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Biomass and grain yield of oats by growth regulator

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ABSTRACT
The use of growth regulator in oats can reduce plant lodging with reflections in biomass and grain yield. The objective of the study was to determine the feasibility and efficiency of using Trinexapac-Ethyl regulator in the growth of white oat under different conditions of N-fertilizer and years favorable and unfavorable for cultivation. In this study, two experiments were conducted in the years 2011, 2012 and 2013, one for quantifying biomass production rate and the other for the determination of grain yield and lodging. The experimental design was randomized blocks with four replicates, in a 4 x 3 factorial scheme, for growth regulator doses (0, 200, 400 and 600 mL ha^{-1}) and nitrogen doses (30, 90 and 150 kg ha^{-1}), respectively. There is a linear reduction of biomass rate with the increase in the growth regulator dose in oat, regardless of the condition of year and use of N-fertilizer. The growth regulator dose of 495 mL ha^{-1} efficiently reduces lodging with reduced, high and very high use of N-fertilizer, without reducing the yield of oat grains, in favorable, intermediate or unfavorable year for cultivation.

Palavras-chave:
Avena sativa
Trinexapac-ethyl
acamamento
nitrogênio
regressão

Produtividade de biomassa e grãos de aveia pelo regulador de crescimento

RESUMO
O uso do regulador de crescimento em aveia pode reduzir o acamamento de plantas com reflexos na produtividade de biomassa e grãos. Objetivou-se, no estudo, determinar a viabilidade e a eficiência do uso do regulador de crescimento Trinexapac-Ethyl em aveia branca em diferentes condições de uso de N-fertilizante e de ano favorável e desfavorável ao cultivo. Neste estudo, dois experimentos foram conduzidos nos anos de 2011, 2012 e 2013, um para quantificar a taxa de produção de biomassa e outro para determinação da produtividade de grãos e o acamamento. O delineamento experimental foi de blocos ao acaso com quatro repetições em esquema fatorial 4 x 3 para doses de regulador de crescimento (0, 200, 400 e 600 mL ha^{-1}) e doses de nitrogênio (30, 90 e 150 kg ha^{-1}) respectivamente. Há redução linear da taxa de biomassa com o incremento da dose de regulador de crescimento em aveia independente da condição de ano e uso de N-fertilizante. No uso reduzido alto e muito alto de N-fertilizante, a dose de 495 mL ha^{-1} de regulador reduz com eficiência o acamamento sem prejuízos na produtividade de grãos de aveia, seja ano favorável, intermediário ou desfavorável ao cultivo.

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Introduction

The high yield of oat grains depends on a set of factors, such as technologies of management, climate and soil (Boschini et al., 2011; Fontaneli et al., 2012). The use of cultivars that are more productive and responsive to nitrogen (N) fertilization is also decisive in the increase of yield (Benin et al., 2012; Silva et al., 2015). Fertilization with N-fertilizer is necessary due to the inefficient amount released by the soil and because it is the nutrient most absorbed by cereals (Costa et al., 2013; Hawerroth et al., 2015). However, the increment in N use combined with favorable climatic conditions stimulates vegetative growth, favoring plant lodging (Flores et al., 2012).

Lodging is the phenomenon in which the plant loses its vertical position, tipping and falling on the soil, which directly affects the yield and quality of oat grains, compromising harvest (Silva et al., 2012; Hawerroth et al., 2015). It is a characteristic that involves the interaction of innumerous factors, such as wind, rainfall, soil, plant density, genetic resistance and management techniques (Silveira et al., 2011; Silva et al., 2015). One alternative adopted in graminee crops like rice (Arf et al., 2012) and wheat (Schwerz et al., 2015) has been the use of growth regulators that modify the internode distance and plant architecture, making the stem more resistant to breaking and lodging (Hawerroth et al., 2015).

Studies with growth regulators under conditions that allow to analyze their interaction with N fertilization and favorable and unfavorable year for cultivation can make viable the use of this technology in the oat production systems of South Brazil. Thus, this study aimed to determine the viability and efficiency of the growth regulator Trinexapac-Ethyl in white oat in different conditions of use of N-fertilizer and favorable and unfavorable year for cultivation.

Material and Methods

The study was carried out in the field, in the years of 2011, 2012 and 2013, in Augusto Pestana, RS, Brazil (28° 26' 30" S and 54° 00' 58" W). The soil of the experimental area is classified as typic dystroferric Red Latosol and the climate of the region, according to Köppen's classification, is Cfa, with hot summer without dry season. Ten days before sowing, soil analysis was performed to determine the following chemical characteristics (Tedesco et al., 1995): pH = 6.2, P = 33.9 mg dm^{-3}, K = 200 mg dm^{-3}, OM = 3.4%, Al = 0 $cmol_c$ dm^{-3}, Ca = 6.5 $cmol_c$ dm^{-3} and Mg = 2.5 $cmol_c$ dm^{-3}. Sowing was performed in a soybean/oat system from May 15 to June 30, using a seeder-fertilizer, to form the plots with five 5-m-long rows spaced by 0.20 m, totaling an experimental unit of 5 m^2. At sowing, 60 and 50 kg ha^{-1} of P_2O_5 and K_2O, respectively, were applied based on the contents of P and K in the soil for an expected grain yield of 3 t ha^{-1}, and 10 kg ha^{-1} of N as basal, while the rest was applied to contemplate the proposed doses as top-dressing in the stage of fourth fully expanded leaf, in the form of urea. The seeds were subjected to germination and vigor tests at the laboratory, to correct the desired density of 300 viable seeds m^{-2}. The experiments received applications of the fungicide Tebuconazole with commercial name of FOLICUR® CE at the dose of 0.75 L ha^{-1}. Weeds were controlled with the herbicide Metsulfuron-methyl with commercial name of ALY® at the dose of 4 g ha^{-1} and additional weedings, always when necessary. The growth regulator (Trinexapac-Ethyl) was applied using a backpack sprayer at constant pressure of 30 lb $inch^{-2}$, by the compressed CO_2, with flat fan spray nozzles, in the stages between the 1st and 2nd visible nodes of the oat stem.

In each cultivation year, two experiments were conducted, one to quantify the biomass production rate by the cuts performed every 30 days until the point of harvest, and another for harvest, to estimate grain yield and lodging. Both experiments used a randomized block design with four replicates in a 4 x 3 factorial scheme, with the sources of variation doses of growth regulator and doses of N-fertilizer, respectively. The sources of variation and their respective levels were: growth regulator doses (0, 200, 400 and 600 mL ha^{-1}) and N doses (30, 90 and 150 kg ha^{-1}) totaling 96 experimental units. To estimate grain yield, the experiments were manually harvested, through the cut of the three central rows of each plot. The moment of grain harvest was that also defined as the last cut in the experiment conducted for the analysis of biomass yield (120 days), a stage close to the point of harvest, with grain moisture around 15% (Silva et al., 2015). The plots were threshed with a stationary harvester and the collected material was taken to the laboratory to correct grain moisture to 13% and obtain grain yield. Lodging was visually estimated before harvest and expressed in percentage, considering the angle formed in the vertical position of the stem in relation to the soil and the area of lodged plants. The estimate was made using the methodology suggested by Moes & Stobbe (1991), modified, with lodging (LD) defined according to the following equation: LD(%) = I x A x 2, where I is the inclination degree of the plants, which varies from 0 to 5, and 0 (zero) is the absence of inclination and 5 is all plants completely lodged; A is the area with lodged plants in the plot, which varies from 0 to 10, and 0 (zero) is the absence of lodged plants and 10 corresponds to plants lodged in the entire plot, regardless of their inclination. Thus, the equation considers the incidence and severity of plant lodging. In the experiments aiming to quantify biomass yield through cuts along the development of the plants, the vegetal material was harvested close to the soil, by collecting one linear meter from the three central rows of each plot, at 30, 60, 90 and 120 days after emergence, totaling four cuts. The samples with the green matter were weighed on a precision scale and dried in a forced-air oven at temperature of 65 °C, until constant weight, with later estimation of total dry matter, converted to kg ha^{-1}.

After meeting the assumptions of homogeneity and normality through the Bartlett's test, analysis of variance was performed to detect the main effects and the effects of interaction. Then, the adjustment of a linear equation ($Y = b_0 \pm b_1x$) was used to estimate biomass yield rate d^{-1} ha^{-1} and the means were subjected to the Scott-Knott test at each dose of the growth regulator under the conditions of use of N-fertilizer. Subsequently, the fit of a second-degree equation ($Y = b_0 \pm b_1x \pm b_2x^2$) was used to estimate the ideal dose of the growth regulator, $x = -[(b_1)/(2b_2)]$, for grain yield and lodging. In the conditions in which the lodging behavior was linear

($Y = b_0 \pm b_1x$), it was considered the possibility of a maximum plant lodging of 0.05, a value added to the parameter "Y" of the equation, for the estimation of the ideal dose of the regulator through $x = [(Y - b_0)/(\pm b_1)]$.

Results and Discussion

At the moment of N-fertilizer application in 2012 (Figure 1), the means of maximum temperature were higher (± 27 °C) than in 2011 and 2013. The N applied as top-dressing in 2012 was followed by a rainfall volume above 50 mm, a volume also observed close to grain harvest. These facts justify the lower yield obtained in this year (Table 1), either by loss of the nutrient through leaching or damages due to the excessive rainfall in maturation, characterizing it as an unfavorable year (UY). In 2011, the maximum temperature close to the N-fertilizer application was lower (±12 °C) in relation to the other years. At the moment of N-fertilizer application, the soil was under adequate moisture conditions due to the accumulation of rains from the previous days (Figure 1). The large volume of rains during the cycle promoted periods of lower insolation, which reduces the photosynthetic efficiency of the plant. Therefore, the mean grain yield (Table 1) justifies a reasonable yield, characterizing it as an intermediate year (IY) for cultivation. In 2013, the maximum temperature recorded at the moment of the N-fertilizer application was around 20 ºC. The application of N-fertilizer occurred under favorable conditions of soil moisture (Figure 1). In this conditions and according to Table 1, although the total rainfall volume was the lowest one, its adequate distribution along the cycle (Figure 1) was decisive for the highest grain yield, above 4 t ha^{-1}, characterizing it as a favorable year (FY) for cultivation.

Battisti et al. (2013) claim that rainfall is the meteorological variable that most affects crop yield, in comparison to temperature, insolation and radiation. Arenhardt et al. (2015) highlight that the condition of the cultivation year in wheat is predominantly defined by the distribution and volume of rainfall.

In the sources of variation year, N-fertilizer dose and growth regulator dose, the main effects and the effects of

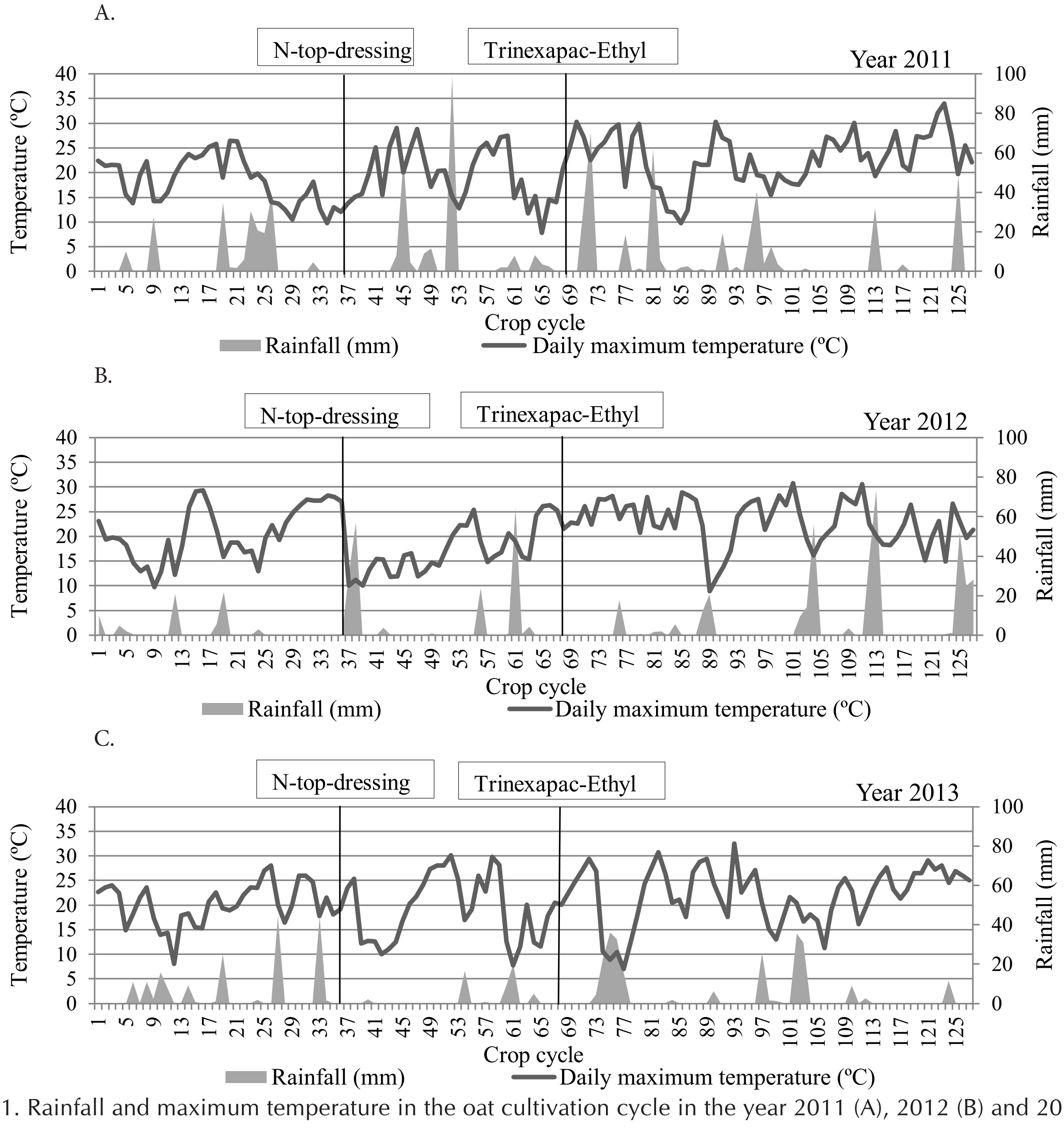

Figure 1. Rainfall and maximum temperature in the oat cultivation cycle in the year 2011 (A), 2012 (B) and 2013 (C)

Table 1. Temperature and rainfall in the months of cultivation and mean grain yield

Month	Temperature (°C)			Rainfall (mm)		GY_g (kg ha^{-1})	Class
	Min	Max	Mean	Mean of 25 years*	Observed		
2011							
May	10.5	22.7	16.6	149.7	100.5	3404	IY
June	7.9	18.4	13.1	162.5	191		
July	8.3	19.2	13.7	135.1	200.8		
August	9.3	20.4	14.8	138.2	223.8		
September	9.5	23.7	16.6	167.4	46.5		
October	12.2	25.1	18.6	156.5	211.3		
Total	-	-	-	909.4	973.9		
2012							
May	11.1	24.5	17.8	149.7	20.3	2841	UY
June	9.3	19.7	14.5	162.5	59.4		
July	7.4	17.5	12.4	135.1	176.6		
August	12.9	23.4	18.1	138.2	61.4		
September	12	23	17.5	167.4	194.6		
October	15	25.5	20.2	156.5	286.6		
Total	-	-	-	909.4	798.9		
2013							
May	10	22.6	16.3	149.7	108.5	4163	FY
June	8.9	20	14.5	162.5	86		
July	7	20.6	13.8	135.1	97		
August	6.6	19.8	13.2	138.2	163		
September	9.6	21	15.3	167.4	119.7		
October	13.2	27.1	20.2	156.5	138.8		
Total	-	-	-	909.4	712.0		

*Rainfall in the months from May to October from 1989 to 2013; FY - Favorable year; UY - Unfavorable year; IY- Intermediate year; GY_g - Mean grain yield

Table 2. Linear regression of biomass yield (BY) and means of grain yield (GY) and lodging (LD) in oat, as a function of growth regulator doses

Year	Growth regulator doses (mL ha^{-1})	BY= $b_0 \pm b_1 x$ (kg ha^{-1})	R^2	P (b_{1x})	GY (kg ha^{-1})	LD (%)
30 kg ha^{-1} of N-fertilizer						
2011 (IY)	0	3722 + 117x	0.92	*	3504 a	28.7 a
	200	3307 + 108x	0.91	*	3544 a	8.7 b
	400	3005 + 100x	0.90	*	3763 a	2.2 c
	600	2584 + 89x	0.91	*	3013 b	1.5 c
2012 (UY)	0	3187 + 109x	0.91	*	2812 a	48.7 a
	200	2768 + 99x	0.89	*	2955 a	38.7 b
	400	2190 + 85x	0.87	*	3016 a	22.5 c
	600	1928 + 78x	0.89	*	2520 b	21.2 c
2013 (FY)	0	4255 + 126x	0.92	*	4077 a	22.5 a
	200	3941 + 118x	0.92	*	3996 a	17.5 a
	400	3821 + 115x	0.90	*	4329 a	3.25 b
	600	3240 + 100x	0.92	*	4011 a	2.75 b
90 kg ha^{-1} of N-fertilizer						
2011 (IY)	0	4295 + 129x	0.93	*	4018 a	61.2 a
	200	3497 + 112x	0.93	*	4016 a	35.0 b
	400	3430 + 111x	0.91	*	4047 a	5.0 c
	600	3168 + 103x	0.90	*	3569 b	2.7 c
2012 (UY)	0	3703 + 120x	0.94	*	3369 a	62.5 a
	200	2704 + 98x	0.91	*	3459 a	68.7 a
	400	2654 + 96x	0.92	*	3401 a	35.0 b
	600	2544 + 94x	0.88	*	3169 a	33.7 b
2013 (FY)	0	4886 + 138x	0.91	*	3990 a	82.5 a
	200	4291 + 127x	0.93	*	3799 a	27.5 b
	400	4206 + 125x	0.90	*	4101 a	3.0 c
	600	3793 + 111x	0.91	*	4150 a	1.5 c
150 kg ha^{-1} of N-fertilizer						
2011 (IY)	0	4362 + 134x	0.93	*	3835 a	87.5 a
	200	4143 + 127x	0.93	*	3858 a	51.7 b
	400	3725 + 120x	0.93	*	3653 a	10.5 c
	600	3639 + 116x	0.90	*	3496 b	3.2 c
2012 (UY)	0	3857 + 129x	0.92	*	3430 a	58.7 a
	200	3741 + 121x	0.94	*	3550 a	57.5 a
	400	3691 + 118x	0.94	*	3669 a	38.7 b
	600	3075 + 109x	0.92	*	3344 b	33.7 b
2013 (FY)	0	4944 + 143x	0.92	*	4423 a	83.7 a
	200	4719 + 139x	0.93	*	4208 a	32.5 b
	400	4677 + 138x	0.91	*	4477 a	5.7 c
	600	4464 + 132x	0.91	*	4396 a	5.2 c

$P(b_{1x})$ - Probability of inclination; *Significant at 0.05 probability of error by t-test; Means followed by the same letter constitute homogeneous group at 0.05 probability of error; FY - Favorable year; UY - Unfavorable year; IY - Intermediate year

interaction were significant. Table 2 shows the effect of the growth regulator dose on the biomass yield (BY) under the conditions of N-fertilizer in favorable year (FY), intermediate year (IY) and unfavorable year (UY) for cultivation. At the N-fertilizer dose of 30 kg ha^{-1} (Table 2), regardless of the years, the increment in growth regulator dose caused reduction in the biomass yield rate. In these conditions, the absence of the growth regulator led to mean grain yields similar to those at 200 and 400 mL ha^{-1} in 2011 (IY) and 2012 (UY) and, at 600 mL ha^{-1}, it caused losses in grain yield. In 2013 (FY), although the biomass yield rate was reduced by the increase in the growth regulator dose, there were no losses in grain yield. Regardless of the condition of the year, the growth regulator dose of 400 mL ha^{-1} did not reduce grain yield and allowed effective reduction of lodging. At the N-fertilizer dose of 90 kg ha^{-1} (Table 2), the biomass yield rate was also reduced by the increment in the growth regulator dose.

In 2011 (IY), the growth regulator dose of 600 mL ha^{-1} significantly reduced grain yield, which did not occur in the other evaluated years. Under this condition, the dose of 400 mL ha^{-1} was also effective in the reduction of plant lodging without compromising grain yield, regardless of the year. At the N-fertilizer dose of 150 kg ha^{-1} (Table 2), there was also a linear reduction in the biomass yield rate by the growth regulator. The doses of 0, 200 and 400 mL ha^{-1} of the product did not alter grain yield in 2011 (IY) and 2012 (UY), except at the highest dose. In 2013 (FY), regardless of the growth regulator dose, grain yield was not affected. Lodging in this condition was also drastically reduced, indicating that the point of 400 mL ha^{-1} also reduces the fall of plants. In Table 2, the years with highest grain yield, especially at high doses of N-fertilizer, high lodging percentage was obtained in the absence of the growth regulator. Thus, the adjustment of an adequate dose, regardless of the condition of the year and N-fertilizer, can qualify the guarantee of recommendation of this technology.

In the plant, the N-fertilizer stimulates vegetative and root growth, with reflex in the absorption of nutrients and production of biomass and grains (Flores et al., 2012); however, nitrogen, along with the favorable meteorological conditions, acts on plant lodging (Bredemeier et al., 2013). Benin et al. (2012) and Prando et al. (2013) observed, in wheat, that the increment in the N-fertilizer dose favors plant lodging, especially in rainy years.

Espíndula et al. (2010) comment that the susceptibility to lodging is related to the excessive vegetative growth caused by the nutritional imbalance, reduced resistance of the stem, type of soil and climatic factors, among others. In wheat, the

Table 3. Regression and estimation of the ideal dose of growth regulator for oat under the condition of year and N-fertilizer

N-fertilizer ($kg\ ha^{-1}$)	Equation $Y = a \pm bx \pm cx^2$	R^2	P (b_{1x})	Ideal dose ($mL\ ha^{-1}$)	Y_g ($kg\ ha^{-1}$) LD (%)
	2011 (IY)				
30	$GY = 3447 + 2.33x - 4.10^{-3}x^2$	0.78	*	291	3786
	$LD = 28.3625 - 0.1163x + 1.3.10^{-4}x^2$	0.99	*	450	2
90	$GY = 3991 + 1.13x - 2.7.10^{-3}x^2$	0.90	*	210	4109
	$LD = 56.825 - 0.103x$	0.91	*	≅500	(5)
150	$GY = 3849 + 0.64x - 1.1.10^{-3}x^2$	0.95	*	290	3942
	$LD = 82.35 - 0.147x$	0.93	*	≅525	(5)
	2012 (UY)				
30	$GY = 2978 + 0.94x - 3.10^{-3}x^2$	0.86	*	156	3051
	$LD = 29.625 - 0.05x$	0.92	*	≅495	(5)
90	$GY = 3346 + 1.89x - 3.10^{-3}x^2$	0.88	*	315	3643
	$LD = 46 - 0.08x$	0.82	*	≅510	(5)
150	$GY = 3408 + 1.6x - 3.10^{-3}x^2$	0.84	*	266	3674
	$LD = 71.25 - 0.127x$	0.89	*	≅520	(5)
	2013 (FY)				
30	$GY = 3947 + 2.32x - 4.10^{-3}x^2$	0.99	*	290	4283
	$LD = 22.52 - 0.037x$	0.89	*	≅475	(5)
90	$GY = 3837 + 2.1x - 3.10^{-3}x^2$	0.87	*	350	4204
	$LD = 82.125 - 0.3343x + 3.5.10^{-4}x^2$	0.99	*	490	2
150	$GY = 4063 + 2.25x - 3.10^{-3}x^2$	0.98	*	375	4484
	$LD = 83.8375 - 0.3214x + 3.2.10^{-4}x^2$	0.99	*	502	3

P(b_{1x}) - Probability of inclination; *Significant at 0.05 probability of error; (5) - Considering maximum lodging of 0.05; GY - Grain yield; LD - Lodging; FY - Favorable year; UY - Unfavorable year; IY - Intermediate year; Y_g - Estimated response variable

reduction of lodging is dependent on the growth regulator dose and the N applied as top-dressing (Penckowsk et al., 2010). According to these authors, high doses of N-fertilizer increase plant lodging and high doses of the growth regulator can compromise grain yield. Similarly, Schwerz et al. (2015), in wheat, and Arf et al. (2012), in rice, observed that the growth regulator promotes reduction of lodging through the decrease in the internode length and increase in stem diameter, without affecting dry matter, making the stem more resistant.

According to the regression (Table 3), regardless of year and N-fertilizer, the second-degree equation explains the behavior of the growth regulator doses on grain yield. The highest doses were obtained with 290 mL ha^{-1} (2011/IY), 315 mL ha^{-1} (2012/UY) and 375 mL ha^{-1} (2013/FY), in the experiments with 30, 90 and 150 kg ha^{-1} of N-fertilizer, respectively. For lodging (Table 3), the second-degree equation showed adjusted dose of 450 mL ha^{-1} of the regulator in 2011 (IY) with 30 kg ha^{-1} of N-fertilizer and 490 and 502 mL ha^{-1} in 2013 (FY) with 90 and 150 kg ha^{-1} of N-fertilizer, respectively, with an estimated lodging below 5%. In the conditions in which the increase in growth regulator dose showed a linear behavior, the simulation of the optimal dose was obtained considering the possibility of a maximum lodging of 5%, a value added to the parameter "Y" of each equation (Table 3). Therefore, regardless of the condition of year, the greatest variations indicated optimal doses from 475 and 525 mL ha^{-1} of the growth regulator. In general, regardless of year and N-fertilizer, the ideal dose of growth regulator was fitted with 495 mL ha^{-1}, with maximum expected lodging of 4% without negative effects on yield.

The effects of the growth regulator Trinexapac-Ethyl on grain yield vary according to species, genotype and concentration used (Arf et al., 2012; Silva et al., 2015). In wheat, Penckowski et al. (2010) and Schwerz et al. (2015) observed adjusted doses of Trinexapac-Ethyl between 400 and 500 mL ha^{-1}, reducing height and lodging, without damages on grain yield. These results are similar to those obtained with oat in the present study.

Conclusions

1. There is a linear reduction in biomass rate with the increment of growth regulator dose in oat, regardless of the condition of year and use of N-fertilizer.

2. For reduced, high and very high use of N-fertilizer, the growth regulator dose of 495 mL ha^{-1} efficiently reduces lodging without damages on oat grain yield, in favorable, intermediate or unfavorable year for cultivation.

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