.39, p.2334-2339, 2009. http://dx.doi.org/10.1590/S0103-84782009005000193

Calonego, J. C.; Poleto, L. C.; Domingues, F. N.; Tiritan, C. S. Produtividade e crescimento de milho em diferentes arranjos de plantas. Agrarian, v.4, p.84-90, 2011.

Costa, E. J. Impactos ambientais no córrego palmital no município de Urutaí - GO. Enciclopédia Biosfera, n. 1, 2005. <http://www.conhecer.org.br/enciclop/enciclop.htm>, 7 Mai. 2013.

Doerge, T.; Hall, T.; Gradner, D. New research confirms benefits of improved plant spacing in corn. Crop insights, v.12, 2004. http://pioneer.com.usa/agronomy/corn/1202.htm. 1 Abr. 2012.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 2.ed. Brasília: Embrapa SPI; Rio de Janeiro: Embrapa Solos, 2006. 306p.

Fancelli, A. L.; Dourado Neto, D. Produção de milho, 2.ed. Piracicaba, 2004. 360p.

Horn, D. Qualidade de plantio: uma nova abordagem. Boletim Informativo da Pioneer, v.3, p.17-19, 2011.

Kappes, C.; Andrade, J. A. C.; Arf, O.; Oliveira, A. C.; Arf, M. V.; Ferreira, J. P. Desempenho de híbridos de milho em diferentes arranjos espaciais de plantas. Bragantia, v.70, p.334-343, 2011. http://dx.doi.org/10.1590/S0006-87052011000200012

Lauer, J.; Rankin, M. Corn response to within row plant spacing. Agronomy Journal, v.96, p.1464-1468, 2004. http://dx.doi.org/10.2134/agronj2004.1464

Liu, W.; Tollenaar, M.; Stewart, G.; Deen, W. Within row plant spacing does not affect corn yield. Agronomy Journal, v.96, 275-280, 2004.

Marchão, R. L.; Brasil, E. M.; Duarte, J. B.; Guimarães, C. M.; Gomes, J. A. Densidade de plantas e características agronômicas de híbridos de milho sob espaçamento reduzido entre linhas. Pesquisa Agropecuária Tropical. v.35, p.93-101, 2005

Nielsen, B. Effect of plant spacing variability on corn grain yield. 2004. <http://www. kingcorn.org./research/psv/Update 2004.html>15 Mar. 2012.

Raij, B. V.; Cantarella, H.; Quaggio, J. A.; Furlani, A. M. C. Recomendações de adubação e calagem para o Estado de São Paulo. 2.ed. Campinas: Instituto Agronômico, 1996. 285p. Boletim Técnico, 100

Ritchie, S. W.; Hanway, J. J.; Benson, G. O. How a corn plant develops. Ames, Iowa State University of Science and Technology, 1993, 26p. Special Report, 48.

Rizzardi, M. A.; Boller, W.; Dalloglio, R. Distribuição de plantas de milho, na linha de semeadura, e seus efeitos nos componentes de produção. Pesquisa Agropecuária Brasileira, v.29, p.1231-1236, 1994.

Sangoi, L. Arranjo de plantas e características agronômicas de genótipos de milho em dois níveis de fertilidade. Pesquisa Agropecuária Brasileira, v.25, p.945-953. 1990.

Sangoi, L.; Ender, M.; Guidolin, A. F. ; Almeida, M. L. ; Heberle, P. C. Influence of row spacing reduction on maize grain yield in regions with a short summer. Pesquisa Agropecuária Brasileira, v.36, p.861-869, 2001. http://dx.doi.org/10.1590/S0100-204X2001000600003

Sangoi, L.; Schmitt, A.; Vieira, J.; Picoli Jr., G. J. Souza, C. A.; Casa, R. T.; Schenatto, D. E.; Giordani, W. Boniatti, C. M.; Machado, G. C.; Horn, D. Variabilidade na distribuição espacial de plantas na linha e rendimento de grãos de milho. Revista Brasileira de Milho e Sorgo, v.11, p.268-277, 2012. http://dx.doi.org/10.18512/1980-6477/rbms.v11n3p268-277

Sangoi, L.; Schweitzer, C.; Silva, P. R. F.; Schmitt, A.; Vargas, V. P.; Casa, R. T.; Souza, C. A. Perfilhamento, área foliar e produtividade do milho sob diferentes arranjos espaciais. Pesquisa Agropecuária Brasileira, v.46, p.609-616, 2011. http://dx.doi.org/10.1590/S0100-204X2011000600006

Schimandeiro, A.; Weirich Neto, P. H.; Gimenez, L. M.; Colet, M. J.; Garbunio, P. W. Distribuição longitudinal de plantas de milho (*Zea mays* L.) na região dos Campos Gerais, Paraná. Ciência Rural, v.36, p.977-980, 2006. http://dx.doi.org/10.1590/S0103-84782006000300040

Silva, A. G.; Cunha Junior, C. G.; Assis, R. L., Imolesi, A. S. Influência da população de plantas e do espaçamento entre linhas nos caracteres agronômicos do híbrido de milho P30K75 em Rio Verde, Goiás. Bioscience Journal, v.24, p.89-96, 2008.

Soratto, R. P.; Pereira, M.; Costa, T. A. M.; Lampert, V. N. Fontes alternativas e doses de nitrogênio no milho safrinha em sucessão à soja. Revista Ciência Agronômica, v.41, p.511-518, 2010. http://dx.doi.org/10.1590/S1806-66902010000400002

Trogello, E.; Modolo, A. J.; Scarsi, M.; Silva, C. L.; Adami, P.F.; Dallacort, R. Manejos de cobertura vegetal e velocidades de operação em condições de semeadura e produtividade de milho. Revista Brasileira de Engenharia Agrícola e Ambiental. v.17, p.796-802, 2013. http://dx.doi.org/10.1590/S1415-43662013000700015

Wang, G.; Kang, M. S.; Moreno O. Genetic analyses of grain-filling rate and duration in maize. Field Crops Research, v.61, p.211-222, 1999. http://dx.doi.org/10.1016/S0378-4290(98)00163-4