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Oat yield through panicle components and growth regulator

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A B S T R A C T

The growth regulator modifies the expression of lodging and panicle components in oat plants, with reflexes in yield. The objective of this study was to define the optimal dose of growth regulator in oat for a maximum lodging of 5%. In addition, this study aimed to identify potential variables of the panicle to compose the multiple linear regression model and the simulation of grain yield in conditions of use of the regulator under low, high and very high fertilization with nitrogen. The study was conducted in 2011, 2012 and 2013 in a randomized block design with four replicates in a 4 x 3 factorial scheme, for growth regulator doses (0, 200, 400 and 600 mL ha^{-1}) and N-fertilizer doses (30, 90 and 150 kg ha^{-1}), respectively. The growth regulator doses of 395, 450 and 560 mL ha^{-1} are efficient, with maximum oat lodging of 5%, under low, high and very high nitrogen fertilization, respectively. The grain weight per panicle and panicle harvest index are potential variables to compose the multiple linear regression model. Multiple linear regression equations are efficient in the simulation of oat grain yield under the conditions of use of growth regulator, regardless of the N-fertilizer dose.

Palavras-chave:
Avena sativa
nitrogênio
trinexapac-ethyl
regressão linear múltipla

Produtividade da aveia por componentes da panícula e regulador de crescimento

R E S U M O

O regulador de crescimento modifica a expressão do acamamento e componentes da panícula da aveia com reflexos na produtividade. O objetivo do estudo é a definição da dose ideal do regulador de crescimento em aveia para no máximo 5% de acamamento. Além disso, o estudo visa também identificar variáveis potenciais da panícula para compor o modelo de regressão linear múltipla e a simulação da produtividade de grãos nas condições de uso do regulador em reduzida, alta e muito alta fertilização com nitrogênio. O estudo foi conduzido em 2011, 2012 e 2013 em delineamento de blocos ao acaso com quatro repetições em fatorial 4 x 3, para doses de regulador (0, 200, 400 e 600 mL ha^{-1}) e de N-fertilizante (30, 90 e 150 kg ha^{-1}), respectivamente. As doses de 395, 450 e 560 mL ha^{-1} de regulador de crescimento são eficientes, com acamamento de plantas de aveia de no máximo 5%, em reduzida, alta e muito alta fertilização com nitrogênio, respectivamente. A massa de grãos da panícula e o índice de colheita da panícula são variáveis potenciais para compor o modelo de regressão linear múltipla. As equações de regressão linear múltipla são eficientes na simulação da produtividade de grãos de aveia nas condições de uso de regulador de crescimento independente da dose de N-fertilizante.

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Introduction

Nitrogen (N) has strong influence on length, number and weight of grains in oat panicles, with direct reflexes on grain yield (Mantai et al., 2016). The increment in N along with favorable climatic conditions, despite significantly favoring grain yield, increase the vegetative growth of the plant, facilitating the occurrence of lodging (Silva et al., 2015). Lodging is directly related to the size of the plant and stem resistance, an event that can limit oat harvest and grain yield (Hawerroth et al., 2015). The use of growth regulators in the reduction of lodging has been a practice already employed in crotalaria (Kappes et al., 2011), rice (Alvarez et al., 2014) and wheat (Chavarria et al., 2015).

Dalchiavon et al. (2012), using multiple linear regression model, estimated rice grain yield incorporating to the model the number of panicles m^{-2}, number of spikelets panicle^{-1} and the weight of one thousand grains. Godoy et al. (2015), also studying soil attributes in rice, simulated grain yield based on the use of copper, nitrogen, iron and phosphorus by multiple linear regression. The relationships between oat panicle components and grain yield can favor the construction of yield simulation models in the more efficient planning of N management with the use of the regulator. The objective of this study was to define the ideal dose of the growth regulator for a maximum lodging of 5% in oat plants. In addition, it also aimed to identify potential variables associated with oat panicle through the use of the regulator to compose the multiple linear regression model and the simulation of grain yield, under conditions of low, high and very high N fertilization.

Material and Methods

The study was carried out at the field, in the agricultural years of 2011, 2012 and 2013, in the municipality of Augusto Pestana-RS, Brazil. 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. For the study, ten days before sowing, the soil was analyzed and showed the following chemical characteristics (Tedesco et al., 1995): pH = 6.2, P = 33.9 mg dm^{-3}, K = 200 mg dm^{-3}, OM = 3.0%, Al = 0 $cmol_c$ dm^{-3}, Ca = 6.5 $cmol_c$ dm^{-3} and Mg = 2.5 $cmol_c$ dm^{-3}. The plots consisted of 5 rows with length of 5 m and spaced by 0.20 m, totaling an experimental unit of 5 m^2. Sowing was performed with a seeder-fertilizer on the vegetal cover of reduced C/N ratio (soybean/oat system). The seeds were subjected to germination and vigor tests in the laboratory to correct the desired density of 300 viable seeds m^{-2}. Along the study, the fungicide tebuconazole was applied at the dose of 0.75 L ha^{-1}. In addition, weeds were controlled with the herbicide metsulfuron-methyl at the dose of 4 g ha^{-1} and additional weedings, always when necessary. The growth regulator was applied with a backpack sprayer at the constant pressure of 30 lb pol^{-2}, by the compressed CO_2, using flat fan nozzles, in the stage between the 1st and 2nd visible nodes of the oat stem.

The experimental design was randomized blocks with four replicates, following a 4 x 3 factorial scheme, for the sources of variation doses of growth regulator (0, 200, 400 and 600 mL ha^{-1}) and doses of N-fertilizer (source: urea) (30, 90 and 150 kg ha^{-1}), respectively, totaling 48 experimental units. Lodging was visually estimated and expressed in percentage in the stage close to grain harvest, following the methodology proposed by Moes & Stobbe (1991). The experiment was manually harvested by cutting the three central rows of each plot. Plants were threshed with a stationary threshing machine and sent to the laboratory to correct grain moisture to 13%, after weighing and estimation of grain yield per hectare (GY, kg ha^{-1}). In the analysis of the oat panicle-type inflorescence, 20 panicles were randomly collected in each experimental unit and sent to the laboratory to correct grain moisture to 13%. Then, threshing was performed to determine the following components: panicle length (cm), number of spikelets per panicle (n), number of grains per panicle (n), panicle weight (g), grain weight per panicle (g) and panicle harvest index (g g^{-1}) by the relationship between grain weight per panicle and panicle weight.

After the assumptions of homogeneity and normality were met, through Bartlett's tests, analysis of variance was performed to detect the main effects and the effects of interaction. The fit of the second-degree equation ($GY = b_0 \pm b_1x \pm b_2x^2$) for grain yield (GY) was used to obtain the dose of the growth regulator (x) by the equation ($x = -b_1/2b_2$). The linear regression equation describing the behavior of the expression of the lodging percentage of oat plants by the increment in the doses of the growth regulator was fitted. This equation considered the possibility of plant lodging of 5%, a value added to the parameter "Y" of the equation, obtained by $x = [(Y - b_0)/(\pm b_1)]$. The potential variables for the multiple linear regression model were selected using the Stepwise technique. This procedure iteratively constructs a sequence of regression models through the addition and removal of variables using partial F statistics, according to the model:

$$F_j = \frac{QS_R\left(\beta_j \mid \beta_1, \beta_0\right)}{QM_E\left(x_j, x_1\right)} \quad (1)$$

where:

QS_R - quadratic sum of the regression; and,

$QM_E(x_j, x_1)$ - quadratic mean of the error for the model containing the variables x_1 and x_j.

The variables selected via Stepwise were used to compose the multiple linear regression equation in the simulation of oat grain yield. This equation is composed of two or more variables in the generation of an equation of the following type:

$$y = b_0 \pm b_1x \pm b_2x_2 \pm b_3x_3 \pm \ldots b_nx_n \quad (2)$$

described in the matrix form as:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ M \\ Y_n \end{bmatrix}; X = \begin{bmatrix} 1 & X_{11} & X_{12} & \ldots & X_{p1} \\ 1 & X_{21} & X_{22} & \ldots & X_{p2} \\ M & M & M & \ldots & M \\ 1 & X_{1n} & X_{2n} & \ldots & X_{pn} \end{bmatrix}; \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ M \\ \beta_n \end{bmatrix}; \text{ and } \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ M \\ \varepsilon_n \end{bmatrix} \quad (3)$$

These matrices are used to obtain the values of the regression coefficients, being

$$\hat{\beta} = \left(X'X\right)^{-1} X'Y \quad (4)$$

and the variance of these coefficients is obtained by the covariance matrix of the vector of the regression coefficients:

$$\hat{Cov}\left(\hat{\beta}\right) = \left(X'X\right) \quad \hat{\sigma} \quad (5)$$

$$\hat{\sigma}^2 = \frac{\left(Y - X\hat{\beta}\right)\left(Y - X\hat{\beta}\right)}{n - p - 1} \quad (6)$$

where:

n - number of equations; and,

p - number of parameters.

The test of hypothesis verified $H_0 : \beta_i = 0$ vs $H_a : \beta_i \neq 0$, expressed by:

$$t = \frac{\hat{\beta}_i - \beta_i}{\sqrt{\hat{V}\left(\hat{\beta}_i\right)}} \quad (7)$$

The values of the ideal dose of the growth regulator were employed in the multiple linear regression model together with the mean values of the oat panicle components validated by the Stepwise technique. The analyses were performed using the computational program Genes.

Results and Discussion

At the moment of N-fertilizer application in 2012, the mean of maximum temperature was higher (± 27 °C) in relation to 2011 and 2013 (Figure 1). N application was followed by more than 50 mm of rainfalls, a volume also observed close to grain harvest. These facts justify the reduced yield obtained (Table 1), characterizing 2012 as an unfavorable year (UY). In 2011, the lowest maximum temperature (± 12 °C) was observed close to the application of N-fertilizer in comparison to the other years. At the moment of fertilization, the soil had favorable moisture conditions due to the accumulation of rainfalls in the previous days (Figure 1). However, the large volume of rainfall during the cycle promoted shorter periods of insolation, reducing the efficiency of photosynthesis, which, combined with the means of grain yield (Table 1), classified 2011 as an intermediate year (IY). In 2013, the maximum temperature at the moment of N-fertilizer application was around 20 °C, with fertilization under favorable conditions of soil moisture

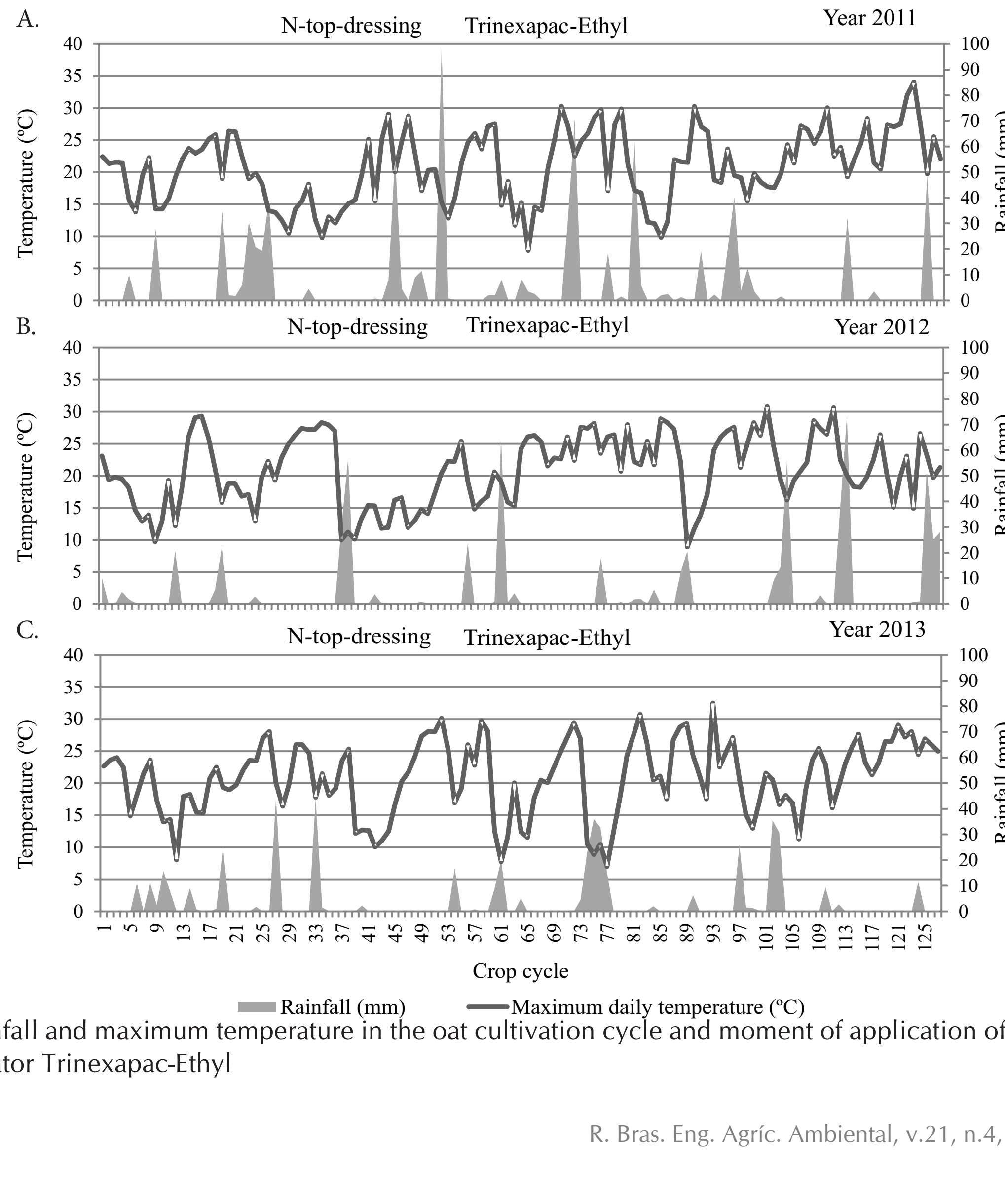

Figure 1. Rainfall and maximum temperature in the oat cultivation cycle and moment of application of N-fertilizer and growth regulator Trinexapac-Ethyl

Table 1. Data of temperature and rainfall in the months and years of oat cultivation with means of grain yield and classification of the agricultural years

Year	Month	Temperature °C			Rainfall (mm)		GY_x (kg ha^{-1})	Class
		Minimum	Maximum	Mean	Mean of 25 years*	Occurred		
2011	May	10.5	22.7	16.6	149	100	3404	IY
	June	07.9	18.4	13.1	162	191		
	July	08.3	19.2	13.7	135	200		
	August	09.3	20.4	14.8	138	223		
	September	09.5	23.7	16.6	167	046		
	October	12.2	25.1	18.6	156	211		
	Total	-	-	-	909	973		
2012	May	11.1	24.5	17.8	149	020	2841	UY
	June	09.3	19.7	14.5	162	059		
	July	07.4	17.5	12.4	135	176		
	August	12.9	23.4	18.1	138	061		
	September	12.0	23.0	17.5	167	194		
	October	15.0	25.5	20.2	156	286		
	Total	-	-	-	909	798		
2013	May	10.0	22.6	16.3	149	108	4163	FY
	June	08.9	20.0	14.5	162	086		
	July	07.0	20.6	13.8	135	097		
	August	06.6	19.8	13.2	138	163		
	September	09.6	21.0	15.3	167	119		
	October	13.2	27.1	20.2	156	138		
	Total	-	-	-	909	712		

*Mean rainfall recorded in the months from May to October from 1982 to 2007; FY - Favorable year; UY - Unfavorable year; IY - Intermediate year; GY - Grain yield

(Figure 1). Although the total volume of rainfalls was the lowest one (Table 1), the adequate distribution of rainfall during the cycle (Figure 1) was decisive for a higher grain yield (Table 1), characterizing 2013 as a favorable year (FY).

According to Storck et al. (2014), the environmental conditions depending on site and year of cultivation decisively alter grain yield, and the agricultural year is the factor that most contributes to the variation in yield. In wheat and oat, the conditions of the cultivation year are predominantly defined by the distribution and volume of rainfall (Arenhardt et al., 2015). It should be pointed out that the excess of rainfalls in the grain filling stage contributes to plant lodging and reduction in the quality, reflecting in losses of yield (Prando et al., 2013). As reported, the variation of grain yield due to the year of cultivation is large, especially because of the distribution and volume of rainfall (Arenhardt et al., 2015). The variations between the years modify the efficiency of use of N in the elaboration of the production components and lodging (Mantai et al., 2015). Therefore, the simulation of grain yield per agricultural year does not contemplate the development of efficient models of expectation and prediction, which justifies the analysis of cumulative effect of the variability between favorable, intermediate and unfavorable years of cultivation in the polynomial regression models in the estimation of the ideal dose of the regulator and of multiple linear regression in the simulation of grain yield through oat panicle components.

In the estimation of the ideal dose of the growth regulator for grain yield, the second-degree equations were significant, regardless of the N-fertilizer dose, adjusted in 255, 300 and 320 mL ha^{-1} under conditions of low, high and very high fertilization, respectively (Table 2). It should be pointed out that these doses do not guarantee grain yield and reduced lodging simultaneously, requiring the fit of the ideal dose through plant lodging. The estimate of the ideal dose of the regulator through plant lodging indicated linear regression equations, regardless of the doses of N-fertilizer (Table 2). The estimate of the ideal

Table 2. Estimate and simulation of the ideal dose of growth regulator in the restriction of plant lodging and grain yield

N-fertilizer (kg ha^{-1})	Equation $Y = b_0 \pm b_1x \pm b_2x^2$	P (b_{ix})	R^2	Ideal dose (mL ha^{-1})	Y_E
	Grain yield (kg ha^{-1}) (2011 + 2012 + 2013)				
30	$3457 + 1.86x - 3.0 \cdot 10^{-3}x^2$	*	0.87	255	3736
90	$3725 + 1.58x - 2.9 \cdot 10^{-3}x^2$	*	0.88	300	3938
150	$3773 + 1.51x - 2.3 \cdot 10^{-3}x^2$	*	0.92	320	4014
	Lodging (%) (2011 + 2012 + 2013)				
30	$24 - 0.05x$	*	0.87	395	(5)
90	$59 - 0.12x$	*	0.82	450	(5)
150	$75 - 0.16x$	*	0.88	560	(5)
	Equation $GY = b_0 \pm b_1x \pm b_2x^2$				GY (kg ha^{-1})
30	$3457 + 1.86x - 3.0 \cdot 10^{-3}x^2$	*	0.87	395	3725
90	$3725 + 1.58x - 2.9 \cdot 10^{-3}x^2$	*	0.88	450	3848
150	$3773 + 1.51x - 2.3 \cdot 10^{-3}x^2$	*	0.92	560	3878

$P(b_{ix})$ - Parameter that measures the significance of the slope of the line; R^2 - Coefficient of determination; *Significant at 0.05 probability of error, respectively; (5) - Consideration of the possibility of maximum plant lodging of 0.05; Y_E - Estimated value; GY_E _ Estimated grain yield

dose of the regulator considered a maximum plant lodging of 5%, value added to the parameter "y" of each equation. Adjusted doses of 395, 450 and 560 mL ha^{-1} were obtained under low, high and very high N fertilization, respectively, maintaining yields similar to those for the use of the optimal dose through grain yield.

In wheat, the increment in N doses favors vegetative growth and yield, promoting greater possibility of lodging (Penckowski et al., 2010). Chavarria et al. (2015) point out that, in wheat, doses between 400 and 500 mL ha^{-1} of regulator with trinexapac-ethyl as the active principle are efficient to reduce lodging. Amabile et al. (2004), in barley, obtained adjusted dose of regulator of 500 mL ha^{-1}. In rice, Nascimento et al. (2009) obtained doses in the interval of 300 to 600 mL ha^{-1}.

The identification of potential variables via Stepwise to compose the multiple linear regression model indicated the variables grain weight per panicle and panicle harvest index as significantly efficient, regardless of the dose of N-fertilizer

Table 3. Identification of potential variables via Stepwise and the respective means to compose the multiple linear regression model

N (kg ha^{-1})	Source of variation	Stepwise model (2011+2012+2013) / Dose of Regulator (mL ha^{-1})				
		0	200	400	600	(0-600)
30	Regression	*	*	*	*	*
	GWP (g)	A 2.70*	B 2.50*	C 2.30*	D 2.06*	2.39*
	PHI (g g^{-1})	A 0.84*	A 0.83*	A 0.83*	B 0.78*	0.82*
	Ideal dose (mL ha^{-1})	ns	ns	ns	ns	395*
90	Regression	*	*	*	*	*
	GWP (g)	A 2.90*	B 2.62*	C 2.43*	D 2.00*	2.5*
	PHI (g g^{-1})	A 0.88*	A 0.86*	A 0.82*	B 0.80*	0.84*
	Ideal dose (mL ha^{-1})	ns	ns	ns	ns	450*
150	Regression	*	*	*	*	*
	GWP (g)	A 2.36*	A 2.30*	B 2.26*	C 2.00*	2.23*
	PHI (g g^{-1})	A 0.89*	A 0.87*	B 0.86*	B 0.84*	0.86*
	Ideal dose (mL ha^{-1})	ns	ns	ns	ns	560*

GWP - Grain weight per panicle; PHI - Panicle harvest index; Ideal dose - Dose of growth regulator for the estimate of lodging lower than 0.05 (mL ha^{-1}); *Significant at 0.05 probability of error by the F-probability; nsNot significant; Means followed by the same letter in the row do not differ significantly at 0.05 probability of error by the Scott-Knott test

Table 4. Multiple linear regression for the estimate of oat grain yield through the components of the panicle and growth regulator doses

N (kg ha^{-1})	Dose of regulator (mL ha^{-1})	Equation	GY		CI	
			E	O	LL	UL
		GY = $f_1(x_1, x_2, ...)$	(kg ha^{-1})			
		(2011 + 2012 + 2013)				
30	0	$GY = 3831 + 2588_{PHI} - 906_{GWP}$	3531	3531	3189	3829
	200	$GY = 5812 - 5015_{PHI} + 732_{GWP}$	3479	3499	3184	3773
	400	$GY = 16585 - 13767_{PHI} - 818_{GWP}$	3275	3303	3101	3680
	600	$GY = 5428 + 2207_{PHI} - 1928_{GWP}$	3178	3181	2715	3588
	Ideal dose	$GY = 5744 - 0.8_{DR} - 1670_{PHI} - 272.8_{GWP}$	3398	3246	2655	3478
90	0	$GY = 1949 + 175_{PHI} - 582_{GWP}$	3792	3792	3569	3987
	200	$GY = 6625 - 4257_{PHI} + 303_{GWP}$	3758	3758	3564	3927
	400	$GY = 2458 - 1252_{PHI} + 954_{GWP}$	3751	3750	3465	3948
	600	$GY = 9827 - 5273_{PHI} - 948_{GWP}$	3710	3629	3321	3898
	Ideal dose	$GY = 5475 - 0.2_{DR} - 3486_{PHI} + 488.8_{GWP}$	3863	3757	3643	3864
150	0	$GY = -8854 + 12335.5_{PHI} + 746_{GWP}$	3886	3896	3595	4158
	200	$GY = -2721 + 8696.1_{PHI} - 444_{GWP}$	3821	3872	3662	4055
	400	$GY = 8871 - 3325.8_{PHI} - 982_{GWP}$	3789	3833	3547	4182
	600	$GY = 2131 + 3715.7_{PHI} - 741_{GWP}$	3768	3745	3402	4044
	Ideal dose	$GY = 2205 - 0.03_{DR} + 1948_{PHI} - 9.7_{GWP}$	3839	3862	3734	3980

GY - Grain yield (kg ha^{-1}); GWP - Grain weight per panicle (g); PHI - Panicle harvest index (g g^{-1}); Ideal dose - Dose of growth regulator for the estimate of maximum plant lodging of 0.05; GY_E - Estimated grain yield (kg ha^{-1}); GY_O - Observed grain yield (kg ha^{-1}); CI_{LL} - Lower limit of the confidence interval; CI_{UL} - Upper limit of the confidence interval

(Table 3). The mean values observed in these variables indicated reduction of expression by the increment in the growth regulator dose. The analysis involving also the growth regulator doses (0-600 mL ha^{-1}) confirmed the possibility of using the grain weight per panicle and panicle harvest index in simulations by multiple linear regression (Table 2). Therefore, the mean values of the potential variables (Table 3) together with the ideal dose of growth regulator in the reduction of lodging (Table 2) were used to simulate grain yield (Table 4). The identification of components that influence grain yield is decisive in the elaboration of simulation models (Leal et al., 2015). The use of the Stepwise technique can qualify the selection of potential variables in the simulation through multiple linear regression (Balbinot Júnior et al., 2005). In the simulation of grain yield through multiple regression in rice, Dalchiavon et al. (2012) identified the number of panicles, weight and number of spikelets panicle^{-1} and thousand-grain weight as potential variables through the Stepwise technique. Also using this technique, in maize, Balbinot Júnior et al. (2005) defined ear weight, number of grains per row, number of rows per ear and number of plants and ears per area as appropriate in the simulation of grain yield through multiple linear regression.

In Table 4, the simulation of grain yield indicated similarity between the estimated (E) and observed (O) values, being within the limits of the established confidence interval (CI). In the multiple model including potential components of the panicle and ideal dose of regulator, the results were satisfactory in the estimate of grain yield, with great proximity of expression of simulated and observed values.

The multiple linear regression was successfully used in species like wheat (Leilah & Khateeb, 2005), rice (Dalchiavon et al., 2012; Godoy et al., 2015), maize (Balbinot Júnior et al., 2005) and soybean (Mercante et al., 2010) for the simulation of grain yield and identification of potential variables of alteration by the management on the species.

Conclusions

1. The growth regulator doses of 395, 450 and 560 mL ha^{-1} are efficient, with maximum lodging of oat plants of 5%, under low, high and very high nitrogen fertilization, respectively.

2. The grain weight per panicle and panicle harvest index are potential variables to compose the multiple linear regression model.

3. The multiple linear regression equations are efficient in the simulation of oat grain yield under conditions of use of growth regulator, regardless of the N-fertilizer dose.

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