Times of Trinexapac-ethyl application associated to plant densities in agronomic performance of second-season corn

Épocas de aplicação de Trinexapac-ethyl associado a densidades de plantas no desempenho agronômico do milho de segunda safra

Tiempos de aplicación de Trinexapac-ethyl asociados a densidades de plantas en el comportamiento agronómico de segundo cultivo del maíz

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Abstract
Plant growth regulators, which can alter the plant size and anatomy, allow the use of cultivars of interest that do not have a modern leaf architecture, making higher plant densities possible. The objective of this study was to evaluate the agronomic performance of second season corn, grown at different plant densities and under Trinexapac-ethyl applications at different stages of crop development. The field study was carried out in two growing seasons (2013 and 2014), at the Fazenda Escola of the State University of Londrina. Fifteen treatments were evaluated in a randomized block, 5 x 3 factorial design, at five plant densities (40,000, 60,000, 80,000, 100,000 and 120,000 plants per hectare), of Trinexapac-ethyl applied in three stages: control (no application), V6 and V9, with four replications. The morphological plant characteristics, the yield components and grain yield were evaluated. Increases in plant density raise the plant height, reduce the number of grains per ear, ear length and 100-kernel weight, and have no influence on grain yield. The application of Trinexapac-ethyl in stage V9 reduces plant and ear insertion height and 100-kernel weight.
Keywords: Zea mays L.; Growth regulator; Gibberellin inhibitor; Yield.

Resumo
Os reguladores de crescimento vegetal são uma alternativa para uso de cultivares de interesse, que não possuem arquitetura foliar moderna, podendo alterar o porte e anatomia das plantas, permitindo o aumento da densidade de

plantas. Objetivou-se avaliar o desempenho agronômico do milho de segunda safra, cultivado em diferentes densidades de plantas associado à aplicação de Trinexapac-ethyl em diferentes estádios de desenvolvimento da cultura. O estudo foi conduzido em condições de campo, em dois anos agrícolas (2013 e 2014), na Fazenda Escola da Universidade Estadual de Londrina. Foram avaliados quinze tratamentos utilizando o delineamento experimental de blocos casualizados, em esquema fatorial 5 x 3, sendo cinco densidades de plantas: 40.000, 60.000, 80.000, 100.000 e 120.000 plantas ha^{-1} e três estádios de aplicação de Trinexapac-ethyl: testemunha (sem aplicação), V6 e V9, com quatro repetições. Foram avaliadas as características fitométricas, os componentes de produção e a produtividade de grãos. Incrementos na densidade de plantas aumenta a altura de planta, reduz o número de grãos e o comprimento da espiga e a massa de 100 grãos, sem influência na produtividade de grãos. A aplicação de Trinexapac-ethyl no estádio V9 reduz a altura de planta e de inserção de espiga e a massa de 100 grãos.

Palavras-chave: Zea mays L.; Regulador de crescimento; Inibidor de giberelina; Produtividade.

Resumen

Los reguladores del crecimiento de las plantas, que pueden alterar el tamaño y la anatomía de la planta, permiten el uso de cultivares de interés que no tienen una arquitectura foliar moderna, lo que posibilita densidades de plantas más altas. El objetivo de este estudio fue evaluar el comportamiento agronómico del maíz de segunda temporada, cultivado a diferentes densidades de planta y bajo aplicaciones de Trinexapac-ethyl en diferentes etapas de desarrollo del cultivo. El estudio de campo se realizó en dos temporadas de cultivo (2013 y 2014), en la Fazenda Escola de la Universidad Estatal de Londrina. Se evaluaron quince tratamientos en bloque al azar, diseño factorial 5 x 3, a cinco densidades de plantas (40.000, 60.000, 80.000, 100.000 y 120.000 plantas por hectárea), de Trinexapac-ethyl aplicado en tres etapas: control (sin aplicación), V6 y V9, con cuatro repeticiones. Se evaluaron las características morfológicas de la planta, los componentes del rendimiento y el rendimiento de grano. Los aumentos en la densidad de la planta aumentan la altura de la planta, reducen el número de granos por mazorca, la longitud de la mazorca y el peso de 100 granos, y no influyen en el rendimiento de granos. La aplicación de Trinexapac-ethyl en la etapa V9 reduce la altura de la planta y la inserción de la mazorca y la masa de 100 granos.

Palabras clave: Zea mays L.; Regulador de crecimiento; Inhibidor de giberelina; Productividad.

1. Introduction

Changes in row spacing and plant density within the rows have been identified as one of the most influential management practices to raise grain yield in corn (Kappes et al., 2011; Silva et al., 2014). This responsiveness is associated with the fact that, in contrast to other Poaceae, the mechanism of space compensation is not efficient in corn, due to the lower ability for tillering, low prolificacy and limited leaf expansion capacity (Testa, Reyneri & Blandino, 2016).

The low plasticity of corn, each production system will have an ideal plant density to ensure maximized grain yield, which will depend on the cultivar, the objective of the producer, water availability, soil fertility, sowing season and plant spacing. However, the cultivar is the main determinant of plant density, early hybrids allow for higher densities and narrower spacing than late cultivars, for having a shorter plant height, and narrower and shorter leaves that result in a smaller leaf area and less intraspecific shading. Therefore, the plant density of these genotypes must be higher to maximize yields and provide sufficient leaf area to optimize the interception of incident solar radiation (Sangoi, Silva & Argenta, 2010; Brachtvogel et al., 2012; Testa, Reyneri & Blandino, 2016).

Studies on first and second season cultivars have investigated the optimal density of corn hybrids with high yield potential to determine the number of plants that can exploit the yield factors most efficiently (Penariol et al. 2003; Marchão et al., 2005; Takasu et al., 2014; Boiago et al., 2017). The authors reported maximum yields at densities of ≥ 80,000 ha-1 plants. This shows that the recommendation of a density between 65,000 and 80,000 ha-1 plants can be extended in favorable environments to increase grain yield, provided the soil fertility and water availability are optimal and the cultivars resistant to lodging (Sangoi, Silva & Argenta, 2010).

A higher plant density coupled with the application of high rates of nitrogen fertilizers induces increases in grain yield, greater plant height and decreases stem diameter, consequently, the plants become prone to lodging, and stem breaking (Lana et al., 2014; Silva et al., 2014). According to Brachtvogel et al. (2012) the size of corn plants should preferably be medium to low, in order to obtain greater efficiency in mechanical harvesting, avoid problems of lodging, this fact hampers mechanical harvesting, leading to losses in yield and quality of the harvested product. For second season corn, for which the

water availability is lower and problems with lodging and stem breaking are greater, shorter cultivars and a reduced sowing density are recommended, resulting in a lower plant density than in first season corn (Faria et al., 2019).

The use of plant growth regulators, which can alter plant size and anatomy, allows for cultivars that do not have modern leaf architecture, making higher plant densities, shorter interrow spacing and the application of high nitrogen rates possible. The growth regulator Trinexapac-ethyl (TE) reduces the cells of the internode elongation, interfering with the biosynthesis of gibberellic acid at the end of the metabolic route, causing a decline in plant growth and a partial inhibition of electron transport in the mitochondria, reducing cellular respiration (Rademacher, 2015) and plant growth (Mendes Fagherazzi et al., 2018).

In Wheat, the Trinexapac-ethyl (TE) proved effective in limiting stem length, reducing plant height and avoiding lodging, aside from increasing grain yield due to changes in grain yield components (Matysiak, 2006; Zagonel & Fernandes, 2007). In corn, the Trinexapac-ethyl answers vary due to weather conditions, cultivar, dose and time of application (Zagonel & Ferreira, 2013; Pricinotto et al., 2015; Leolato et al., 2017; Mendes Fagherazzi et al., 2017).

Thus, Trinexapac-ethyl application to mainly winter cereals is being investigated, associated with the management of plant density, to study the response of genotypes to these practices, as well as the determination of the best application times of the growth regulator without damaging the crop, during the phases of vegetative crop development. In view of the scarcity of studies on corn, the objective of this study was to evaluate the agronomic performance of second season corn, grown at different plant densities and under Trinexapac-ethyl applications at different stages of crop development.

2. Methodology

The experiments were carried out under field conditions at Fazenda Escola da Universidade Estadual de Londrina (UEL), in the city of Londrina, PR, Brazil. The experimental structure was quantitative in nature and applied statistical methods for the evaluation of the collected data (Pereira et al., 2018). It was in the second season corn preceded by soybean, in a no-tillage system with sowing (on March 6 in both years) on mulch. The meteorological data of the study period were obtained from the Meteorological Station of the Agronomic Institute of Paraná (Figure 1).

The single-cross corn hybrid cultivar Status Viptera was used, indicated for the first and second seasons in the South, Southeast and Central-West regions of Brazil. The cultivar was chosen based on Pricinotto et al. (2015), who observed a positive response to Trinexapac-ethyl application in the insect-resistant transgenic corn cultivar Status TL (Lepidoptera).

The experiments were carried out on soil classified as Dystrophic Red Latosol (Oxisol) (Embrapa, 2006). Soil samples for chemical analysis were collected from the 0-20 cm layer of the experimental area, according to the methodology of Raij et al. (2001). Prior to sowing, the experimental area was desiccated with 3.0 L per hectare glyphosate (0,48 g e.a. ha^{-1}) with a volume of 200 L per hectare solution. Sowing fertilization (N-P-K) was applied, based on the results of soil chemical analysis (Table 1), and on the official recommendations for the region (Iapar, 2003). For the experiment in 2013, sowing fertilization was 250 kg per hectare of the N-P-K fertilizer 08-20-10 and in 2014, 312 kg per hectare of the N-P-K fertilizer 08-28-16.

A randomized complete block, 5 x 3 factorial design was used, at five plant densities (40,000, 60,000, 80,000, 100,000 and 120,000 plants per hectare), combined with three application seasons of Trinexapac-ethyl (control without TE application, in V6 and in V9), with four replications. The plots consisted of six 5-m rows, spaced 0.45 m apart. Disregarding the lateral rows and 0.5 m from the ends of the rows, the plot area was defined by the central rows. The application seasons of Trinexapac-ethyl were based on the phenological growth stages described by Ritchie et al. (2003).

Figure 1. Daily maximum and minimum temperatures and rainfall during the cultivation period of second season corn in 2013 (A) and 2014 (B), Londrina, PR, Brazil.
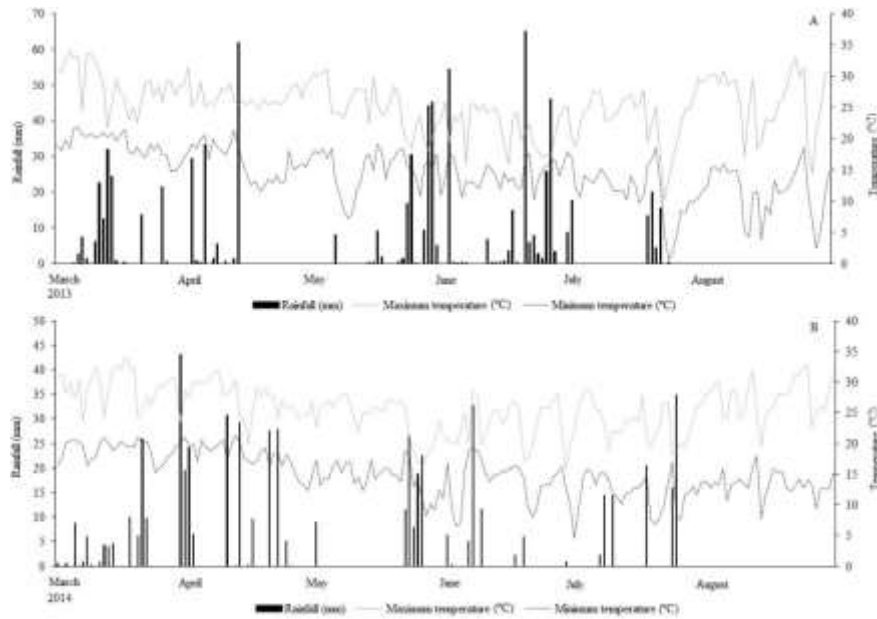
Source: Authors.

Sowing was performed mechanically according to the defined plant densities, and manual thinning was carried out in the vegetative development stage V3 (Ritchie et al., 2003). The plant growth regulator was applied to the leaves with a hand-pump backpack sprayer (CO_2) under pressure at a volume of 150L per hectare and a concentration of 1L per hectare (250 g i.a. ha^{-1} TE, Moddus®), as proposed by Pricinotto et al. (2015). The applications were performed according to the treatments, based on the number of fully expanded leaves and the scale of Ritchie et al. (2003), whereas the applications in the control treatment consisted of water only.

Table 1. Chemical characterization of the soil of the experimental area in the 0-20 cm layer, 2013 and 2014, Londrina, PR, Brazil.

Year	Ph	H+Al	Ca^{2+}	Mg^{2+}	K$^+$	SB	CTC	Al^{+3}	V	P
	CaCl$_2$	-------------------------- cmolc dm^{-3}------------------------							%	mg dm^{-3}
2013	5.49	3.66	4.91	1.37	0.57	6.85	6.86	0.00	65.21	8.08
2014	4.70	2.67	5.45	1.40	0.99	7.84	10.56	0.05	74.24	15.24

*Extractors: Ca, Mg, Al: KCl 1mol L^{-1}; P, K: Mehlich^{-1}; H+Al: SMP method. Source: Authors.

During crop development, the experimental area was monitored for pests, diseases and weeds. In 2013, fall armyworm (*Spodoptera frugiperda*) was controlled in the crop development stage V3 with Teflubenzuron, at a rate of 200 mL per hectare (150 g e.a. L^{-1}) in a solution volume of 150L per hectare. Foliar diseases were controlled by fungicide applications of the fungicide Azoxystrobin in stage V6, at a rate of 250 mL per hectare. In 2014, about 50 days after sowing, Teflubenzuron was applied to control fall armyworm (*Spodoptera frugiperda*), at 100 mL per hectare (150 g e.a. L^{-1}) in a volume of 100L per hectare solution. Gray leaf spot of corn was controlled with Azoxystrobin (200 g e.a. L^{-1}) and Ciproconazole (80 g e.a. L^{-1}), at 300 mL per hectare of the commercial product in a solution volume of 100L ha^{-1}.

Nitrogen sidedressing was applied in both years, when the plants had six expanded leaves, in stage V6, 31 days after sowing. Using urea (45% N) as source in all treatments, 150 kg per hectare N was broadcast on the crops. Corn was harvested

by hand in stage R6, when the grains had a mean water content of 200 g kg^{-1} grains in the plot area.

The phytometric characteristics, yield components and grain yield were evaluated. The phytometric characteristics were determined in 10 random plants of the evaluated area of each plot, computing the mean data in meters, measured with a ruler, beginning at full flowering of the crop: plant height: distance from the plant collar to the point of flag leaf insertion and ear insertion height: distance from the plant base to the insertion height of the first ear.

For the evaluation of the yield components, 10 ears were randomly harvested from the evaluated area of each plot, to determine: number of grains per ear: counting of the number of rows of grains and number of grains in the longest row, averaged in both evaluations; by multiplying these variables, the mean number of grains per ear was calculated; ear length: distance between the first and the last grain of the longest row on the unhusked ear, mean value in cm; 100-kernel weight: after threshing of the ears of each assessed plot, and afterwards, two replications of 100 grains were separated, weighed on a digital scale, and the mean weight (g) calculated.

The grain water content was determined by a digital capacitance meter, with a G-600 (Gehaka) apparatus, adjusted and calibrated for corn. The grain yield was obtained by threshing and weighing the harvested grains of the evaluated area in in the plot. The data were transformed into kg per hectare, correcting the mean water content to 130 g water kg^{-1} grain (13%).

The data were tested for homoskedasticity (Bartlett's test) and the normality of errors (Lilliefors). With homogeneous variances and normal errors, analysis of variance was performed without data transformation, at an F-probability level of 5%. The effect of plant density was evaluated by means of polynomial regression analysis, and the effect of times ($p < 0.05$) of Trinexapac-ethyl application by the Tukey test. Statistical analyses were performed using the statistical program Sisvar (Ferreira, 2010).

3. Results and Discussion

A significant effect of the time of Trinexapac-ethyl (TE) application on plant height and corn ear insertion height was observed in the second season of 2013. The factor plant density altered plant height only in 2014. There was no effect of interaction between the studied factors for plant and ear insertion height in either year of cultivation (Table 2).

In the growing season 2013, plant height was not influenced by plant density, with a mean of 2.00 m (Figure 2A), but was reduced by TE application in stage V9 (Table 2). Ear insertion height followed the same pattern as plant height, being uninfluenced by plant density, with a mean of 1.14 m (Figure 2C). In addition, TE application in V9 also reduced ear length in relation to the control treatment, indicating a correlation between these characteristics.

In an evaluation of the same hybrid Status Viptera, Pricinotto et al. (2015) reported satisfactory results of reduction in corn plant and ear insertion height in a greenhouse, under increasing Trinexapac-ethyl rates (0, 125, 250 and 375 g e.a. ha^{-1}), applied in stage V6. Likewise, Mendes Fagherazzi et al. (2018) analyzed the sequential applications of Trinexapac-ethyl in different phenological stages for two corn varieties grew in a greenhouse. The sequential applications of 100 g e.a. ha^{-1} TE among stages V2 to V7 were effective at reducing plant height and ear insertion height in both corn genotypes by 45% of final height, it indicated the corn plants were highly sensitive to Trinexapac-ethyl applications after the V6 stage.

Table 2. Summary of the analysis of variance for plant height (PH) and ear insertion height (EH) as a function of plant densities and stages (S) of Trinexapac-ethyl application to second season corn, Londrina. PR, Brazil.

Source of Variation		Phytometric characteristics			
		PH (m)		EH (m)	
Stage		2013	2014	2013	2014
Control		2.08 a	2.22	1.19 a	1.30
V6		2.04 a	2.26	1.16 ab	1.28
V9		1.87 b	2.24	1.06 b	1.28
	DF	Mean square			
Block	3	0.06534	0.2207	0.00530	0.0787
Plant Density (PD)	4	0.01247^{ns}	0.0829^{*}	0.05203^{ns}	0.0043^{ns}
Stage (S)	2	0.25904^{*}	0.0080^{ns}	0.09397^{*}	0.0022^{ns}
PD x S	8	0.02256^{ns}	0.0100^{ns}	0.03686^{ns}	0.0053^{ns}
C.V. (%)		5.27	3.79	12.92	6.99

ns = not significant by the F test; * significant $p < 0.05$ by the F test. Means followed by the same letter in the column do not differ from each other, at 5% probability, by the Tukey test. Source: Authors.

However, Zagonel & Ferreira (2013) observed no changes in plant and ear insertion height at TE rates of 0.0; 187.5; 375.0 and 562.5 g e.a ha^{-1}, regardless of the application time, in the stages V2, V4, V6 and V8. This divergence between the above authors' results and those of this study in relation to plant height in response to Trinexapac-ethyl and the application time may be related to variations in management and environmental conditions between the experiments.

Figure 2. Plant height and ear insertion height of corn plants in the second season in 2013 (A and C) and in 2014 (B and D), in response to plant density, Londrina, PR, Brazil. * p <0.05
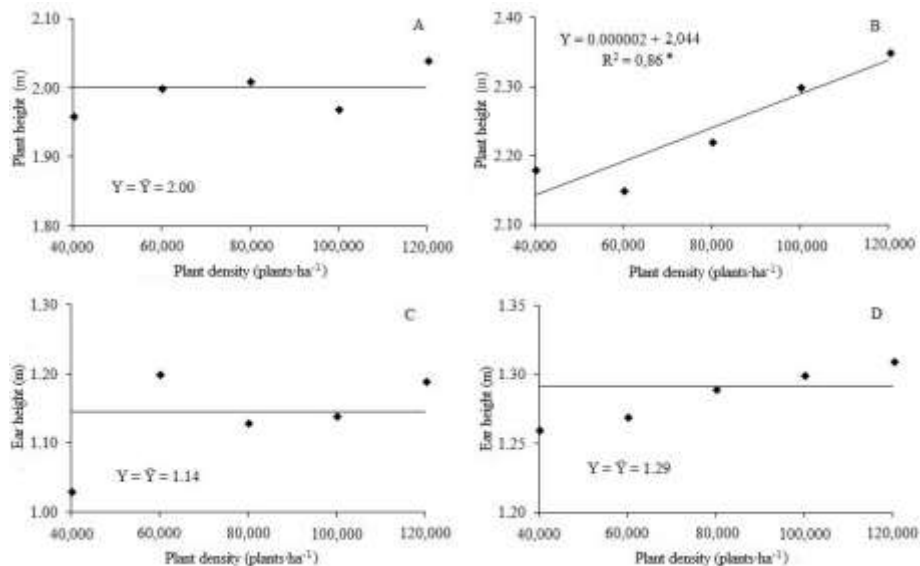
Source: Authors.

As observed in the second season of 2013, in the plants treated with the growth regulator in stage V9, cell division and elongation were significantly reduced in this period considered most relevant for stem elongation increase (Ritchie et al., 2003), resulting in more compact plants with shorter ear length. Trinexapac-ethyl application is a management tool for height reduction of tall hybrids, because plant height is the main characteristic a growth regulator must alter in the plants, by reducing

the elongation of internode cells, interfering with the biosynthesis of gibberellic acid at the end of the metabolic route (Rademacher, 2015).

The size of corn plants should preferably be medium to low, in order to obtain greater efficiency in mechanical harvesting and avoid problems of lodging, and breaking stems. Generally, small plants tolerate larger plant populations, maintaining the uniformity of the ears (Brachtvogel et al., 2012). According to Sangoi et al. (2001), a shorter plant height and lower ear insertion height brings the center of gravity of the plants closer to the soil, reducing the tendency to lodging of the crop. Also, shorter plants are less prone to intraspecific competition for the environmental resources due to the altered leaf architecture, favoring the use of light interception, allowing the use of new population arrangements, with increases in plant density, which can provide greater grain yield.

In 2014, a linear adjustment in plant height was observed as a function of the increase in plant density (Figure 2B), without influence of TE application time. Freitas et al. (2013) also observed increases in plant height at densities increased up to 80,000 plants ha^{-1} in second season cultivation. Likewise, Silva et al. (2014) described increases in plant height and ear insertion height at densities from 40,000 to 80,000 plants ha^{-1}.

However, ear insertion height (in the mean 1.29 m) did not influence plant density (Figure 2D), and was not influenced by TE application times. The differentiated pattern of phytometric characteristics in the study period was possibly associated to an interaction between genotype, environment and crop management. The ideal plant density depends on the cultivar, water availability, soil fertility, sowing time and plant spacing (Sangoi, Silva & Argenta, 2010), and these factors may explain the variation in response of these characteristics in the growing seasons, as shown in this study.

The linear increase in plant height observed in the second season of 2014 as a function of higher plant density is explained by Sangoi et al. (2002), in that a greater intraspecific competition of plants for light causes a greater development and stem elongation towards the light in the upper part of the canopy, varying according to the environment and planted genotype.

For the variables number of grains and ear length, the factor plant density was significant in both growing seasons, without effect of application times and interactions among the factors studied. The 100-kernel weight was altered by plant density and TE application times in both years. Grain yield was not significantly altered in 2013 by the studied factors. In 2014, it was only significant for the period of TE application, without effect of plant density and interaction between these factors (Table 3).

The increase in plant density reduced the variables number of kernels per ear and ear length of corn plants for both growing seasons (Figure 3). These results confirm those of Marchão et al. (2005), who observed a reduction in ear length and number of kernels per row with the increase in corn plant density. These authors further stated that plant density seems to exert a greater influence on increasing female sterility, thus reducing the number of kernels per ear. In second-season crops, Penariol et al. (2003) observed a reduction in the number of kernels per ear at densities from 40,000 to 80,000 ha^{-1} plants. Likewise, Kappes et al. (2011) and Silva et al. (2014) reported a progressive reduction in ear length as a function of increases in plant density.

According to Sangoi (2001), the competition among plants for incident solar radiation, nutrients and water determines the formation of corn ears, especially under reduced spacing, which may imply in carbon and nitrogen deficiency for the plants. Consequently, there may be an increase in plant sterility and a decrease in the number of grains per ear as well as grain weight, due to the reduction in grain development in the upper part of the ear, which does often not develop, even if fertilization of the ovules occurred.

Table 3. Summary of variance analysis of number of grains per ear (NGE), ear length (EL), 100-kernel weight (W100G) and grain yield (GY) as a function of plant densities and stages (S) of Trinexapac-ethyl application to second season corn, Londrina, PR, Brazil.

Source of variation		NGE		EL		W100G		GY	
Stage		2013	2014	2013	2014	2013	2014	2013	2014
Control		495.04	434.33	14.75	12.60	29.16 a	15.36 a	4058.71	3984.79 b
V6		475.97	460.93	14.06	12.86	27.82 ab	15.95 a	4226.87	4611.28 a
V9		499.35	433.66	14.61	12.36	26.72 b	13.53 b	4285.32	3941.76 b
	DF								
Block	3	610.5	692.2	0.72	0.20	4.21	5.75	264955.7	85799.6
Plant Density (PD)	4	26428.8*	26487.9*	18.71*	14.81*	65.53*	9.50*	761635.8ns	951756.9ns
Stage (S)	2	3095.4ns	4838.3ns	2.59ns	1.21ns	29.83*	31.78*	276825.2ns	2808619.6*
PD x S	8	1114.4ns	1132.8ns	1.13ns	0.52ns	12.28ns	1.65ns	476121.4ns	687265.2ns
C.V. (%)		7.67	10.32	7.75	7.12	10.8	13.36	18.52	17.4

ns = not significant by the F test; * significant at p <0.05 by the F test. Means followed by the same letter in a column do not differ from each other, at 5% probability, by the Tukey test. Source: Authors.

Figure 3. Number of kernels per ear and ear length of corn plants in the second growing season of 2013 (A and C) and 2014 (B and D), in response to plant density, Londrina, PR, Brazil. * p<0.05
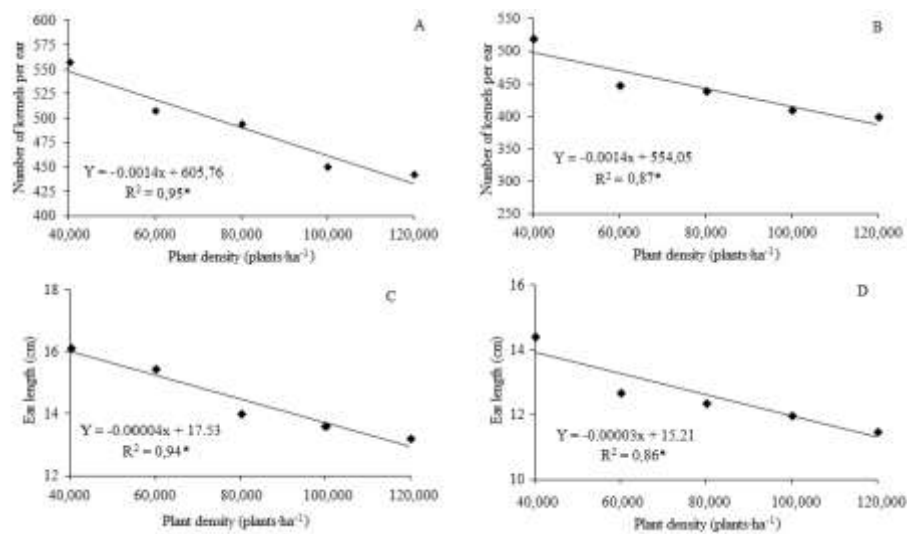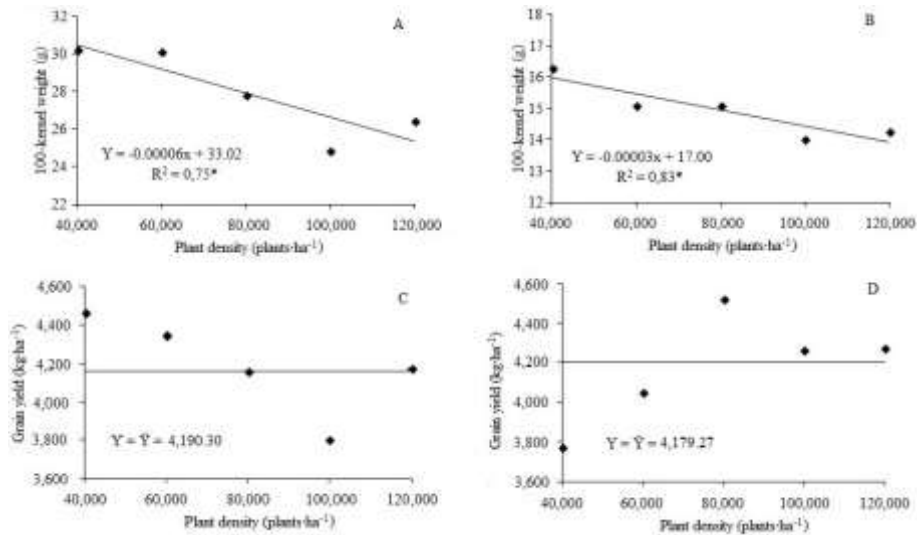

Source: Authors.

According to Penariol et al. (2003), the competition of plants for yield factors is even greater in the second season, due to the less favorable weather conditions, with lower incident radiation and temperatures, as well as reduced rainfall and irregular rain distribution throughout the crop cycle. Under these conditions, it is recommended to adopt a plant population of 10 to 20% less than in the main cropping season, of about 60,000 plants ha^{-1}. In this study, densities higher than those indicated for the second season were studied and, according to Sangoi (2001), excessive densification increases intraspecific competition by photoassimilates, mainly at the flowering stage of the crop, which stimulates apical dominance, increases female sterility and limits grain yield per area.

The 100-kernel weight was linearly reduced according to the increases in plant density in both evaluation years (Figure 4), as also observed by Pereira et al. (2008), Farinelli, Penariol and Fornasieri FIlho, (2012) and Testa, Reyneri and Blandino, (2016). According to Sangoi (2001), this reduction is possibly associated with increased intraspecific competition for water, nutrients and light.

Figure 4. 100-kernel weight and grain yield in the second growing season of 2013 (A and C) and 2014 (B and D), in response to plant density, Londrina, PR, Brazil. * $p<0.05$

Source: Authors.

There was a reduction in 100-kernel weight after TE application in V9, differing from the control without TE application in 2013 and the other treatments in 2014 (Table 3). Zagonel & Ferreira (2013) reported no significant effect of Trinexapac-ethyl in the stages V2, V4, V6 and V8 on hybrid Status TL and Maximus TLTG on 1000 kernels weight. However, Pricinotto et al. (2015) observed a reduction in 100-kernel weight for cultivar Status Viptera, with increasing rates of Trinexapac-ethyl applied in V6. The reduction in plant height and possibly leaf area, caused by Trinexapac-ethyl may be related to a reduction in the quantity of photoassimilates designated for grain filling, resulting in a lower grain weight.

Grain yield was not influenced by plant densities (Figure 4 C and D). According to the meteorological data (Figure 1), it is likely that the low water availability after 40 days after sowing in 2013, during plant development including important phases of definition of yield components such as number of grains per row, as well as the drought mainly in the period prior to flowering in 2014, may be affected the grain yield and response to the studied factors.

Water and/or nutritional deficiencies after V12 stage can lead to a serious reduction in the potential number of grains and ear size. Moreover, the period between two weeks before and two weeks after flowering, between stages V15 and R2, constitutes the most critical phase of the crop cycle, when environmental stresses cause a marked reduction in grain yield (Ritchie et al., 2003). Possibly, these limitations prevented the expression of the genetic potential of the cultivar, with low response of the crop to the increments in plant density, and can be explained by sowing close to the time limit recommended for the region. According to Cardoso et al. (2004), the risks for the establishment of second season corn increase with the delay of sowing after February, with decreases in yields of up to 38% of the potential yield and 44% of the yield under water stress according to the delay in sowing, due to the coincidence of critical periods of development with suboptimal conditions of solar radiation, temperature and water availability.

In view of these limitations, the average yield was 4190.80 kg per hectare and 4179.27 kg per hectare in the growing seasons of 2013 and 2014 (Figure 4 C and D), respectively. In 2014, the TE application in stage V6 increased grain yield (Table 3), with no significant effects in 2013. The absence of response to TE application in the growing season of 2013 corroborates observations of Zagonel & Ferreira (2013) for first season corn, of the same hybrid Status, but with TL technology and hybrid Maximus TLTG, who found no change in grain yield after TE applications (0.0; 187.5; 375.0 and 562.5 g e.a. ha^{-1}), regardless of the application time, in stages V2, V4, V6 and V8. The difference in response in grain yield to TE application in the years of study was possibly due to the interaction between the studied factors and the soil and climatic factors influencing each crop.

It was expected that plant height reduction by TE would allow maximum yield response to higher population densities. However, this interaction seems to be more likely for early corn or early sowing of second season corn, when there is greater availability of yield factors that allow an increase in plant density. The favorable conditions of water, radiation and temperature favor more intensive growth and plant development with greater plant competition in the row. Under these conditions, TE can induce more compact plants, with a more adequate architecture to exploit the resources of the environment, with less intraspecific competition, which allows for a higher plant density and reduced row spacing, favoring grain yield.

In the literature, several studies addressed the ideal density of corn hybrids with high grain yield potential, to identify the number of plants at which the yield factors in the main season (Marchão et al., 2005; Kappes et al., 2011; Testa, Reyneri & Blandino, 2016) and the second season (Penariol et al., 2003; Freitas et al., 2013; Takasu et al., 2014) can be exploited most efficiently. The authors reported that maximum yields were obtained with increases in plant density of $\geq$ 80,000 ha^{-1} corn plants. These results show that the recommendation for a density of 60,000 to 80,000 ha^{-1} plants can be extended in favorable environments to increase grain yield, provided the soil fertility and water availability are good and the cultivar is lodging-resistant (Sangoi, Silva & Argenta, 2010).

Thus, to ensure that a higher plant density associated with reduced spacing will increase the yield potential of corn, favorable meteorological conditions are indispensable, such as water availability, soil fertility and a region-specific cultivar, to potentiate the expression of the adopted genotype, translating into higher grain yield at harvest. In this regard, the late sowing period resulted in unfavorable meteorological conditions in this study, limiting the expression of the genetic potential of the plant material, impairing the grain yield and even the possible interaction between the studied factors, times of Trinexapac-ethyl application and increases in plant density.

New studies under more favorable weather conditions are needed to find concrete results that can explain the pattern of Trinexapac-ethyl application associated with increment of plants per area in the second season corn crop. That association makes possible the increase of plant density, adoption of reduced spacing and the application of high N rates, minimizing the risks of lodging by the application of the growth regulator, allowing a higher plant density, with a view to increase grain yield per area.

4. Conclusion

Increases in plant density raise the plant height, reduce the number of grains per ear, ear length and 100-kernel weight, and have no influence on grain yield.

The application of Trinexapac-ethyl in stage V9 reduces plant and ear insertion height and 100-kernel weight.

New studies may be conducted for further clarification of Trinexapac-ethyl action in corn second season associating higher plant density, reduced spacing and the application of high N rates.

Acknowledgments

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