academicJournals

Vol. 12(10), pp. 795-804, 9 March, 2017
DOI: 10.5897/AJAR2016.11784
Article Number: B2FEE8A63077
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Contributive effect of growth regulator Trinexapac-Ethyl to oats yield in Brazil

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Received 3 October, 2016; Accepted 24 January, 2017

Studies on efficient use of the plant growth regulator can make this technology possible for leveraging oat yield in Brazil. This study aims to define the optimal dose growth regulator in oat, which allows plant lodging at most 5%. Establishing equations describe the yield indicators behavior and by using the optimal growth regulator dose for lodging, simulate the expression of these indicators regardless of reduced, high and very high conditions of nitrogen fertilization and favorable and unfavorable cultivation year. The study was conducted in 2013, 2014 and 2015, in carrying out two experiments, one to quantify the biomass yield and another aiming at estimating grain yield and lodging. The experimental design was a randomized block with four replications, following factorial scheme 4 x 3 to growth regulator doses (0, 200, 400 and 600 mL ha^{-1}) and N-fertilizer rates (30, 90 and 150 kg ha^{-1}), respectively. The use of 495 mL ha^{-1} growth regulator trinexapac-ethyl active principle is shown efficient at the reduction of oat plant lodging, regardless of the agricultural year condition and N-fertilizer rate. In the expression of grain yield and harvest index, quadratic behavior is obtained, however with decreasing linearity on the biomass yield and straw by increasing the growth regulator dose. The optimal dose of growth regulator in reducing oat lodging does not affect grain yield, but it reduces biological yield via biomass straw with elevation on the harvest index.

Key words: *Avena sativa*, biomass, straw, harvest index, multiple linear regression

INTRODUCTION

Oats have been shaping up as an important cultivation species in Brazil, either as coverage and soil protection or as human and animal consumption, for the plant and grains high nutritional and functional value.The search for healthy foods rich in protein and fiber has increased the demand for oats in the national market (Hawerroth et al., 2015; Silva et al., 2015).

High oats yield is associated with the cultivars performance, management technologies, favorable climate and soil (Fontaneli et al., 2012; Silva et al., 2015). Within the technologies management, nitrogen fertilization has significant effect in increasing yield (Costa et al., 2013; Mantai et al., 2015). In wheat (Flores et al., 2012) and oat (Mantai et al., 2015), increasing the dose and the right time of N-fertilizer application with the favorable growing conditions promote significant increase in grain yield. However, in unfavorable years, the nitrogen use efficiency may be compromised, reducing yield and increasing production costs (Benin et al., 2012; Silva et al., 2015). Flores et al. (2012) and Silva et al. (2015) also point out that the increase of nitrogen together with favorable climatic conditions increase the plant´s vegetative growth of the plant, facilitating the lodging occurrence.

The lodging is a complex phenomenon in which the plant loses its vertical position, leans and falls on the soil, resulting in recurved plants or even stems breakage, directly affecting the yield and the grains quality, besides bringing difficulties in harvesting (Silva et al., 2015; Hawerroth et al., 2015). Its expression depends on genetic factors, inter-related with external factors, such as wind, rainfall, soil, plant density and handling techniques, being the oats, a highly sensitive specie to lodging (Silveira et al., 2011; Silva et al., 2015). The lodging affects the morphological structure of the plant and the earlier it occurs, the greater the reduction in yield and grain quality (Trevizan et al., 2015). To minimize the lodging occurrence, there have been evaluated the use of growth regulators, as trinexapac-ethyl in crops such as soybeans (Souza et al., 2013), rice (Arf et al., 2012), wheat (Schwerz et al., 2015) and crotalaria (Kappes et al., 2011). The trinexapac-ethyl acts by reducing cell elongation in the vegetative stage and obstructing the gibberellic acid biosynthesis, plant hormone responsible for growth (Heckman et al., 2002; Kaspary et al., 2015). The growth regulators have been used to make the plants architecture more adapted and efficient at the use of natural resources and agricultural inputs, and to ensure high yield with quality (Souza et al., 2013; Hawerroth et al., 2015).

The biomass yield is related to the photosynthesis and respiration processes during the oats´ vegetative and reproductive phase (Demétrio et al., 2012). The relation between grain yield and biomass yield allows the determination of the harvest index, important parameter to define the efficiency with which the plant converts its photoassimilated into straw and grains (Silva et al., 2012). Expression of these traits is influenced by genotype, cultivation techniques, water availability, nutrients and climatic conditions (Mantai et al., 2015). Thus, studies of use efficiency of the growth regulator on the expression of lodging and its impact on yield indicators can enable the use of this technology for the yield oats in Brazil.

The aim of the study was to define the optimal dose growth regulator in oat, which allows plant lodging at most 5%. To establish equations describing the yield indicators behavior and by using the optimal dose growth regulator for lodging, to simulate the expression of these indicators independent of reduced, high and very high conditions of nitrogen fertilization along with both favorable and unfavorable cultivation year.

MATERIALS AND METHODS

The study was developed in the field during the agricultural years 2013, 2014 and 2015, in Augusto Pestana city, RS State, Brazil (28°26'30" South latitude and 54°00'58" West longitude). The experimental soil of the area is classified as Distrofic Red Latosol Typical, which its U.S. equivalent is Rhodic Hapludox (USDA, 2014), and the climate of the region, according to Köppen classification, is 'Cfa type', with hot summer without a dry season. In the study, ten days before sowing, soil analysis was performed and it was identified the following chemical characteristics of the local: pH = 6.2; P = 33.9 mg dm^{-3}; K =200 mg dm^{-3}; Organic Matter = 3.0%; Al= 0.0 $cmol_c$ dm^{-3}; Ca = 6.5 $cmol_c$ dm^{-3} and Mg = 2.5 $cmol_c$ dm^{-3}. In the years of study, the sowing was carried out on the vegetation cover of reduced C/N relation (soybean/oat system), between the dates of May 15th to June 30th, with seeder-fertilizer for composition of 5 rows of 5 m in length and row spacing of 0.20 m, forming the experimental unit of 5 m^2. At the oats sowing time 60 and 50 kg ha^{-1} of P_2O_5 and K_2O, were applied, respectively, based on levels of P and K in the soil and nitrogen base with 10 kg ha^{-1} and rest in order to contemplate the doses proposed as coverage at the stage of fourth leave expanded, with nitrogen available as urea. The seeds were submitted to germination and vigor tests in the laboratory in order to correct the desired density of 300 viable seeds m^{-2} for carrying out two experiments in each cultivation year. During the study execution, tebuconazole fungicide applications, trademark FOLICUR® CE were made at the dosage of 0.75 L ha^{-1}. Moreover, the weeds control was carried out with metsulfuron-methyl herbicide, trademark ALLY® C, at a dose of 4 g ha^{-1} and additional weeding whenever necessary. The growth regulator (Trinexapac-ethyl) was applied by spraying at constant pressure of 30 pol^{-2}, by compressed CO_2, with flat fan nozzle at the stage between the 1st and 2nd stem nodes oats visible.

In the study, two experiments were conducted, one to quantify the total biomass yield and another to estimate grain yield and lodging. In both experiments the experimental design was randomized blocks with four repetitions, following factorial scheme 4 x 3 the sources of variation of the growth regulator doses (0, 200, 400 and 600 mL ha^{-1}) and N-fertilizer rates (urea source) (30, 90 and 150 kg ha^{-1}), respectively, totaling 96 experimental units. The

*Corresponding author. Email: marollia@yahoo.com.br harvest of experiments to estimate the biomass and grain yield occurred manually by cutting three central rows of each plot, stage near the harvesting point (120 days), with grain moisture around 15%. The plots directed to grain harvest were threshed with a stationary harvester and directed the laboratory to correct grain moisture to 13%, and weighing to estimate grain yield per hectare (GY, kg ha^{-1}). The plots for biomass analysis were directed to forced-air oven at a temperature 65°C, until it reached constant weight to the biomass yield estimation per hectare (BY, kg ha^{-1}). From these determinations, the straw yield was estimated (SY, kg ha^{-1}) by subtraction $\mathrm{BY} - \mathrm{GY}$ and the harvest index (HI, kg kg^{-1}) by division GY/BY. The lodging was estimated visually and expressed in percentage, having considered the angle formed in the vertical position of the plants culm in relation to the ground and the area of lodged plants. For this estimate it was used the methodology suggested by Moes and Stobbe (1991), modified, with the lodging (LODG) defined by the equation: LODG% = I x LODG x 2; where: (I) reflects the plants inclination degree, ranging from 0 to 5 (0, absence of inclination and 5, all plants completely lodged); LODG represents the area with lodged plants in the plot, which ranges from 0 to 10, where 0 corresponds to the absence of lodged plants in the plot and 10 to lodged plants over the whole plot, regardless of their inclination. Therefore, this equation considered the incidence and severity of plants lodging.

To meet the homogeneity and normality assumptions via *Bartlett* tests, analysis of variance were performed for detection of the main effects and interaction. Through the regression, equations were obtained that describe the lodging behavior, grain yield, biomass yield, straw yield and harvest index. It was proceeded the adjustment of the linear equation ($\mathrm{Y}=\mathrm{b}_0 \pm \mathrm{b}_1\mathrm{x}$) considering the possibility of plant lodging of at most 5%, value added to the parameter "Y" of the equation, to estimate the optimal dose growth regulator, obtained by x= $[(\mathrm{Y} - \mathrm{b}_0)/(\pm \mathrm{b}_1)]$. Finally, the simulation of oat yield indicators was performed using the optimal dose of growth regulator by lodging, in the fertilization conditions with nitrogen and the cultivation year. The average grain yield values per crop year along with the maximum temperature and rainfall information in the oat crop cycle, were used to classify the years as favorable, intermediate and unfavorable. For all the determinations the computational program GENES was employed (Cruz, 2013) was used.

RESULTS AND DISCUSSION

In Figure 1, of the moment of N-fertilizer application in 2014, the averages of maximum temperature showed more elevated (±27°C) in relation to 2013 and 2015. The nitrogen topdressing applied in 2014 was followed by rainfall volume higher than 50 mm, volume also observed near to the grain harvest. These facts justify the lower yield obtained this year (Table 1), by the loss of the nutrient by leaching and losses by excessive rainfall in the maturation, characterizing unfavorable year (UY). In 2015, the maximum temperature next to the N-fertilizer application was the smallest (±12°C) compared to the other years. At the time of N-fertilizer application, the soil presented with conditions of adequate moisture by the rainfall accumulation from the previous days (Figure 1). On the other hand, the high rainfall volume during the culture cycle afforded periods of lowest insolation, possibly causing lower photosynthesis efficiency by the plant. Thus, the weather conditions with the grain yield average of Table 1, justifies a reasonable yield, characterizing as an intermediate year (IY) of cultivation. In 2013, the maximum temperature obtained at the time of N-fertilizer application was around 20°C and N-fertilizer application occurred in favorable conditions of soil moisture (Figure 1). In this condition, although the total volume of rainfall has been further reduced (Table 1), proper distribution of rainfall throughout the cycle (Figure 1) was decisive in the highest grain yield, more than 4 t ha^{-1}, characterizing favorable year (FY) of cultivation. Rainfall has been the main weather variable that affects agricultural productivity, although temperature, light and sunlight are also important (Battisti et al., 2013). Stress caused by lack or excess of water adversely affects the wheat and oats´ development (Benin et al., 2012; Mantai et al., 2015). Arenhardt et al. (2015) highlight that the rainfall defines the favorable and unfavorable year condition to the wheat cultivation.

In the analysis of the sources of variation year, N-fertilizer rate and growth regulator dose, differences between the main effects and interaction were observed (data not shown). Therefore, in the Tables 2, 3, 4 and 5, the decomposition of these interactions are illustrated in the distinct fertilization conditions with N-fertilizer and favorable year (FY), intermediate (IY) and unfavorable (UY) of cultivation. In Table 2, the reduced N-fertilizer rate (30 kg ha^{-1}) showed the largest plants lodging in 2014 (UY), independent of growth regulator dose. In the high nitrogen rate (90 kg ha^{-1}), high lodging was also observed in 2014, in the presence of the regulator doses. This same trend was also observed at the highest N-fertilizer rate (150 kg ha^{-1}). In high and higher N-fertilizer rates, the absence of regulator use indicated higher plant lodging in the most favorable cultivation year. Moreover, the point of 400 mL ha^{-1} indicated the lowest average lodging, similar to the highest dose of the product (600 mL ha^{-1}), which suggests the optimal dose adjustment at this concentration range. In generally, trend of reduction in the lodging was observed with increasing growth regulator dose, regardless of the year condition and N-fertilizer. Studies performed on wheat (Chavarria et al., 2015; Schwerz et al., 2015), rice (Arf et al., 2012), crotalaria (Kappes et al., 2011) and oats (Hawerroth et al., 2015; Kaspary et al., 2015) point out that regardless of N-fertilizer, the increasing of the growth regulator doses decreases the plant height and consequently the lodging. Hawerroth et al. (2015) still claim that the regulator use is effective when administered in favorable oat cultivation years.

In the estimation of the optimal dose of growth regulator for lodging expression (Table 3), the tested regression equations identified linear trend, regardless of year and N-fertilizer rate. For this estimate, the possibility of plant lodging was taken into consideration at most 5%, value added to the parameter "Y" of each equation.

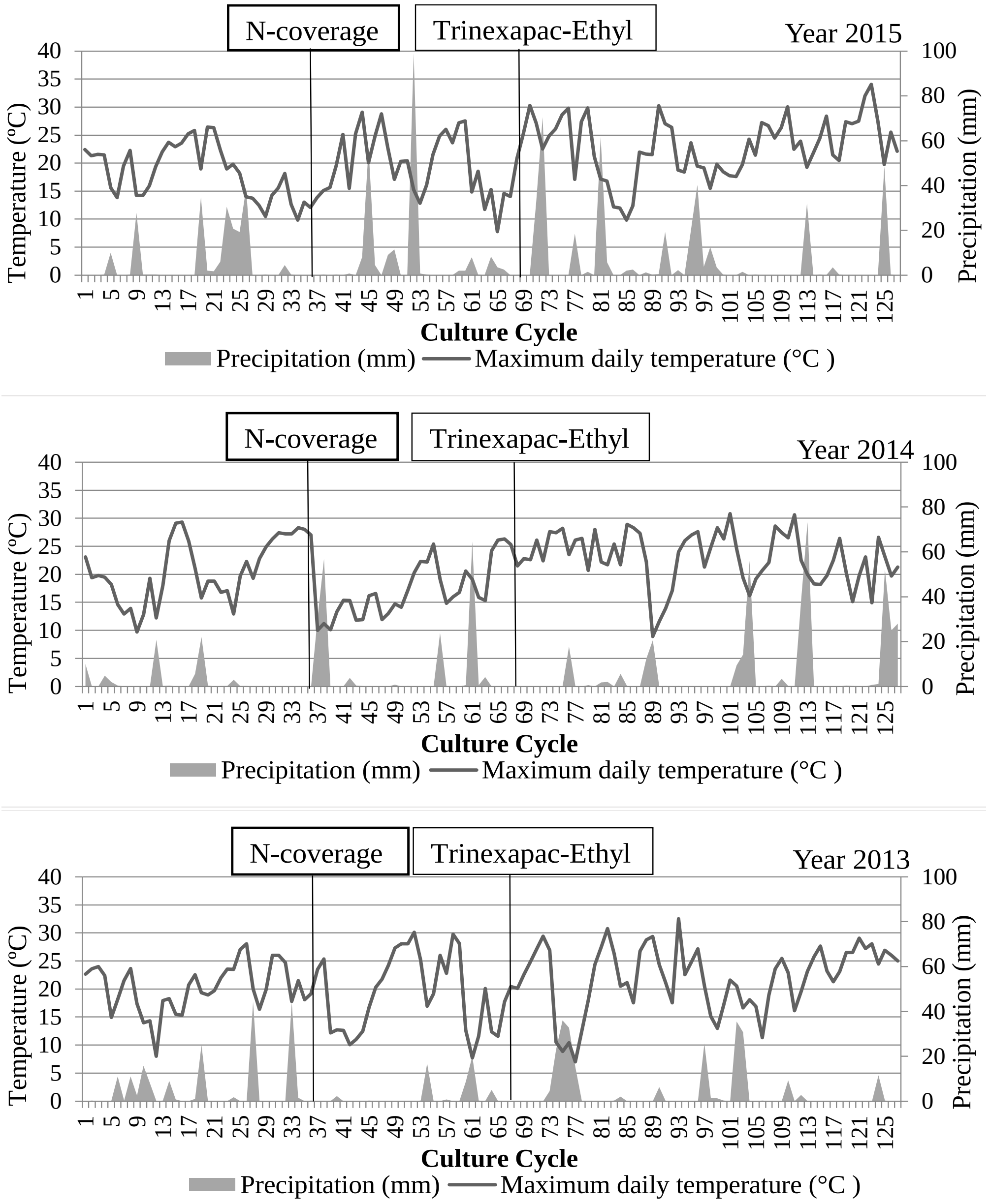

Figure 1. Precipitation and maximum temperature during the oat cycle. Application of N-fertilizer and Trinexapac-ethyl

Regardless of the cultivation year condition, the growth regulator doses averages obtained for the different N-fertilizer rates remained between 460 and 523 mL ha^{-1}. In general, regardless of year and N-fertilizer, the optimal dose of growth regulator proved to be adjusted to 495 mL ha^{-1}, concentration that would theoretically nullify the oat plants lodging.

In wheat (Pagliosa et al., 2013; Trevizan et al., 2015) and rice (Arf et al., 2012; Alvarez et al., 2014) observed reduction in plant lodging with the use dose of 400 mL ha^{-1} of regulator. In crotalaria (Kappes et al., 2011) and soybean (Souza et al., 2013) the efficient reduction of the lodging was obtained with the dose application of 500 mL ha^{-1} of regulator. Kaspary et al. (2015) and Guerreiro and Oliveira (2012), studying the growth regulator effects on grain yield and quality of oat seeds, claim that the dose of 500 mL ha^{-1} reduced the plant height by 60% and, consequently, altering the expression of plants lodging.

In Table 4, the analysis of grain yield behavior (GY), regardless of year and N-fertilizer rate, the two-degree equation was adequate. In this equation, the including of the optimal dose of growth regulator for lodging (Table 3),

Table 1. Temperature and precipitation data in the months and years of oat cultivation and average grain yield.

Year	Month	Temperature (°C)			Precipitation (mm)		$GY_{\bar{x}}$ (kg ha^{-1})	Class
		Minimum	Maximum	Average	Average*	Occurred		
	May	10.5	22.7	16.6	149	100		
	June	07.9	18.4	13.1	162	191		
	July	08.3	19.2	13.7	135	200		
2015	August	09.3	20.4	14.8	138	223	3404	IY
	September	09.5	23.7	16.6	167	046		
	October	12.2	25.1	18.6	156	211		
	Total	-	-	-	909	973		
	May	11.1	24.5	17.8	149	020		
	June	09.3	19.7	14.5	162	059		
	July	07.4	17.5	12.4	135	176		
2014	August	12.9	23.4	18.1	138	061	2841	UY
	September	12.0	23.0	17.5	167	194		
	October	15.0	25.5	20.2	156	286		
	Total	-	-	-	909	798		
	May	10.0	22.6	16.3	149	108		
	June	08.9	20.0	14.5	162	086		
	July	07.0	20.6	13.8	135	097		
2013	August	06.6	19.8	13.2	138	163	4163	FY
	September	09.6	21.0	15.3	167	119		
	October	13.2	27.1	20.2	156	138		
	Total	-	-	-	909	712		

*= Average rainfall obtained in the months from May to October 1982 to 2007; FY= Favorable year; UY= Unfavorable year; IY= Intermediate year; $GY_{\bar{x}}$= average grain yield; Class= classification of the year.

Table 2. Averages oat plant lodging by year and N-fertilizer rate in response to the use of growth regulator.

N-coverage (kg ha^{-1})	Year	Growth regulator dose (mL ha^{-1})			
		0	200	400	600
		LODG (%)			
	2015 (IY)	28^{b}	08^{c}	02^{b}	01^{b}
30	2014 (UY)	48^{a}	38^{a}	22^{a}	21^{a}
	2013 (FY)	22^{b}	17^{b}	03^{b}	02^{b}
$\bar{x}_{30}$		33	21	09	08
	2015 (IY)	61^{b}	35^{b}	05^{b}	02^{b}
90	2014 (UY)	62^{b}	68^{a}	35^{a}	33^{a}
	2013 (FY)	82^{a}	27^{b}	03^{b}	01^{b}
$\bar{x}_{90}$		68	43	14	12
	2015 (IY)	87^{a}	51^{a}	10^{b}	03^{b}
150	2014 (UY)	58^{b}	57^{a}	38^{a}	33^{a}
	2013 (FY)	83^{a}	32^{b}	05^{b}	05^{b}
$\bar{x}_{150}$		76	46	18	14
$\bar{x}_{\text{overall}}$		59	36	14	12

Averages followed by different letters are statistically different group by Scott-Knott test at 5% error probability; $\bar{x}_{N}$= average obtained lodging in the three years of study; $\bar{x}_{\text{overall}}$= overall average.

Table 3. Estimate the optimal dose of growth regulator by year and N-fertilizer rate of the predictability maximum lodging of 5%.

N-coverage (kg ha^{-1})	Year	Equation $\mathbf{LODG = a \pm bx}$	R²	P (bx)	Y_E (%)	Optimal dose (mL ha^{-1})
	2015 (IY)	$23.55 - 0.045x$	0.80	*		≅410
30	2014 (UY)	$29.62 - 0.050x$	0.92	*	(5)	≅495
	2013 (FY)	$22.52 - 0.037x$	0.89	*		≅475
$\bar{x}_{30}$						≅460
	2015 (IY)	$56.82 - 0.103x$	0.91	*		≅500
90	2014 (UY)	$46.00 - 0.080x$	0.82	*	(5)	≅510
	2013 (FY)	$48.75 - 0.088x$	0.93	*		≅490
$\bar{x}_{90}$						≅500
	2015 (IY)	$82.35 - 0.147x$	0.93	*		≅525
150	2014 (UY)	$71.25 - 0.127x$	0.89	*	(5)	≅520
	2013 (FY)	$75.15 - 0.133x$	0.94	*		≅525
$\bar{x}_{150}$						≅523
$\bar{x}_{\text{overall}}$						≅495

P(bx)= parameter that measures the line slope; R²= determination coefficient; * = Significant at 5% error probability by t test.; ( ) = considering the possibility the maximum lodging of 5%; $\bar{x}_N$= average obtained in the three years of study; $\bar{x}_{\text{overall}}$= overall average; Y_E = estimated value; Optimal dose = dose regulator that allows maximum lodging of 5%.

indicates grain yield expectation greater than 3000 kg ha^{-1}, except for the year 2012 (UY) in the reduced dose of N-fertilizer (30 kg ha^{-1}). In the average of the years for the reduced of N-fertilizer condition, the optimal dose of growth regulator was 460 mL ha^{-1}, with grain yield expectation in 3490 kg ha^{-1}. In high rate (90 kg ha^{-1}) and highest (150 kg ha^{-1}) of N-fertilizer, regardless of the agricultural year condition, little change was obtained in the regulator dose, ranging from 500 and 520 mL ha^{-1}, with grain yield expectation of 3544 and 3900 kg ha^{-1}, respectively. In the low and highest dose of nitrogen rate the variation of the growth regulator dose was between 460 and 520 mL ha^{-1}, respectively. On the general average, regardless of year and N-fertilizer rate, the use of 495 mL ha^{-1} of growth regulator brings a grain yield expectation of 3645 kg ha^{-1}.

In Table 4, in the analysis of biological yield (BY), regardless of year and N-fertilizer rate, the linear equations proved adjusted, indicating that the increasing of growth regulator dose causes a reduction in the total biomass. The inclusion of the optimum dose of growth regulator obtained for the lodging (Table 3), in the equation that describes the behavior of biological yield, indicated high expression values and, with strong dependence of the cultivation year, condition most favored in 2013 (FY). In the years' average, the supply of 30 kg ha^{-1} of N-fertilizer with use of the optimal dose regulator (460 mL ha^{-1}) showed biological yield of 7725kg ha^{-1}. The nitrogen in high rate (90 kg ha^{-1}) and highest (150 kg ha^{-1}), indicate biological yield of approximately 9000 kg ha^{-1}, in the adjusted rates of 500 and 520 mL ha^{-1} of regulator, respectively, regardless of agricultural year condition. On the general average, the use of 495 mL ha^{-1} of growth regulator indicated biological yield of 8570 kg ha^{-1}.

Effects of trinexapac-ethyl on the biological yield and grain vary according to the species, the genotype within the species and concentration used (Arf et al., 2012; Silva et al., 2015). The growth regulators use in the bean crop (Bernardes et al., 2010) and rice (Alvarez et al., 2014), contributed to control the excessive vegetative growth, without causing changes in grain yield. In maize, the regulator use causes increase in width and decreases the leaves length without effect on yield components (Zagonel and Ferreira, 2013). Researching the use of growth regulator on wheat, in different nitrogen rates, Zagonel et al. (2002) observed that even in higher nitrogen rates, the regulator use provided decrease in plant height, without effect on stem diameter and mass of dried plants. These authors highlight that in adverse conditions by weather, the plant lodging can be avoided with the regulator use. These results differ from those obtained by Espindula et al. (2010) who reported wheat yield reductions with the use of trinexapac-ethyl. In oats, Guerreiro and Oliveira (2012) note that the use of trinexapac-ethyl causes reduction in plant height and negatively affects the grain yield. Result contrary to that obtained by Kaspary et al. (2015) who claim that the

Table 4. Regression equation to estimate grain yield (GY) and biological yield (BY) in oat using the optimal dose of growth regulator.

N-coverage (kg ha^{-1})	Year	Equation	R²	P (cx²)	Optimal dose (mL ha^{-1})	Y$_E$ (kg ha^{-1})
		$\mathbf{GY = a \pm bx \pm cx^2}$				
	2015 (IY)	$3447 + 2.33x - 4.9.10^{-3}x^2$	0.88	*	410	3580
30	2014 (UY)	$2978 + 0.94x - 2.8.10^{-3}x^2$	0.86	*	495	2760
	2013 (FY)	$4024 + 0.95x - 1.5.10^{-3}x^2$	0.96	*	475	4140
$\bar{x}_{30}$	-	$3483 + 1.40x - 3.0.10^{-3}x^2$	0.90	*	460	3490
	2015 (IY)	$3991 + 1.13x - 2.9.10^{-3}x^2$	0.90	*	500	3831
90	2014 (UY)	$3368 + 0.87x - 2.0.10^{-3}x^2$	0.99	*	510	3295
	2013 (FY)	$3952 + 0.80x - 2.0.10^{-3}x^2$	0.91	*	490	3508
$\bar{x}_{90}$	-	$3926 + 0.93x - 2.3.10^{-3}x^2$	0.93	*	500	3544
	2015 (IY)	$3849 + 0.64x - 1.1.10^{-3}x^2$	0.95	*	525	3882
150	2014 (UY)	$3408 + 1.60x - 2.8.10^{-3}x^2$	0.83	*	520	3483
	2013 (FY)	$4381 + 0.41x - 0.8.10^{-3}x^2$	0.95	*	525	4375
$\bar{x}_{150}$	-	$3879 + 0.88x - 1.6.10^{-3}x^2$	0.91	*	520	3900
$\bar{x}_{\text{overall}}$	-	$3762 + 1.07x - 2.3.10^{-3}x^2$	0.91	*	495	3645
		$BY = a \pm bx$				
	2015 (IY)	$8929 - 4.32x$	0.86	*	410	7157
30	2014 (UY)	$8636 - 3.62x$	0.71	*	495	6840
	2013 (FY)	$11061 - 3.96x$	0.94	*	475	9180
$\bar{x}_{30}$	-	$9542 - 3.96x$	0.84	*	460	7725
	2015 (IY)	$9958 - 1.75x$	0.99	*	500	9083
90	2014 (UY)	$8758 - 0.73x$	0.97	*	510	8385
	2013 (FY)	$12511 - 6.03x$	0.98	*	490	9557
$\bar{x}_{90}$	-	$10409 - 2.83x$	0.98	*	500	9000
	2015 (IY)	$9950 - 2.95x$	0.95	*	525	8402
150	2014 (UY)	$9692 - 3.55x$	0.98	*	520	7846
	2013 (FY)	$12719 - 3.84x$	0.85	*	525	10700
$\bar{x}_{150}$	-	$10787 - 3.44x$	0.93	*	520	8982
$\bar{x}_{\text{overall}}$	-	$10246 - 3.41x$	0.92	*	495	8570

P(cx²)= parameter that measures the slope of the line; R²= determination coefficient; * = Significant at 5% error probability by t test.; $\bar{x}_N$= average obtained in the three years of study; $\bar{x}_{\text{overall}}$= overall average; Y$_E$ = estimated value; Optimal dose = dose regulator that allows maximum lodging of 5%.

growth regulator use generates increase in grain yield, but with reduced physiological seed quality. According to Rodrigues et al. (2003), the effect of growth regulator is dependent on the dose, environmental conditions and nutrition and plant health culture.

In Table 5, the behavior of straw yield (SY), regardless of year and N-fertilizer rate, decreasing linear trend is observed, similar to that obtained in biological yield (Table 4). It highlighted that the effects of reducing the biological productivity (Table 4) by the use of the regulator are fully achieved by reducing the straw yield (Table 5) and not by changes in grain yield. In average years, the reduction of N-fertilizer condition (30 kg ha^{-1}), with use of the optimal dose regulator showed expected straw yield of 4510 kg ha^{-1}. In high (90 kg ha^{-1}) and highest doses (150 kg ha^{-1}) of N-fertilizer, regardless of the agricultural year condition, the use of optimal dose regulator under these conditions indicates straw yield expectation of 5290 and 5160 kg ha^{-1}, respectively. On the general average, the optimal dose of regulator, regardless of year and N-fertilizer dose (495 mL ha^{-1}) scales an expectation of straw yield of 4987 kg ha^{-1}. For

Table 5. Regression equation to estimate straw yield (SY) and harvest index (HI) in oat using the optimal dose of growth regulator.

N-coverage (kg ha^{-1})	Year	Equation	R²	P (bx)	Optimal dose (mL ha^{-1})	Y_E (kg ha^{-1})
		$\mathbf{SY = a \pm bx}$				
	2015 (IY)	$5284 - 3.69x$	0.81	*	410	3770
30	2014 (UY)	$5547 - 2.92x$	0.94	*	495	4102
	2013 (FY)	$6977 - 4.02x$	0.98	*	475	5065
$\bar{x}_{30}$	-	$5936 - 3.54x$	0.91	*	460	4510
	2015 (IY)	$5847 - 1.09x$	0.86	*	500	5303
90	2014 (UY)	$5310 - 0.41x$	0.93	*	510	5100
	2013 (FY)	$8619 - 6.42x$	0.99	*	490	5470
$\bar{x}_{90}$	-	$6592 - 2.64x$	0.93	*	500	5290
	2015 (IY)	$6056 - 2.34x$	0.90	*	525	4827
150	2014 (UY)	$6172 - 3.48x$	0.93	*	520	4363
	2013 (FY)	$8371 - 3.94x$	0.78	*	525	6303
$\bar{x}_{150}$	-	$6866 - 3.25x$	0.87	*	520	5160
$\bar{x}_{overall}$	-	$6464 - 3.14x$	0.90	*	495	4987
		$\mathbf{HI = a \pm bx \pm cx^2}$				
	2015 (IY)	$0.37 + 7.4.10^{-4}x - 9.8.10^{-7}x^2$	0.98	*	410	0.51
30	2014 (UY)	$0.33 + 6.2.10^{-4}x - 9.2.10^{-7}x^2$	0.99	*	495	0.41
	2013 (FY)	$0.37 + 1.2.10^{-4}x - 1.9.10^{-7}x^2$	0.97	*	475	0.38
$\bar{x}_{30}$	-	$0.35 + 4.9.10^{-4}x - 6.9.10^{-7}x^2$	0.98	*	460	0.43
	2015 (IY)	$0.40 + 1.8.10^{-4}x - 3.0.10^{-7}x^2$	0.94	*	500	0.42
90	2014 (UY)	$0.38 + 1.4.10^{-4}x - 2.5.10^{-7}x^2$	0.99	*	510	0.39
	2013 (FY)	$0.31 + 1.2.10^{-4}x - 2.3.10^{-7}x^2$	0.99	*	490	0.32
$\bar{x}_{90}$	-	$0.36 + 1.4.10^{-4}x - 2.6.10^{-7}x^2$	0.97	*	500	0.38
	2015 (IY)	$0.37 + 2.8.10^{-4}x - 3.6.10^{-7}x^2$	0.99	*	525	0.43
150	2014 (UY)	$0.35 + 3.8.10^{-4}x - 3.7.10^{-7}x^2$	0.93	*	520	0.48
	2013 (FY)	$0.33 + 3.0.10^{-4}x - 3.0.10^{-7}x^2$	0.91	*	525	0.40
$\bar{x}_{150}$	-	$0.35 + 3.2.10^{-4}x - 3.4.10^{-7}x^2$	0.94	*	520	0.44
$\bar{x}_{overall}$	-	$0.35 + 3.2.10^{-4}x - 4.3.10^{-7}x^2$	0.96	*	495	0.42

P(bx)= parameter that measures the slope of the line; R²= determination coefficient; * = Significant at 5% error probability by t test.; $\bar{x}_N$= average obtained in the three years of study; $\bar{x}_{overall}$= overall average; Y_E = estimated value; Optimal dose = dose regulator that allows maximum lodging of 5%.

Mantai et al. (2015), the oats straw on the soil is essential for preserving and improving the physical, chemical and biological attributes, as well as help protect against erosion as well as reduce soil loss water by evaporation. Silva et al. (2012) also commented on the straw layer ability to control weeds on the soil surface. Hawerroth et al. (2015) stated that the use of trinexapac-ethyl growth regulator in oats is responsible for the reduction of vegetative growth, thereby decreasing the straw volume.

On analysis of the harvest index (Table 5), regardless of year and N-fertilizer dose, the two-degree equation was adequate. In this equation, at the inclusion of the optimal dose of growth regulator (Table 3) showed lower harvest index in 2013 (FY). In fact, the grain yield reached stability based on the quadratic behavior, which in biological yield, mainly via straw, the linear behavior promotes steady growth, reducing the harvest index. Thus, in oats, observed high harvest index reflected in greater efficiency, though occasionally, as in favorable condition, greater use is obtained via straw yield.

Schaedler et al. (2009) studying the genetic variability of the physiological parameters of oat yield, observed harvest index between 0.33 and 0.45. The results found by these authors are in line with those obtained in this study which revealed that with the use of optimal dose regulator dedicated the lodging plants at most 5%, ranging from 0.38 to 0.44, regardless of the agricultural year condition and N-fertilizer rate. Mantai et al. (2015) and Silva et al. (2012) highlighted that the sowing density, nitrogen fertilization and the favorable weather conditions are the main factors which affect the harvest index expression of the cereals. In oats, Mantai et al. (2015) point out that the reduction in harvest index in favorable year does not express the efficiency obtained for the grains elaboration, because the increase in grain yield does not follow the same way as the expression of biological yield, causing reduction of the harvest index by higher volume of biomass via straw. In wheat, with regulator application, Zagonel and Fernandes (2007) observed decrease in harvest index with increasing nitrogen rate. Trevisan et al. (2015) pointed out that the growth regulator application increase the harvest index by reducing the biomass straw.

On average, Table 4 revealed the zero regulator dose (y=a), and the grain yield estimate of 3762 kg ha^{-1}, as similar to those obtained using the optimal dose (495 mL ha^{-1}), with 3645 kg ha^{-1}. On the other hand, there was significant reduction of the biological yield estimate from zero to the optimal dose, with 10246 to 8570 kg ha^{-1}, respectively. This behavior is better understood by the general average estimate of straw yield (Table 5), which showed significant reduction in the zero point to the use of optimal dose, from 6464 to 4987 kg ha^{-1}, confirming that the reduction of biological yield occurs at the expense of straw yield and not by grain yield. This fact also justifies the increase of expression in the estimate of the harvest index (Table 5) at the zero dose to optimal dose regulator from 0.35 to 0.42, respectively, because the grains relation versus straw by the harvest index is obtained by the division between grain yield by the biological yield (grain + straw). Therefore, a reduction of the biological yield without changing the grain yield promotes natural increase of the harvest index. The results presented by the growth regulators used in other species, corroborate with the ones obtained in oat, indicating that the use of trinexapac-ethyl efficiently reduces the plant lodging without losses in grain yield; however it reduces biological yield at the expense of biomass straw, consequently promoting an increase on the harvest index.

Conclusions

The use of 495 mL ha^{-1} of the growth regulator of trinexapac-ethyl active principle shows to be efficient in reducing the oat plant lodging, regardless of the agricultural year condition and N-fertilizer rate. In the expression of grain yield and harvest index, quadratic behavior is obtained, however, with decreasing linearity on the biomass and straw yield at higher doses the growth regulator. The growth regulator optimal dose in reducing oat lodging does not affect grain yield, but it reduces biological yield via biomass straw with elevation on the harvest index.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to CNPq, FAPERGS, CAPES and UNIJUÍ for the resources contributed towards development of this research and to the Scholarship for Scientific and Technological Initiation and Research Productivity.

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