



Doses and application times of trinexapac-ethyl in upland rice¹

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ABSTRACT

The use of growth regulators as a technique that can reduce plant height and thus strengthen stalks, which may be an option to eliminate or reduce plant lodging, thereby avoiding crop loss. However, there is a lack of information on the subject. The purpose of this study was to evaluate the effect of the dose (0; 37.5; 75.0; 112.5 e 150.0 g ha⁻¹ active ingredient) and the application times of trinexapac-ethyl (sixth, seventh and eighth leaves), in a randomized complete block, in a 5x3 factorial scheme, with four replicates. The field experiment was performed during the 2016/17 crop season, in the experimental farm located in Selvíria, Mato Grosso do Sul State, Brazil, at Universidade Estadual Paulista - UNESP, Ilha Solteira, São Paulo State, Brazil – Campus. It is not recommended to apply the trinexapac-ethyl at eighth leaf, especially in the doses of 75.0; 112.5 and 150.0 g ha⁻¹, since they generated the lowest values for yield parameters, thus reducing productivity, and providing greater number of unfilled grains. Taking into account the reduction in plant height, the minimization of lodging and grain yield, trinexapac-ethyl should be applied to the seventh leaf of the BRS Esmeralda rice at the dose of 75 g ha⁻¹.

Keywords: gibberelins; *Oryza sativa* L.; plant growth regulator; plant lodging.

INTRODUCTION

Rice is an important source of energy and protein in the diet of the population in both underdeveloped and developed countries, as part of the daily diet of most of these populations. It is one of the most consumed and produced cereals in the world, characterizing itself as the main food of more than half the world's population. It stands out as the third largest cereal crop in the world. China is the largest rice producer with 212.6 million tons of grain, and Brazil ranks the ninth position, producing 12.5 million tons (FAO, 2017).

Upland rice cultivated with the use of sprinkler irrigation eliminates the risk of water deficiency caused by periods without rain, therefore keeping the production stability (Yamashita, 2013) and profitability, stimulating

the use of higher technology practices. However, this may stimulate the exaggerated development of the plants of some cultivars, causing lodging (Arf *et al.*, 2012), especially if associated to high doses of fertilizers, particularly nitrogen. Depending on the type of cultivar, the lodging tends to vary, being able to reach high levels, hindering the mechanized harvesting and increasing the losses.

The growth regulators have an action to reduce the plant height, reducing the distance from the internodes and leading to the strengthening of the stems, thus contributing to the reduction of lodging, avoiding losses in productivity. In addition to the effects of growth regulator on the plant, the time of the application also interferes in the expressive reduction of its size.

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The use of plant regulators in wheat cultivation is efficient in reducing the size of plants (Espindula *et al.*, 2010), as well as in the cultivation of white oats to avoid plant lodging (Hawerth *et al.*, 2015). However, information on the effect of plant regulators on plant physiological processes on the impact of crop production for upland rice cultivation, and yield components is still scarce (Yamashita, 2013; Alvarez *et al.*, 2016).

The reduction in the height of the rice plant is greater when applications start at the floral differentiation as the size of the rice plants is determined by the elongation of the last four internodes and begins with the initiation of the panicle primordium. The elongation of the last internode determines the emergence of the panicle through the sheath of the "flag leaf" (Fornasieri Filho & Fornasieri, 2006). The moment and modes of application of the data flow regulator have been the subject of research, for example, on an inconsistent demonstration production, with the importance of some cases being the increases in the productivity and, in others, the decrease (Buzetti *et al.*, 2006).

In the search for results that demonstrate greater precision in doses of plant regulator and moment of application, the objective of this study was to analyze the effect of doses and times of application of trinexapac-ethyl in the development and productivity of upland rice. Aiming to reduce the plants height, therefore, the minimum of plant lodging facilitating the accomplishment of the harvest without interfering in the quality and productivity of grains.

MATERIAL AND METHODS

The present work was carried out in the agricultural year 2016/17 in an experimental area owned by the Universidade Estadual Paulista - UNESP, Campus of Ilha Solteira, located in the city of Selvíria - MS, located approximately at 51° 22' west longitude of Greenwich and 20° 22' Latitude South, at an altitude of 335 meters. The soil of the site is a typical Red Clay Latosol clay-type (Embrapa, 2013). The average annual rainfall is 1370 mm, the annual average temperature is 23.5 °C and the relative humidity is between 70 and 80% (annual average).

Before the experiment installation, a composite sample was collected from 20 simple soil samples in the experimental area, in the 0-20 cm layer. The chemical characteristics of the area showed the following values: O.M.= 18 g. dm⁻³; P resin = 16 mg. dm⁻³; pH (CaCl₂) = 4.8; K= 8.4 mmolc. dm⁻³; Ca= 12 mmolc. dm⁻³; Mg= 12 mmolc. dm⁻³; H+Al= 15 mmolc. dm⁻³; and V = 68%. When necessary, water was supplied by a fixed conventional sprinkler irrigation system with a mean precipitation of 3.3 mm.h⁻¹ in the sprinklers.

For the experimental design, it was used randomized blocks arranged in a 5 x 3 factorial scheme, with four

replications. The treatments consisted of the combination of five doses of trinexapac-ethyl (0; 37.5; 75.0; 112.5 and 150.0 g.ha⁻¹ of the active ingredient), applied at three distinct stages of plant development. The evaluation of the stages of development of the crop was carried out following the scale of Counce *et al.* (2000). The applications of trinexapac-ethyl doses were performed with the development of the 6th, 7th and 8th leaves of the main stem. The panicle differentiation (R1) occurs at the seven expanded leaves stage, regardless of the cultivar and sowing season adopted (Freitas *et al.*, 2006).

Counce *et al.* (2000) developed a physiological age-scale of rice cultivation, divided into seedling development and vegetative and reproductive stages, so, there is a greater understanding of plant development and improvement in crop management conditions (SOSBAI, 2016). The application of growth reducers based on the time schedule (days) implies in a high probability of reaching the plants at a not-recommended stage of development (Rodrigues *et al.*, 2003).

Soil preparation was carried out with a scarifier and gradation for leveling. Sowing was performed on May 11 2016 using the amount of seeds required to obtain 180 m² plants of the BRS Esmeralda. Seed treatment with pyraclostrobin (25 g.L⁻¹) + methyl thiophanate (225 g L⁻¹) + fipronil (250 g.L⁻¹) at the dose of 2 mL kg⁻¹ of seed was carried out to pests and soil diseases. The plots consisted of five lines with 4.5 m length spaced 0.35 m apart.

Seedling emergence occurred on November 11 2016. The cultivar BRS Esmeralda has as main characteristics the high productivity, vigorous plants with good architecture and stay-senescence (stay-green) (de Castro *et al.*, 2014). Mineral fertilization was in the sowing furrows as well as the topdressing, calculated according to the chemical characteristics of the soil and the crop. It was composed of 250 kg ha⁻¹ of the formulation 8-28-16 and 60 kg ha⁻¹ of N (ammonium sulfate) applied at 26 days after emergence (DAE) of the seedlings.

The evaluation of rice development stages was based on Freitas *et al.* (2006), which evaluated ten plants identified in the intermediate line of each treatment and the development of these plants during the whole cycle. In the vegetative stages, a plastic yarn was used to follow the emission of the leaves in the main stem; the plastic yarn was transferred to it, and according to the development of the crop, the plastic yarn was then transferred.

The plant regulator was applied in the form of a directed jet, with a backpack spray (model PJH, brand Jacto), with a volume of approximately 200 L ha⁻¹, using a hollow-cone type hydraulic nozzle. The applications were performed in the afternoon, from 17h00 to 18h00, with the absence or low wind incidence.

Weed management was performed using pre-emergence herbicides (pendimethalin, 1.400 g ha⁻¹ a.i.) and in post-emergence (metsulfuron-methyl, 2 g ha⁻¹ a.i.). The weeds not affected by the herbicides were manually controlled with the aid of a hoe. An application of trifloxystrobin + tebuconazole (75 + 150 g ha⁻¹ a.i.) was carried out with the aim of preventing a possible blast occurrence; thiamethoxam (25 g ha⁻¹ a.i.) was also applied to stem stink control. The harvest was performed manually on February 20, 2017 at 102 DAE.

The evaluations were based on plant height: the measurement was performed in the area, at the grain stage in the pasty form, determining five points per plot; on an average distance comprised from the soil surface to the upper end of the highest panicle; on plants lodging: obtained through visual observations, in the maturation phase, using the following scale of notes: 0 = without lodging; 1 = up to 5% of plants lodging; 2 = 5% to 25%; 3 = 25% to 50%; 4 = 50% to 75%; and 5 = 75% to 100%; panicle number m⁻²: determined by counting the number of panicles in 1.0-m row of plants in the useful area of the plots and subsequently converted per square meter; total number of grains per panicle: count of the 20 panicle grains, collected at harvest; number of filled grains and unfilled grains per panicle: count of filled and unfilled grains, after their separation by air flow, obtained with the samples used to determine the total number of grains per panicle; hectolitre mass: determined on special tool for hectolitre mass, using two samples; mass of 100 grains: mass of two samples of one hundred grains collected at random from each plot and also based on grain yield: determined by weighing the grains in the bark, from the useful area of the plots, converted into kg ha⁻¹. The values of the masses were corrected for moisture of 13% (wet basis).

The data were submitted to analysis of variance by the F test, and the qualitative data were compared by the test of Tukey and the quantitative data by the polynomial regression analysis. Statistical analyzes were performed using the statistical program software SISVAR (Ferreira, 2007).

RESULTS AND DISCUSSION

In relation to the height of the plants, it is observed an interaction between times of application and the doses of the growth regulator (Table 1). The distribution of this significant interaction is shown in Figure 1. It can be seen stay senescence a reduction in plant height in relation to application times and doses of trinexapac-ethyl.

For plant height (Figure 1), the correct use of the doses within the application times allowed to obtain linear equations for the application of the regulator on the sixth and seventh leaves, and a quadratic equation when applied on the eighth leaf. The height of plants decreased at all the

times with the growth regulator application. Similar behavior was observed by Nascimento *et al.* (2009) when studying the application of doses and times of trinexapac-ethyl regulator the in sprinkler-irrigated upland rice. The authors observed that the increasing doses of the plant regulator promoted a reduction in the height of the cultivar Primavera. Castilho *et al.* (2012), also evaluating the effect of the use of the regulator trinexapac-ethyl on the Primavera cultivar sown with different densities, observed that at 150 g ha⁻¹, there was a reduction in height of rice plants, approximately 15 and 39 cm, in the years 2007/08 and 2008/09, respectively.

The adjustment of the quadratic equation of height in this study with the 138g ha⁻¹ dose of trinexapac-ethyl applied at the eighth leaf showed a reduction in height of the BRS Esmeralda cultivar at 0.36 m in relation to the control. It also provided the lowest value of height of the plants when compared to the applications on the sixth and seventh leaves (Figure 1). This fact was visible in the field in which the plots that received applications on the eighth leaf at larger doses had plants with a smaller flag leaf, retraction of the panicle in the stem and smaller size of the panicle.

Inhibitors of gibberellin biosynthesis have been useful for crops in which a reduction in plant height is desirable. For example, height is a disadvantage for cereals grown under conditions of cold and humid climate, such as in Europe, where lodging may become a problem. The curvature of stems towards the soil, occasioned by the weight of the water accumulated in the mature spikes makes it difficult to harvest the grain with the use of harvesters. Shorter internodes reduce the planting tendency to lodging, increasing crop productivity (Taiz & Zeiger, 2013). Besides the reduction in plant height, this result is significant when associated with application times.

The reduction in plant height using this growth regulator was also found in other works such with sugarcane (Faria *et al.*, 2015), white oats (Hawerth *et al.*, 2015) and maize (*Zea mays L.*) (Pricinotto *et al.*, 2015). Regarding the values obtained for lodging, a significant effect was observed for the application period and for the doses applied (Table 1). As for the effect of the application times, the use of trinexapac-ethyl on the eighth leaf resulted in lower values for lodging scores. The plant lodging had similar behavior to that of height, lower values of height yielded lower lodging scored. In the case of doses, the values obtained were adjusted to the quadratic equation. Plots that did not receive the application of the regulator, reached the highest lodging scores, a fact observed in the field, that in the event of rain with strong winds on the eve of the harvest resulted in completely camped plots that did not receive the trinexapac-ethyl application. The effect of the growth regulator depends on several factors, such as sowing time, dose, time of application, environmental

conditions and nutritional and phytosanitary status of the crop (Rodrigues *et al.*, 2003).

When studying the effects of trinexapac-ethyl and times of application in upland rice, using the cultivar Primavera, Nascimento *et al.* (2009) observed that the application of 75 to 150 g ha⁻¹ doses of the regulator at floral differentiation could minimize or eliminate lodging in rice plants. The analysis in panicle values per square meter showed no significant interaction in relation to doses and times (Table 1), a fact also observed by Arf *et al.* (2012) in some tested cultivars combined with doses of trinexapac-ethyl in sprinkler-irrigated upland rice. In this specific case, the trinexapac-ethyl may have influenced the formation of higher order tiller, such as tertiary and quaternary tiller (Alvarez, 2003).

Regarding filled and total grains, a significant interaction occurred for regulator doses and application times (Table 2). In both cases, the number of filled and total grains decreased with the application on the eighth leaf when compared to the application in the sixth leaf. For the growth regulator doses the values obtained were adjusted to the linear regression. Thus, the higher the dose used of the growth regulator, the lower the amount of filled and total grains.

Similar results were observed by Nascimento *et al.* (2009), who verified lower values for number of grains per panicle as the doses of trinexapac-ethyl increased. The same was observed by Alvarez *et al.* (2007a), where there was a reduction in the number of filled and total grains per panicle with the use of the trinexapac-ethyl growth

regulator at the dose of 200 g ha⁻¹. The likely cause is that with the use of the growth regulator affects the processes of plant formation, such as branches of the rachis and spikelets through ramifications, and in the processes of flower formation (stamens and ovary) and meiosis (formation of male gametes and female), thus reducing the fertility of spikelets (Alvarez *et al.*, 2007a).

However, by evaluating the effect of trinexapac-ethyl on different sowing densities in upland rice, Castilho *et al.*

- 6th leaf $y = -0.0008x + 1.0445$ $R^2 = 0.8493$
- 7th leaf $y = -0.0016x + 1.0155$ $R^2 = 0.9195$
- ▼ 8th leaf $y = 2E-05x^2 - 0.0058x + 1.0564$ $R^2 = 0.9733$

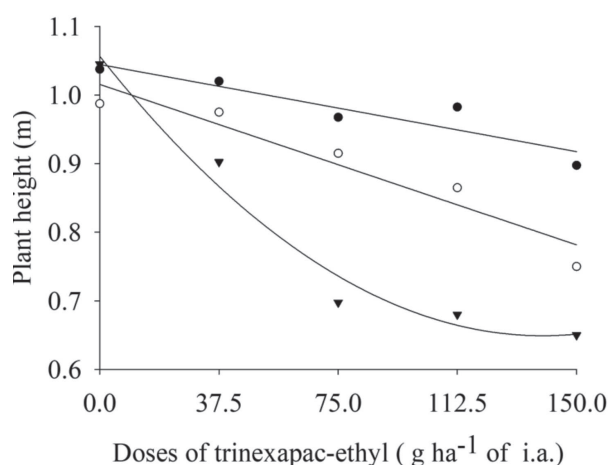


Figure 1: Deployment significant interaction of variance analysis referring to plant height. Selvíria (MS), harvest 2016/17.

Table 1: Mean values of plant height, lodging degree and panicles per square meter in upland rice influenced by doses and times of application of trinexapac-ethyl. Selvíria (MS), harvest 2016/17

Treatments	Height (m)	Lodging ⁽¹⁾	Panicles m ⁻²
Application times			
6 th leaf	0.98	1.90 a	288
7 th leaf	0.89	1.50 ab	283
8 th leaf	0.79	0.75 b	263
Doses of trinexapac-ethyl (g ha ⁻¹ a.i.)			
0	1.02	4.25 ⁽²⁾	284
37.5	0.96	1.08	295
75.0	0.86	1.08	295
112.5	0.84	0.5	253
150.0	0.76	0	264
F Values			
Times (E)	54.23*	6.29*	2.03 ^{ns}
Doses (D)	39.42*	25.87*	2.53 ^{ns}
E*D	6.34*	1.48 ^{ns}	1.79 ^{ns}
C.V. (%)	6.35	31.88	14.76

n.s - not significant and * significant at the 5% probability level by the F test. Means followed by the same letter, within the application time do not differ statistically from each other by the test of Tukey at 5% probability. C.V. - coefficient of variation. ⁽¹⁾ Lodging scale: 0 (without lodging); 1 (1 to 5% of lodged plants); 2 (5 to 25%); 3 (25 to 50%); 4 (50 to 75%); 5 (75 to 100% of lodged plants). The analysis refers to the transformed data in $(x + 0.5)^{0.5}$. ⁽²⁾ $y = 0.00024x^2 - 0.060x + 3.88$ ($R^2 = 0.89$).

(2012) observed that the application of 150 g.ha⁻¹ of trinexapac-ethyl in the floral differentiation increased the number of filled grains per panicle, probably because a better distribution of photoassimilates occurred, which were used for the excessive growth of the crop, thus leading to better grain filling.

There was significant effect only for application times for the number of unfilled grains per panicle (Table 2). The application on the eighth leaf resulted in larger numbers of unfilled grains per panicle in relation to the applications in the other times.

Similar data were found by Yamashita *et al.* (2013), when evaluating doses of trinexapac-ethyl and times of application in sprinkler-irrigated upland rice, finding a significant effect on the number of unfilled grains only for times in the 2010/11 crop year, and higher numbers of unfilled grains per panicle were observed in the “booting stage” of the crop, in relation to the other times. Those results differ from Alvarez *et al.* (2007a), in which it was compared treatments with and without application of trinexapac-ethyl at different stages of rice plants development, and found no significant effects for number of unfilled grains per panicle.

An interaction was found between application times and growth regulator doses for the mass for one hundred grains, hectolitre mass and productivity (Table 3).

As for the doses within application times for both hectolitre and mass of one hundred grains, linear equations were obtained in the regulator application on the sixth leaf. Quadratic equations were obtained in the seventh and eighth leaves (Figure 2).

Regarding times within doses, lower values for mass of a hundred grains and hectolitre were observed with the growth regulator application at the eighth leaf at doses greater than 75g ha⁻¹ a.i. (Figure 2).

Zagonel & Fernandes (2007) observed in wheat cultivars that late applications of trinexapac-ethyl greatly reduces the length of the last internode, with part or all of the spike retained in the sheath of the “flag leaf”, therefore interfering with anthesis and grain formation. Thus, care should be taken in late applications, which demonstrates the importance in adapting the doses and the times of growth regulator application to be used in the crop.

For grain productivity (Figure 2), application of doses within times resulted in quadratic equations in the regulator application at the sixth and seventh leaves, with maximum productivity point estimated at the doses of 84 and 71g.ha⁻¹ a.i., respectively and a negative linear one in the eighth leaf. Applications on the seventh leaf at the dose of 75g ha⁻¹ a.i. resulted in the highest values for hectolitre mass and one hundred grain mass, and did not differ statistically from the higher value for grain productivity.

It was found that the doses of 75.0; 112.5; and 150.0 g ha⁻¹ a.i. allied to the regulator application in the eighth leaf significantly reduced productivity in relation to the applications in the sixth and seventh leaves. This fact could already be expected, due to the shorter plant length, which delays the development of grain filling and could cause losses in productivity.

Alvarez *et al.* (2007b) found that the application times and trinexapac-ethyl doses in sprinkler-irrigated upland rice reduced the height of the plant and negatively

Table 2: Mean values of filled grains, unfilled grains and total grains per panicle in upland rice according to the doses and application times of trinexapac-ethyl. Selvíria (MS), 2016/17 harvest

Treatments	Filled grains	Unfilled grains	Total grains
Application times			
6 th leaf	134 a	9 b	143 a
7 th leaf	123 ab	9 b	132 b
8 th leaf	117 b	19 a	136 ab
Doses of trinexapac-ethyl (g ha ⁻¹ of a.i.)			
0	137 ⁽¹⁾	15	152 ⁽²⁾
37.5	131	12	143
75.0	125	13	138
112.5	120	9	129
150.0	110	13	123
F values			
Times (E)	6.56*	19.48*	3.21*
Doses (D)	5.77*	1.34 ^{ns}	8.11*
E*D	1.81 ^{ns}	0.66 ^{ns}	2.14 ^{ns}
C.V. (%)	12.02	47.53	10.23

n.s - not significant and * significant at the 5% probability level by the F test. Means followed by the same letter within Application Times do not differ statistically from each other by the test of Tukey at 5% probability. C.V. - coefficient of variation. (1) $y = -0.173x + 137$ ($R^2 = 0.98$); (2) $y = 0.194x + 152$ ($R^2 = 0.99$).

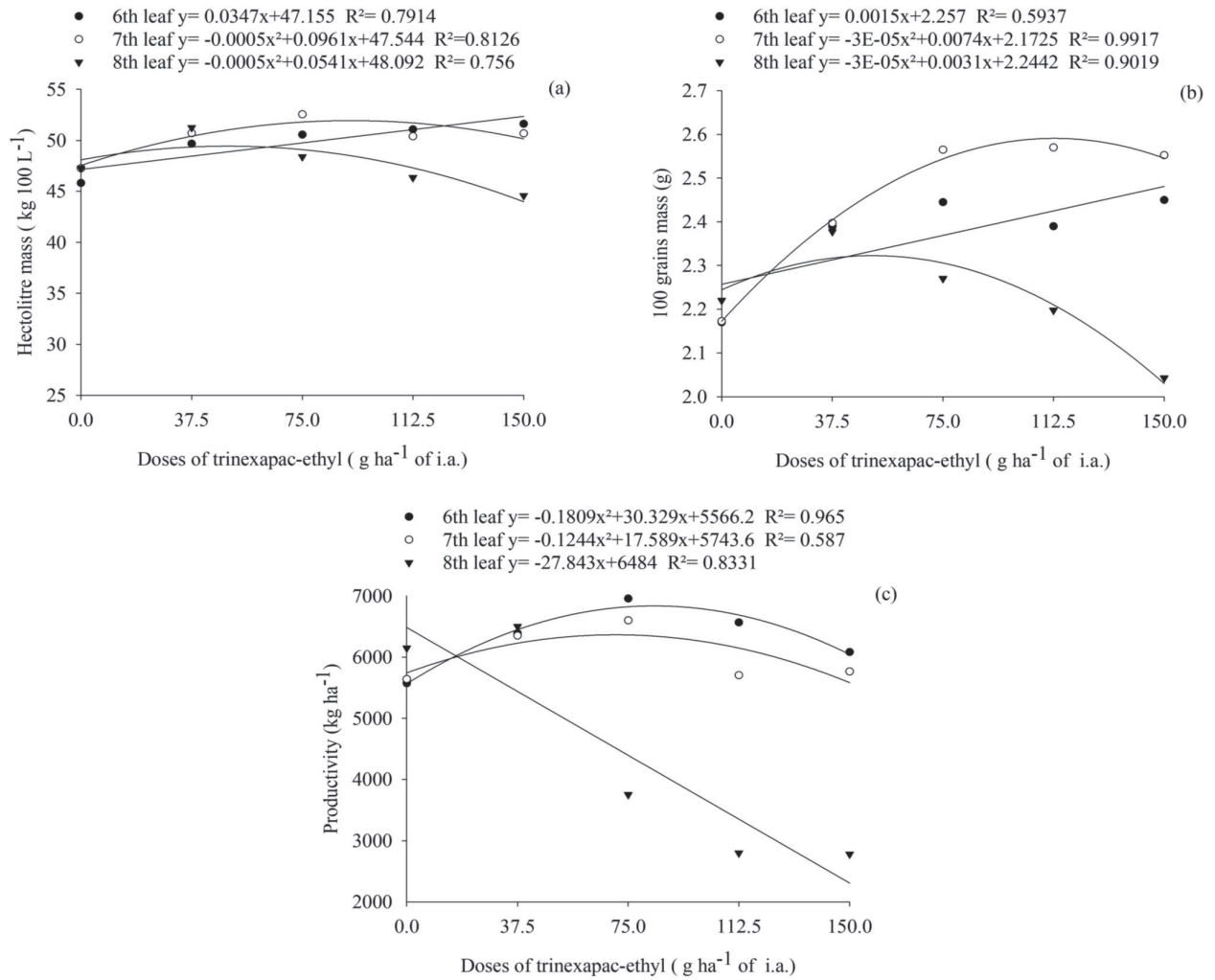


Figure 2: Interaction between doses of growth regulator and application times in relation to the (a) hectolitre mass, (b) 100-grains mass and (c) productivity. Selvíria (MS), 2016/17 harvest.

Table 3: Mean values of mass for one hundred grains, hectolitre mass and productivity of grains in upland rice according to the doses and application times of trinexapac-ethyl. Selvíria (MS), 2016/17 harvest

Treatments	100-grains mass (g)	Hectolitre mass (kg 100 L ⁻¹)	Productivity (kg ha ⁻¹)
Application times			
6 th leaf	2.4	49.7	6314
7 th leaf	2.4	50.3	6013
8 th leaf	2.2	47.6	4396
Trinexapac-ethyl doses (g ha ⁻¹ of a.i.)			
0	2.2	46.8	5788
37.5	2.4	50.5	6415
75.0	2.4	50.5	5771
112.5	2.4	49.3	5023
150.0	2.3	48.9	4876
F values			
Times (E)	13.93*	9.54*	63.00*
Doses (D)	5.39*	6.35*	14.04*
E*D	3.21*	3.65*	15.06*
C.V. (%)	5.95	4.29	10.43

n.s -not significant and * significant at the 5% probability level by the F test. Means followed by the same letter, within Application Times do not differ statistically from each other by the test of Tukey at 5% probability. C.V. - coefficient of variation.

influenced the productivity of the grains and the components of production, using the cultivar Primavera, with application of the regulator at the tillering of the plants.

Yamashita (2013), considering the reduction in plant height, elimination of lodging and grain productivity recommended the use of trinexapac-ethyl applied at a dose of 50g ha⁻¹, at floral differentiation in the BRS Primavera cultivar. Therefore, Nascimento *et al.* (2009) recommended the dose of 150 g.ha⁻¹. The applications also at the panicle primordium differentiation at doses of 50 g ha⁻¹ and 150 g ha⁻¹ in a study of Arf *et al.* (2012) resulted an in productivity of Caiapó cultivar and BRS Primavera respectively. However, Alvarez *et al.* (2014) did not find an appropriate dose that did not interfere with grain productivity, as the increment in the growth regulator doses reduced rice production, where trinexapac-ethyl was the most harmful to productivity.

These results suggest the need for further studies on the appropriate doses, application times and sources of plant regulators, specially to reduce plant height, to minimize lodging, without affecting the productivity of grains and their components.

Growth regulators have been employed to make plant architecture more adapted and efficient in the use of natural resources and inputs in order to support high agronomic yields (Souza *et al.*, 2013); however, doses and times of application are key to maximize its use. As the South-Brazilian Irrigated Rice Society (SOSBAI, 2016) elucidates, the use of a scale that is appropriate to express the plant development aiming at greater precision in the time of application of the management practices employed, facilitating the communication between technicians and producers, in addition to determining the timing of application, such as the Counce *et al.* (2000), which is the most used in southern Brazil.

CONCLUSION

The recommended dose of trinexapac-ethyl for BRS Esmeralda rice is 75 g.ha⁻¹, and should be applied to the seventh growth leaf, in relation to the reduction in plant height, lodging minimization and grain yield.

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