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Trinexapac-ethyl in the vegetative and reproductive performance of corn

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This study aimed to measure the effects of rates of plant growth regulator trinexapac-ethyl on the development of the aerial, root parts and yield components of corn. The experiments were conducted in a greenhouse: one assay was aimed at evaluating the growth and development of the plant, in a 4 x 4 factorial arrangement, with four rates of trinexapac-ethyl (0, 125, 250 and 375 g of i.a. ha^{-1}) and four assessment periods (14, 21, 28 and 35 days after application), and the other was aimed at assessing the yield productions for corn in response to the same four rates of the regulator. The present study demonstrates that grain yield per plant was reduced with the use of trinexapac-ethyl, due to decrease in spike length, number of kernels in each row and hundred grain mass. The use of trinexapac-ethyl does not change the cycle of corn, but increases stem diameter and chlorophyll index, and reduces the plant height and spike insertion height, leaf area, dry mass of aerial part, dry mass and volume root system. The trinexapac-ethyl changes the size of the corn plants, enabling new spatial arrangements.

Key words: Leaf architecture, yield components, plant growth, plant growth regulator, *Zea mays* L.

INTRODUCTION

Corn (*Zea mays* L.) is considered one of the world's most important crops worldwide, due to several factors, particularly the nutritional characteristics of the grain that ensure large-scale consumption (Fancelli and Dourado Neto, 2004).

Modern management techniques have provided increased grain yield in corn crop, where it is possible to explore the crop production capacity by developing techniques that ensure the maximum utilization of resources (Zagonel and Ferreira, 2013). Sangoi et al. (2007) claim that corn is one of the most efficient species at converting radiant energy into biomass. Thus, taking full advantage of solar radiation is a strategy to increase the productivity of the crop.

To ensure an optimal use of solar radiation, the adoption of high densities of plants is required, as well as reduction in spacing between lines to be able to quickly capture solar radiation and retain it for a long period.

Higher plant densities are not usually used due to the tendency of the culture of lodging and self-shading of

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plants. The use of corn cultivars with lower plants, having smaller and more erect leaves may minimize the problem. However, cultivars with these characteristics are not always available or are not adapted to a given region, which requires the adoption of alternative methods such as the use of plant growth regulators.

Plant growth regulators act on plant physiology to change characteristics of leaf architecture and reduce the height of stem in order to facilitate crop treatments, reduce propensity to lodging, maximize solar radiation absorption and thus, increase yield (Zagonel and Fernandes, 2007; Zagonel and Ferreira, 2013).

In wheat crop, the use of the plant growth regulator trinexapac-ethyl, besides reducing the height and plant lodging, may change the foliar architecture, allowing greater solar radiation use and increased productivity (Matysiak, 2006; Zagonel and Fernandes, 2007; Penckowski et al., 2009). Increases in grain yield due to changes in plant height and morphology were also observed with the use of trinexapac-ethyl (TE) in upland rice (Nascimento et al., 2009; Arf et al., 2012).

Several species of grasses showed an increase in chlorophyll content, higher photosynthetic activity with the use of TE, becoming more tolerant to shading (Fan et al., 2009; Wang et al., 2009; Costa et al., 2010).

In corn crop, TE has been used experimentally, but the results may vary depending on the climate, hybrid variety, rate and time of application (Zagonel and Ferreira, 2013), as well as on the management practices.

In order to obtain more information on corn response to the use of this plant growth regulator, the present study evaluated the impact of different rates of TE on the growth and development of aerial and root parts and yield components of corn in greenhouse.

MATERIALS AND METHODS

Implementation and execution of the experiments

The study was conducted in a greenhouse with soil collected in an area under no-tillage upon straw. The soil was classified as Oxisol (EMBRAPA, 2006), where chemical analysis of 0 - 20 cm layer was performed prior to the experiment, and the following characteristics were observed: pH_{CaCl2} = 5.3, P = 12.93 mg dm^{-3}, K^+= 0.77 $cmol_c$ dm^{-3}, Ca^{2+} = 7.2 $cmol_c$ dm^{-3}, Mg^{2+} = 2.1 $cmol_c$ dm^{-3}, Al^{3+} = 0.00 $cmol_c$ dm^{-3}, H^++Al^{3+} = 4.96 $cmol_c$ dm^{-3}, $CTC_{efetiva}$ = 15.03 $cmol_c$ dm^{-3}, base saturation (V) = 67%. Based on the results of soil analysis, the seeding fertilization levels with the equivalent to 350 Kg ha^{-1} of the formulated 08-28-16 (N-P-K) was defined.

The experimental plots were formed using 25 kg capacity plastic containers, to which 20 kg of soil were added. In order to assess different characteristics of the plants two simultaneous experiments were mounted, both with completely randomized designs and random rotation of containers every seven days.

Experiment 1 was mounted to evaluate growth and development characteristics following the use of the plant growth regulator in a 4 x 4 factorial arrangement, with four replications: 4 rates of the plant growth regulator TE (0, 125, 250 and 375 g of i.a. ha^{-1}) and 4 assessment periods (14, 21, 28, 35 days after application of TE (DAA)), in a total of 64 experimental units. Experiment 2 was mounted with 4 rates of the plant growth regulator TE (0, 125, 250 and 375 g of i.a. ha^{-1}), and 4 replicates to evaluate the yield components.

Sowing was performed on October 19, 2012, with 5 seeds per container. 10 days after seedling emergence, pruning was performed and there were only two plants per container in experiment 1, and only one plant per container in experiment 2. The cultivar used was the hybrid variety Status Viptera, of early maturity, hard orange-colored grains and high yield potential. Pest and disease control was not necessary because the hybrid variety used in the experiment is resistant to major corn pests and diseases.

At V5 growth stage, nitrogen fertilization was performed with the equivalent of 153 Kg of N ha^{-1}, followed by sprinkler irrigation to prevent volatilization. At V6 growth stage, TE was applied in both experiments using a backpack motorized sprayer with 150 L ha^{-1} volume, and the containers were removed from the greenhouse and separated into groups according to the rates applied.

Assessments

In experiment 1, the following estimations were made: plant height (taking the distance between the ground and the insertion of the last fully expanded leaf), the number of fully expanded leaves and stem diameter at the second internode above the ground, with the aid of calipers, on 14, 21, 28 and 35 DAA. Also, the chlorophyll index was measured in the middle third of the last two fully expanded leaves, with an electronic meter of type ClorofiLOG model CFL 1030.

After these assessments, the aerial part of the plants was collected to calculate the leaf area of all the leaves on the plant using Li-Cor meter, model LI-3100.

The dry mass of the aerial part and of the root system was determined by placing them at 60°C forced draft oven until a constant mass was obtained. The root volume was measured using the graduated cylinder and the water displacement method. In the assessments of experiment 1 the values were derived from the average of the two plants in each container/pot.

In experiment 2, at the end of the crop cycle, the following measurements were performed: plant height and spike insertion height; and of yield components: spike length, number of rows of kernels, number of kernels in a single row, hundred grains mass and grain yield per plant. In the last two assessments, the result expressed in grams was corrected to 130 grams of water per kilogram of grains.

Statistical analysis

In experiment 1, the data were analyzed via analysis of variance (ANOVA) followed by breakdown of the sum of squares into orthogonal polynomials of degree 2. The same occurred in experiment 2.

RESULTS AND DISCUSSION

Analysis of variance in experiment 1 showed significant interaction between TE rates and assessment periods only for variables as chlorophyll index and dry mass of aerial part (Table 1).

Except for the chlorophyll index, all other variables grew linearly over time. However, in the variable, dry mass of aerial part, after breaking down the equation, the data indicate different intensities of growth with

Table 1. Summary of analysis of variance (Mean Squares) for the variables analyzed at 14, 21, 28 and 35 days after application of trinexapac-ethyl (DAA). Londrina-PR/2013.

Causes of variation	**GL**	**Analyzed variables**							
		PLH		**SDI**		**NEL**		**LAR**	
Rate	3	3,735.2	*	7.343	*	0.375	ns	263,598	ns
DAA	3	148,454	*	29.604	*	141.375	*	121,736	*
Rate x DAA	9	68.0	ns	0.246	ns	0.361	ns	102,395	ns
Residue	48	46.5		0.559		0.197		70,828	
CV %		4		4		4		5	
Average		166.00		19.9		12.5		5,208.13	

Cause of variation	**GL**	**Analyzed variables**							
		CPI		**DMA**		**DMR**		**RSV**	
Rate	3	53.76	*	2,178.3	*	461.5	*	7,414.8	*
DAA	3	334.86	*	32,831	*	4,832	*	60,947	*
Rate x DAA	9	45.30	*	258.2	*	78.4	ns	1,302.3	ns
Residue	48	6.29		24.3		57.4		844.9	
CV %		5		7		25		22	
Average		48.1		74.88		30.48		132.32	

*- Significant at 5% probability by F test, ns – not significant by F test. PLH – plant height, SDI – stem diameter, NEL – number of expanded leaves, LAR – leaf area, CPI – chlorophyll index, DMA – dry mass of the aerial part, DMR – dry mass of root system, RSV – root system volume.

increasing rates of the plant growth regulator, which has already been observed in studies with rice (Alvarez et al., 2007) and soybean (Linzmeyer et al., 2008).

As in wheat (Espindula et al., 2011), reduction in plant height was observed in the present study with increasing rates of the plant growth regulator (Figure 1A). The reduction in plant height occurs by inhibition of cell division and elongation, because TE inhibits the enzyme 3β-hydroxylase, at the end of the biosynthesis pathway of gibberellic acid, dramatically reducing the level of active gibberellic acid (GA_1), increasing its precursor (GA_{20}), with low activity (Davies, 2010). The decrease in gibberellic acid (GA_1) levels would cause the reduction of plant growth (Rademacher, 2000).

On the other hand, Zagonel and Ferreira (2013), in a field study with the same hybrid variety did not obtain reduction in plant height with the use of this plant growth regulator. The discrepancy between the results observed by Zagonel and Ferreira (2013) and those of the present study is possibly associated with the interaction between genotype and the different environments, as well as the different sowing periods. Reduction in plant height with the use of TE was also observed in wheat (Espindula et al., 2011; Contreras et al., 2012), rice (Arf et al., 2012) and soybean (Linzmeyer et al., 2008).

Although the regulator restricted the growth of corn plants, the stem diameter increased with increasing rates of TE (Figure 1B). Zagonel and Ferreira (2013), in turn, obtained quadratic response of stem diameter with the use of TE, and the diameter of the plant's stem was reduced with lower rates of TE and increased with increasing rates of this plant growth regulator.

Lozano and Leaden (2002) reported that the use of TE interferes with the internal diameter of the stem of wheat, by thickening the sclerenchyma, causing greater resistance to lodging. However, this internal thickening may or may not interfere with the external diameter of the stem of wheat. Comparison of the morphology of stems of wheat and corn showed that corn stem is completely filled, and thus, the thickening of tissues inside the stem directly affects the external diameter.

Souza et al. (2013) noticed an increase in the stem diameter of soybean plants with the use of TE, and said that it was caused by the fact that the photo assimilates were diverted from their function of plant growth regulation, which resulted in the increase in the stem diameter. This may also have occurred with the corn plants.

The number of fully expanded leaves was not affected by the use of the plant growth regulator (Figure 1C), indicating that the use of TE did not result in delay of phonological stages of corn.

The leaf area of corn plants was significantly reduced with the use of the TE plant growth regulator (Figure 1D). Zagonel and Ferreira (2013) did not observe TE effects on the leaf area of corn cultivars Status TL and Maximus TL. However, the authors observed a decrease in length and increase in width of the leaf above the spike.

The use of TE led to increases in the chlorophyll index at 14 DAA, with quadratic adjustment with the point of maximum technical efficiency (MTE) at the rate of 279.7 g i.a. ha^{-1} (Figure 2A). Nevertheless, a decrease in

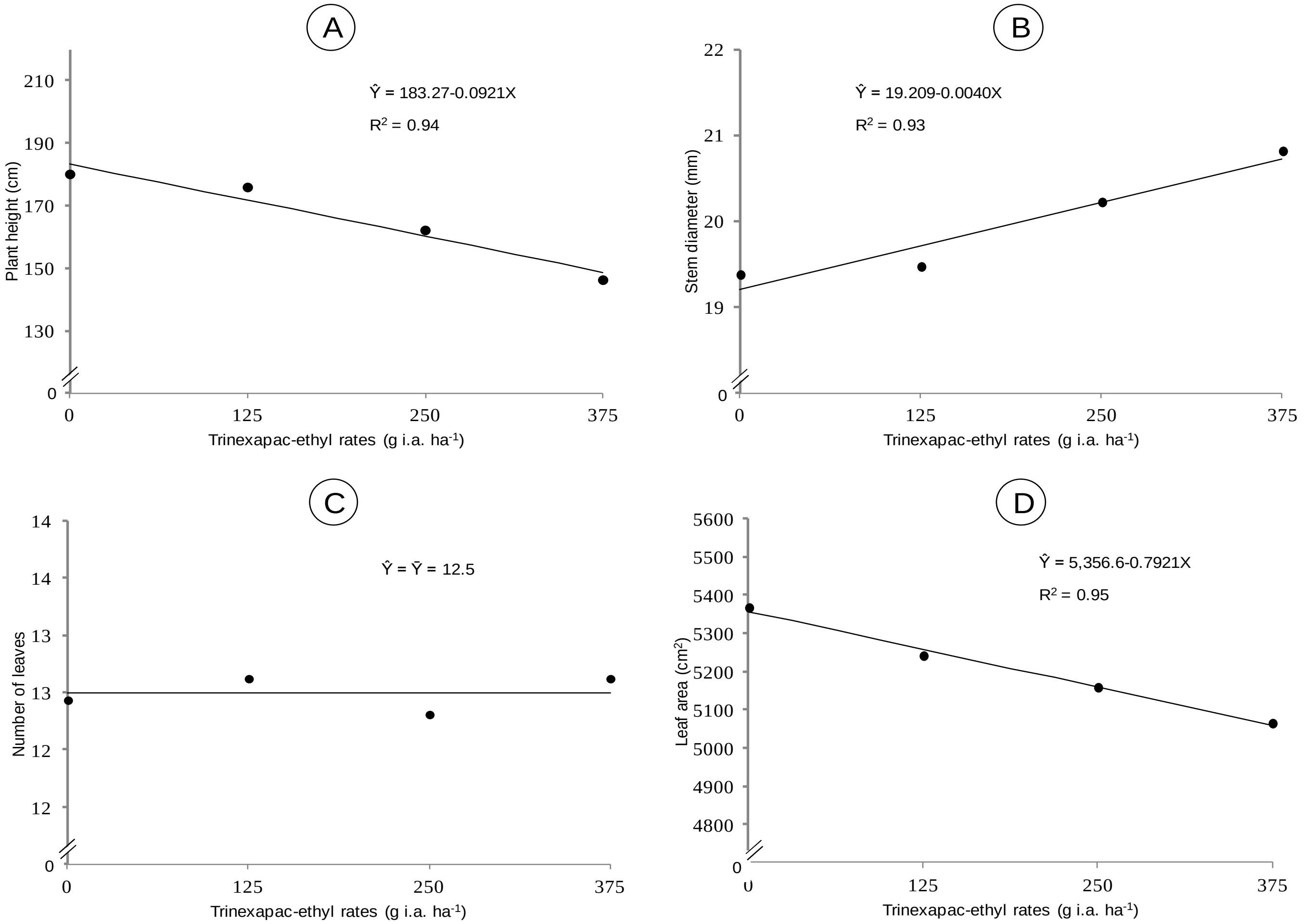

Figure 1. Plants height (A), stem diameter (B), number of leaves (C) and leaf area (D) of corn plants in response to rates of trinexapac-ethyl.

chlorophyll index was observed at 21 and 28 DAA, with increasing rates of TE. However, at 35 DAA a quadratic adjustment with slight increase at low dosage was also observed. But with rates of 108.1 g i.a. ha^{-1} (MTE) or higher, the product reduced the chlorophyll index. Espindula et al. (2009a) studied the effects of TE on chlorophyll content (SPAD index) in leaves of wheat and observed increases in chlorophyll contents with increasing rates of the plant growth regulator and affirmed that such increases are probably due to the increase in the chlorophyll content per unit area and/or volume of leaf tissue, once TE reduced the leaf area.

Analysis of the behavior of the chlorophyll index over time for each of the assessed rates (Figure 2B) shows that on day 14 DAA, all TE rates led to an average increase of 13% compared to rate 0 g i.a. ha^{-1}. However, the rate 0 g i.a. ha^{-1} continued increasing the chlorophyll index for a longer time, while the other rates led to earlier decrease of chlorophyll index at 21 DAA. However, at 35 DAA all TE rates showed chlorophyll index similar to those of the control rate, except the highest rate. A similar result was obtained by Ervin and Koski (2001) who observed an increase in the total chlorophyll content at 14 days after application, though they did not observe any effects at 28 days after application in bluegrass (*Poa pratensis* L.).

The findings demonstrate that the use of TE at the lowest rates increased the chlorophyll index earlier. The same was reported by McCann and Huang (2007), who studied the effect of TE on plants of *Agrostis stolonifera* L. and found that the chlorophyll content in the plants is significantly higher up to 10 days after application of the plant growth regulator. Also, according to the authors, these findings indicate that the application of TE improves the photosynthetic capacity of the canopy and the photosynthetic efficiency of the leaf. This effect on the chlorophyll index can be beneficial to the crop due to the increase in the photosynthetic rate of plants during the vegetative stage, which, in turn, can favor the relative growth rate and consequently, the growth rate of the crop.

The dry mass of aerial part of corn plants decreased

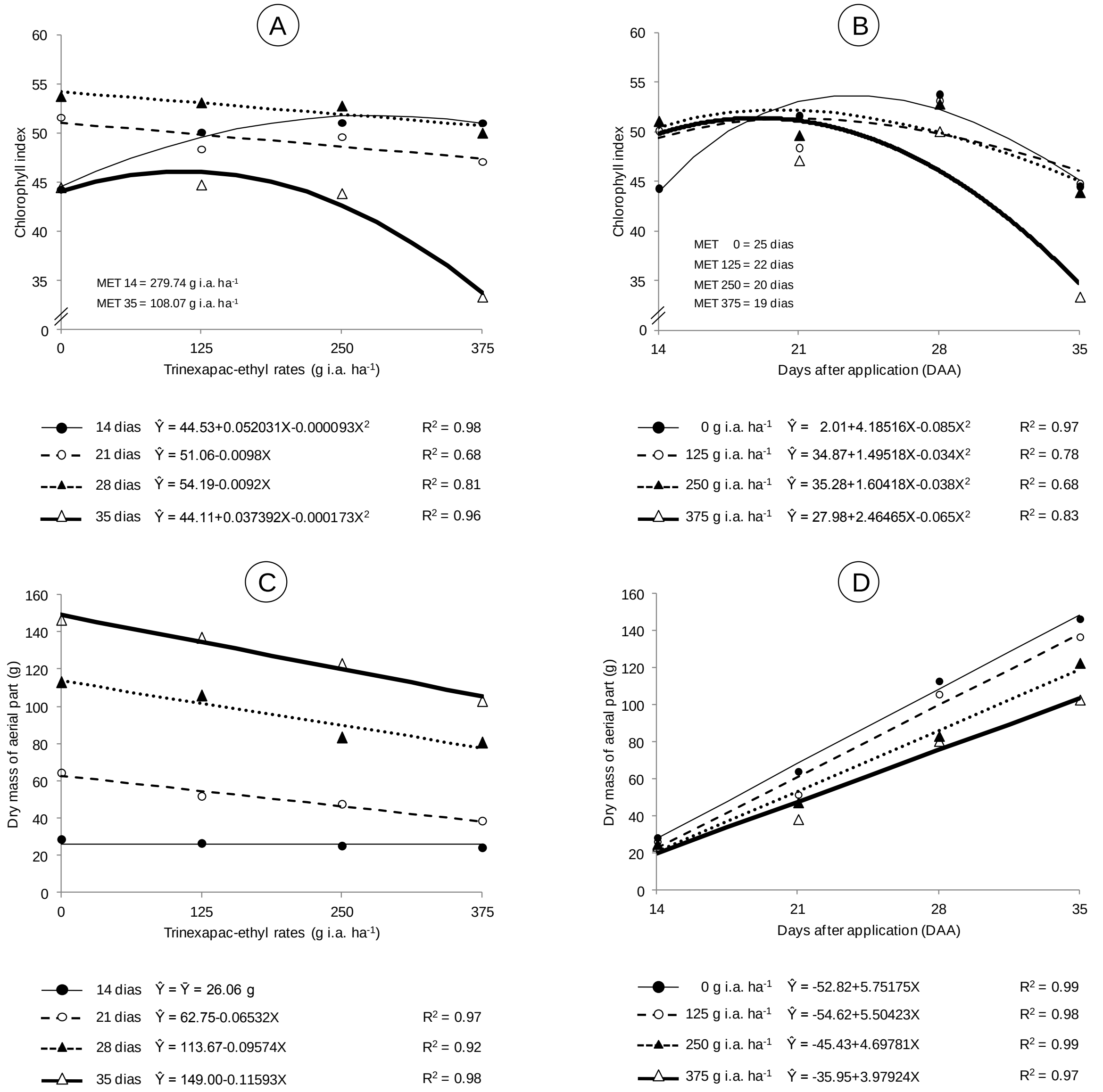

Figure 2. Chlorophyll index and dry mass of the aerial part of corn plants in response to rates of trinexapac-ethyl (A and C) and periods of assessment (B and D).

with the use of TE from at 21 DAA, and no effect was observed at 14 DAA (Figure 2C). Although it did not change the number of leaves, TE reduced the dry mass of the aerial part, which can be explained by the decrease in the plant height, which having smaller stems and leaf area showed a lower dry mass of aerial part. Similar results were described by Espindula et al. (2009b), who affirmed that this decrease is related to the lower mass of wheat plants. However, the author stresses that decrease in dry mass may be responsible for later decrease in grain yield. The highest rates led to lowest growth rate (Figure 2D) of the dry mass of the aerial part, resulting in lower values of the dry mass of aerial part at 35 DAA. The inhibition of synthesis of gibberellins by TE also reduced cell division and elongation of cells in the roots of corn plants, reducing the dry mass and the root volume (Figure 3A and B).

Measurements of TE effects are usually carried out in field studies and they concern only the aerial part of the plants. The present study highlights the effects of trinexapac- ethyl also on the reduction in the root system, which in association with the reduction in the aerial part may be responsible for reduction in individual plant yield.

In the assessments performed at the end of the crop cycle (Experiment 2), significant effects of TE were observed on the studied variables, except for the number of rows of kernels per spike.

Plant height and spike insertion height presented significantly decreased with increasing rates of the plant growth regulator (Figure 4A and B), where the highest

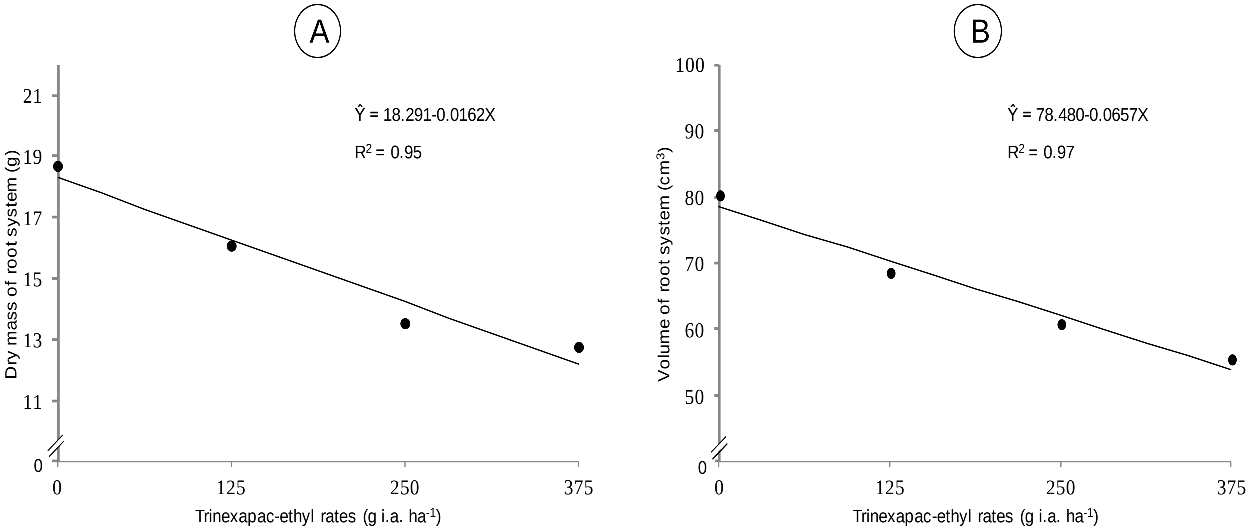

Figure 3. Dry mass (A) and volume (B) of roots system of corn plants in response to rates of trinexapac-ethyl.

rate was responsible for the lowest heights. Since TE inhibits the synthesis of gibberellins, the plants treated with rates of the plant growth regulator at V6 growth stage showed significant reduction in cell division and elongation during a period of significant stem elongation and growth (Ritchie et al., 2003), with reduction in its final height. With the achievement of a lower height of plant and spike insertion, we obtain plants with a center of gravity closer to the soil, reducing propensity to lodging (Sangoi et al., 2001). Thus, lower height of plant and spike insertion associated with higher stem diameter confirms the effects of prevention of lodging provided by the use of TE.

The number of rows of kernels per spike did not respond to the rates of TE ($\hat{Y}=\bar{Y}=16.625$), which was also observed by Zagonel and Ferreira (2013). The lack of response of the variable to the plant growth regulator is due to the fact that this characteristic is strongly determined by the genotype and not the environment (Nielsen, 2007).

Application of TE reduced the length of spikes and the number of kernels per row (Figure 4C and D), this reduction being linear according to the increase in the rate applied and up to 1.1 cm and 4.6 kernels per row after the application of the highest rate (375 g of i.a. ha^{-1}). Zagonel and Ferreira (2013) did not observe effects of TE rates on the number of kernels per row, regardless of the time of application, and said that this occurred because the plant growth regulator has no effects on the height of plants and other morphological characteristics.

According to Ritchie et al. (2003), the development of female inflorescences begins at V9 growth stage, and at V12 the development the number of ovules (potential kernels) and the size of spike are determined. Therefore, since TE has strong action in plant meristems, it may have impacted cell division and elongation in this period of grain determination, reducing them. Alvarez et al. (2007) reported increase in the number of shrunken grains of rice following the use of TE and relate this result to the effects of the plant growth regulation on the formation of flowers (stamens and ovaries) and in meiosis. Thesame was observed by Nascimento et al. (2009) with the use of TE in cultivation of upland rice applied during flower differentiation.

A significant reduction in the hundred-grain mass was also observed with increasing rates of TE (Figure 4E). Zagonel and Ferreira (2013) obtained quadratic responses with increases in the mass per 1000 seeds with the lowest rates and later a decrease with application of rates above 272 g de i.a. ha^{-1}. The lowest organic production of plants, as demonstrated by the lower dry mass of the aerial part, reduced the photosynthetically active area and reserves of assimilates, leading to decrease in the hundred- grain mass. The same was reported by Espindula et al. (2009a) in wheat plants. The action of the plant growth regulator in the beginning of grain formation (R1 and R2) possibly inhibited cell division and the number of cells per grain, thus restraining its potential size.

Due to the decrease in spike length, number of kernels per row and hundred grain mass, the use of TE also reduced the grain yield per plant depending on the rates, with a 22 % decrease with application of the highest rate (Figure 4F). On the other hand, Zagonel and Ferreira (2013) did not observe TE effects on the yield of corn crop. The authors affirmed that the lack of response is associated with the little effect of the product on the plants, with response being also dependent on the hybrid variety.

The decrease in grain yield in wheat is caused by

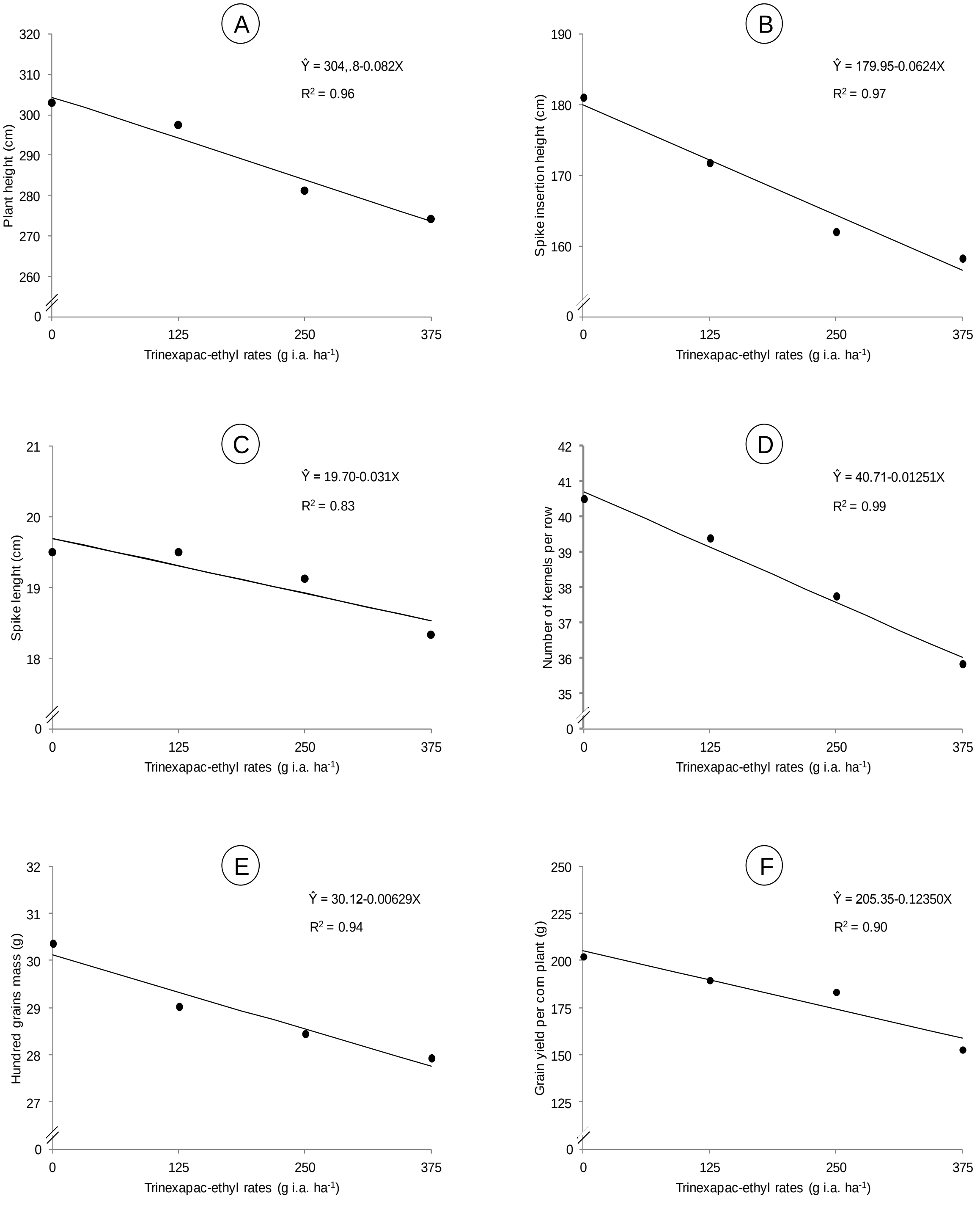

Figure 4. Plant height (A), Spike insertion height (B), spike length (C), number of kernels per row (D), hundred grain mass (E) and grain yield per corn plant (F) in response to rates of trinexapac-ethyl.

decrease in photosynthetic capacity, and reserves of assimilates in the stem was also observed by Espindula et al. (2011). Alvarez et al. (2012) affirm that there is a very close relationship between yield components and grain yield, as well as of plant height with these variables. Thus, decrease in plant height caused by TE had negative effects on yield components and on the yield of upland rice.

It is important to stress that the effects observed here concern isolated plants of a given hybrid variety cultivated in greenhouse, and further studies involving cultivars, plant arrangement and crop management are needed. The decrease in individual plant yield caused by the plant growth regulator can be balanced by a higher number of plants in the area, since the plants treated with TE showed reduced height and dry mass. At higher plant densities, with better spatial distribution, the interception of solar radiation can be optimized, with improvement of the photosynthetic capacity of the canopy and increased yield (Argenta et al., 2001). Therefore, studies on the performance of plants treated with rates of TE would help understand whether the application of the product allows the use of thickened populations, without losses in grain yield due to lower intraspecific competition.

The present study demonstrates that individual plant yield was reduced by TE, due to decrease in spike length, in the number of kernels per row and in the hundred-grain mass. The use of TE does not change the cycle of corn crop, but increases stem diameter and chlorophyll index and reduces the height of plant and spike insertion, leaf area, dry mass of the aerial part, dry mass and volume root system. The use of TE changes the size of corn plants, allowing new spatial arrangements.

Conflict of Interest

The authors have not declared any conflict of interests.

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