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A PROPOSAL OF SIMULATION OF WHEAT GRAIN PRODUCTIVITY BY NITROGEN AND METEOROLOGICAL ELEMENTS

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ABSTRACT

The development of efficient simulation models can facilitate the crop planning and the crop predictability analysis. The objective of the study is to propose a simulation model of wheat grain productivity by the nitrogen supply management with variables related to the plant and the meteorological elements, in high succession systems and reduced N-residual release. In the study, two experiments were conducted in 2013, 2014 and 2015, one to quantify the biomass productivity and another one to stablish grain productivity. The design was a randomized block with four replicates in factorial 4 x 3, for N-fertilizer doses (0, 30, 60, 120 kg ha^{-1}) and nutrient supply forms [single condition (100%) at the phenological stage V_3 (third leaf expanded); fractionated, (70 and 30%) in the phenological stage V_3/V_6 (third and sixth leaf expanded); fractionated (70 and 30%) in the phenological stage V_3/E (third leaf expanded and in the beginning of grain filling)], and respectively, in soy/wheat and corn/wheat systems. The proposed model that interacts polynomial regression with multiple linear regression is efficient in the simulation of wheat grain productivity in the single and fractionated supply of nitrogen with weather elements in the systems of high and low release of N-residual.

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INTRODUCTION

Wheat is the second most produced and consumed cereal in the world, with significant importance in the global agricultural economy due to the great demand of its derivatives in the production of food (Camponogara *et al*., 2016; Santos *et al*., 2016). Wheat grain productivity is dependent on cultivation techniques, genetic potential of cultivars, and edaphoclimatic conditions (Pinnow *et al*., 2013; Ferrari *et al*., 2016). Among the cultivation techniques, nitrogen management is decisive on wheat productivity (Chavarria *et al*., 2015). The cultivars of wheat of high genetic potential are highly dependent on nitrogen fertilization and appropriate weather conditions to obtain high productivity (Rosa *et al*., 2009; Silva *et al*., 2014). Nitrogen fertilization becomes necessary because of the insufficient quantity in the soil, generating the need for the nutrient supply in the form of fertilizers (Costa *et al*., 2013; Pietro-Souza *et al*., 2013). It is worth noting that the weather conditions and cropping systems alter the use efficiency of nitrogen on the biomass and wheat grain productivity (Arenhardt *et al*., 2015, Ferrari *et al*., 2016). The quantity and appropriate timing of nitrogen supply in wheat must be better explored. Small doses limit the productivity and high doses increase the production costs and favor lodging (Ma *et al*., 2010; Arenhardt *et al*., 2015), apart from environmental contamination by nutrient losses (Theago *et al*., 2014; Arenhardt *et al*., 2015). The higher efficiency of the nitrogen in the coverage is directly linked to adequate soil moisture, condition not always obtained at the time of fertilization (Santos *et al*., 2016; Silva *et al*., 2016b). Therefore, research aimed at the fertilization improvement suggests that fractionated nitrogen supply can reduce losses with greater use of the nutrient to the elaboration of biomass and grains (Ferrari *et al*., 2016). Although there are several estimation models of grain productivity in cereals (Souza *et al*., 2013; Rosa *et al*., 2015), few studies have been carried out to simulate the productivity of wheat involving, simultaneously, variables related to the plant, the weather condition and important managements that influence productivity (Silva *et al*., 2016b; Mantai *et al*., 2017). Therefore, the simulation of grain productivity of wheat by the analysis of the biomass productivity and harvest index, with the determination of the thermal sum and precipitation in the crop cycle and involving the management of nitrogen in different doses and provided in single and fractionated way, can contribute to the development of an efficient simulation model of crop predictability in agricultural systems. The objective of the study is to propose a simulation model of wheat grain productivity by nitrogen supply management with variables related to plant and meteorological elements, in high succession systems and reduced N-residual release.

MATERIALS AND METHODS

The field experiments were conducted in the years 2013, 2014 and 2015, in Augusto Pestana (28° 26' 30" South and 54° 00' 58" West), Rio Grande do Sul, Brazil. The soil of the experimental area is classified as typical dystrophic red latosol and the climate is classified as Cfa, according to Köppen classification, with hot summer and without dry season. Ten days before sowing, soil analysis was performed and identified in the average of the years the following chemical characteristics (Tedesco *et al*., 1995): i) soy/wheat system (pH= 6.5, P= 23.6 mg dm^{-3}, K= 295 mg dm^{-3}, OM= 2.9%, Al= 0 cmolc dm^{-3}, Ca= 6.8 cmolc dm^{-3}, and Mg= 3.1 cmolc dm^{-3}) and; ii) corn/wheat system (pH= 6.1, P=49.1 mg dm^{-3}, K= 424 mg dm^{-3}, OM= 3.0%, Al= 0 cmolc dm^{-3}, Ca= 6.3 cmolc dm^{-3} and Mg= 2.5 cmolc dm^{-3}). Sowing was carried out according to the wheat technical indications, mechanically, with experimental units using 5 rows of 5 m in length and spaced 0.20 m apart, totaling 5 m^2. In sowing were applied 30 and 20 kg ha^{-1} of P_2O_5 and K_2O, respectively, based on the soil P and K contents for expected grain productivity of 3 t ha^{-1} and N at the base with 10 kg ha^{-1}, the remainder aiming to contemplate the doses proposed in coverage, with nitrogen made available in the form of urea. The seeds have been submitted to germination and vigor tests in laboratory in order to provide the desired density of 400 viable seeds per m^2. During the execution of the study were performed applications of the fungicide tebuconazole in the dosage of 0.75 L ha^{-1}. Weed control was performed with metsulfuron-metil herbicide at the dose of 4g ha^{-1}. In the study, BRS Guamirim low-growing, early-season, resistant to lodging, of commercial class type "bread", with high productive potential was used. This cultivar represents the standard biotype commonly desired by the triticulturists of southern Brazil.

In each cultivation system (soybean/wheat, corn/wheat), two experiments were conducted, one to quantify biomass production and another for grain productivity. In both experiments the design was of randomized blocks with four replicates in a 4 x 3 factorial scheme for N fertilizer doses (0, 30, 60 and 120 kg ha^{-1}) and forms of nutrient supply [single way (100%) in the V_3 phenological stage (third leaf expanded); fractionated (70 and 30%) in the V_3/V_6 phenological stages (third and sixth leaves expanded); and fractioned (70 and 30%) in the V_3/E phenological stages (third leaf expanded and early grain filling)], respectively, totaling 192 experimental units. It is noteworthy that in all the years of cultivation the application of N-fertilizer in V_3, V_6 and E, occurred at 30, 60 and 90 days after emergence of wheat, respectively. The harvest of the experiments to estimate the productivity of biomass and grains occurred manually by cutting the three central lines of each plot, near the harvest point (125 days), with grain moisture of 15% (Silva *et al*., 2015). The plots directed to the grain harvest were harvested with a stationary harvester and sent to the laboratory for correction of grain moisture to 13%, after weighing and estimation of grain productivity (GP, kg ha^{-1}). The plots for biomass analysis were directed to a forced air heater at 65 ºC until reaching constant weight for weighing and estimation of biomass productivity (BP, kg ha^{-1}). The values of the general averages, along with the information of temperature and rainfall, were used to classify the years as unfavorable, intermediate and favorable to the crop. The meteorological data of thermal sum and pluviometric precipitation were obtained through a meteorological station located at about 500 meters from the experiments. The thermal sum (Ts) was obtained from the emergence of plants by the following model:

$$Ts = \sum_{i=1}^{n} \left(\frac{T_{max} + T_{min}}{2} \right) - Bt \tag{1}$$

where T_{max} = maximum temperature; T_{min} = minimum temperature; n = number of days of the sowing-harvest period; Bt = base temperature. The base temperature used in the study was 4 ºC, according to results found by Pedro Júnior *et al*. (2004). Catering to the assumptions of normality and homogeneity via Bartlett tests, variance analysis for detection of main and interaction effects was carried out. The adjustment of the polynomial regression equation in the estimation of the harvest index (HI) was performed as a function of the nitrogen rates, in each supply condition (V_3, V_3/V_6 and V_3/E), given by:

$$HI = a \pm bx \pm cx^2 \tag{2}$$

where a, b and c are coefficients obtained by polynomial regression and x and x^2 are the nitrogen rates. For the composition of the multiple linear regression model in the estimation of wheat biomass productivity, involving meteorological variables (thermal sum and precipitation) and nitrogen doses, the potential variables were chosen through the StepWise technique. This procedure iteratively constructs a sequence of regression models by adding and removing variables, selecting the ones with larger relation to the main variable (y), using the statistic of partial F, according to the model:

$$F_j = \frac{SQ_R(\beta_j | \beta_1, \beta_0)}{MQ_E(x_j, x_1)} \tag{3}$$

where SQ_R is the quadratic sum of the regression and $MQ_E(x_j, x_1)$ is the quadratic average of the error in the model containing the variables x_1 and x_j. The variables selected through StepWise were used to determine the multiple linear regression equation, for the simulation of wheat biomass productivity (BP), given by an equation of the type

$$BP = b_0 \pm b_1 x \pm b_2 x_2 \pm b_3 x_3 \pm \cdots \pm b_n x_n \tag{4}$$

where $b_0, b_1, b_2, b_3, \ldots, b_n$ are coefficients obtained by multiple linear regression and $x, x_1, x_2, x_3, \ldots, x_n$ are variables classified as significant by the StepWise model. The equation is described in matrix form as:

$$y = \begin{bmatrix} Y_1 \\ Y_2 \\ M \\ Y_n \end{bmatrix}; X = \begin{bmatrix} 1 & X_{11} & X_{12} & \cdots & X_{p1} \\ 1 & X_{21} & X_{22} & \cdots & X_{p2} \\ M & M & M & \ldots & M \\ 1 & X_{1n} & X_{2n} & \cdots & X_{pn} \end{bmatrix}; \ \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ M \\ \beta_n \end{bmatrix}; e\ \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ M \\ \varepsilon_n \end{bmatrix} \tag{5}$$

From these matrices is obtained the value of the regression coefficients, considering

$$\hat{\beta} = (X'X)^{-1} X'Y \tag{6}$$

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

$$C\hat{o}v(\hat{\beta}) = (X'X)^{-1}\hat{\sigma}^2 \tag{7}$$

$$\hat{\sigma}^2 = \frac{(Y - X\hat{\beta})(Y - X\hat{\beta})}{n - p - 1} \tag{8}$$

where n is the number of equations and p is the number of parameters. The hypothesis test verified $H_0: \beta_i = 0$ vs $H_a: \beta_i \neq 0, \neq 0$, expressed by:

$$t = \frac{\hat{\beta}_i - \beta_i}{\sqrt{\hat{V}(\hat{\beta}_i)}} \tag{9}$$

Since wheat grain productivity is the product between biomass productivity and harvest index (GP = BP x HI), equation 10 represents the proposed model for the simulation of grain productivity of wheat, given by the combination of equation 4 with equation 2, expressed by:

$$GP = [(b_0 \pm b_1 x \pm b_2 x_2 \pm b_3 x_3 \pm \cdots \pm b_n x_n) \times (a \pm bx \pm cx^2)] \tag{10}$$

All statistical procedures have been performed using the software Genes.

RESULTS AND DISCUSSION

In Figure 1C, at the moment of supply of nitrogen at the V_3 stage in 2015, the average maximum temperature was the highest in relation to the other years. High temperatures were observed without rainfall before or after fertilization, favoring losses of nutrients by volatilization, implying reduction of the development of fertilizers and spikes per area. The N-fertilizer application in the phenological stage V_6 was followed by high volume of rainfall, favoring the loss of nutrient by leaching. At the phenological stage E, little quantity of the supply was assimilated by the plant due to the long period of rainfall followed by high temperatures. These facts, along with productivity averages (Tables 1), classify the year of 2015 as intermediate (IY) to the crop. In 2013 (Figure 1A), the occurrence of rainfall in days prior to N-fertilizer supply, at the phenological stages V_3, V_6 and E, implied in soil moisture favorable to the nutrient management and, in addition, with milder temperatures in the vegetative cycle, favoring the production of tillers and distribution of photoassimilates to the productivity. Under these conditions and according to Table 1, the total rainfall volume was similar to the historical average, with adequate rainfall distribution throughout the cycle (Figure 1). These characteristics were decisive in the higher productivity, characterizing 2013 as a favorable year (FY) to the crop. In 2014 (Figure 1B), there were high temperatures followed by excessive rainfall in the beginning of the crop development cycle, a condition also observed near to the grain harvest.

These facts justify the lower productivity (Table 1), either due to the loss of nutrients because of leaching in V_3, with a reduced soil moisture in phenological stage E and the losses caused by the excessive rainfall at ripeness (Figure 1B), which characterizes 2014 as an unfavorable year (UY) to the crop. The volume and distribution of rainfall along with air temperature are potential variables in the favorable and unfavorable year to wheat cultivation (Arenhardt *et al*., 2015). In wheat, tillering is favored under milder conditions with adequate distribution of rainfall (Ferrari *et al*., 2016). Water stress is considered the main environmental factor which directly affects crop productivity (Condé *et al*., 2010; Santos *et al*., 2016). Previous knowledge of precipitation conditions may indicate ways of management that ensure the success of the agricultural activity (Arf *et al*., 2015). Espindola *et al*. (2010), comment that the variation of the climate alters the nitrogen absorption by the plant.

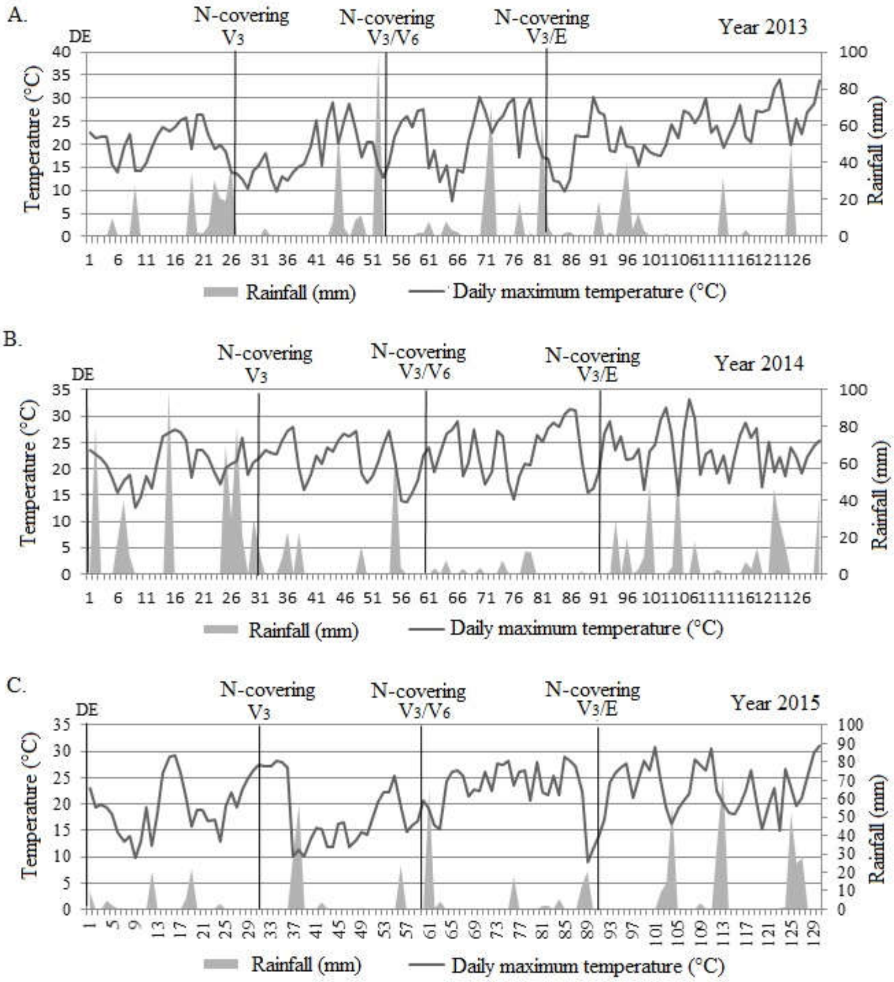

Figure 1. Rainfall and maximum temperature in the crop cycle of wheat with the days of nitrogen application. DE = date of emergence: 2013 (17 June); (25 June) 2015 (27 June). DAE = days after emergence. V_3 = full condition (100%) of the nitrogen dose in the third leaf expanded. V_3/V_6 = fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth leaves expanded, and V_3/E = fractioned condition (70 and 30%) of the nitrogen dose in the third leaf expanded and beginning of grain filling

Table 1. Temperature and rainfall in the cultivation months and the average of productivity

Year	Month	Temperature (°C)			Rainfall (mm)		**$GP_{\bar{x}}$**	**$BP_{\bar{x}}$**	Class
		Minimum	Maximum	Average	Average 26 years*	Occurred	(kg ha^{-1})		
2013	May	10.5	22.7	16.6	149.7	100.5	3357 a	7058 a	FY
	June	7.9	18.4	13.15	162.5	191			
	July	8.3	19.2	13.75	135.1	200.8			
	August	9.3	20.4	14.85	138.2	223.8			
	September	9.5	23.7	16.6	167.4	46.5			
	October	12.2	25.1	18.65	156.5	211.3			
	Total	-	-	-	909.4	973.9			
2014	May	10.8	23.6	17.2	149.7	412	1414 c	5245 c	UY
	June	8.6	19	13.8	162.5	412			
	July	9.7	21.82	15.76	135.1	144			
	August	8.8	23.66	16.23	138.2	77.8			
	September	13.33	23.58	18.46	167.4	274.8			
	October	16.02	27.49	21.76	156.5	230.8			
	Total	-	-	-	909.4	1551.4			
2015	May	11.1	24.5	17.8	149.7	20.3	2441 b	6096 b	IY
	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			

* = Average rainfall obtained in the months of May to October from 1989 to 2015; Averages followed by the same letter in the column do not differ from each other in a probability of error of 5% by the Scott & Knott test; IY = intermediate year; FY = favorable year; UY = unfavorable year; $GP_{\bar{x}}$= Grain productivity average; $DB_{\bar{x}}$ = ABP = Average biomass productivity.

Table 2. Average values of biological productivity, grain productivity and wheat harvest index under the conditions of nitrogen supply in the succession systems

Phenological	Dose N	Observed values		
Stage	(kg ha^{-1})	GP (kg ha^{-1})	BP (kg ha^{-1})	HI (kg kg^{-1})
	soy/wheat system (2013 + 2014 + 2015)			
V_3	0	1659	6174	0.27
	30	2154	6115	0.35
	60	2694	6593	0.41
	120	2997	7361	0.41
V_3/V_6	0	1479	5487	0.27
	30	2358	6943	0.34
	60	2540	6841	0.37
	120	2950	7685	0.38
V_3/E	0	1469	5234	0.28
	30	2138	5917	0.36
	60	2562	6733	0.38
	120	2984	7449	0.40
	corn/wheat system (2013 + 2014 + 2015)			
V_3	0	943	3921	0.24
	30	1924	5848	0.33
	60	2222	6586	0.34
	120	2728	6960	0.39
V_3/V_6	0	931	3278	0.28
	30	1728	5503	0.31
	60	2304	7017	0.33
	120	2739	7184	0.38
V_3/E	0	954	3483	0.27
	30	1658	5340	0.31
	60	1889	5311	0.36
	120	2706	6624	0.41
Selected variables		Minimum	Medium	Maximum
	(2013 + 2014 + 2015)			
Thermal sum (degrees day^{-1})		1371	1593	1802
Rainfall (mm m^{-2})		777	867	1009

N Dose = dose of nitrogen (kg ha^{-1}); V_3 = full condition (100%) of the nitrogen dose in the third leaf expanded, V_3/V_6 = fractional condition (70 and 30%) of the nitrogen dose in the third and sixth leaves expanded; V_3/E = fractional condition (70 and 30%) of the nitrogen dose in the third leaf expanded and beginning of grain filling; GP = grain productivity (kg ha^{-1}); BP = biomass productivity (kg ha^{-1}); HC = harvest index (kg kg^{-1})

Table 3. Polynomial regression equation for estimation of the harvest index under the conditions of nitrogen supply in the cropping systems

Phenological	Equation	P	R^2
Stage	$HI = E \pm F_{Ndose} \pm G_{Ndose}{}^2$	(b_{ix})	(%)
	soy/wheat system (2013 + 2014 + 2015)		
V_3	$0.27 + 3.1 \times 10^{-3}{}_{Ndose} - 1.6 \times 10^{-5}{}_{Ndose}{}^2$	*	99
V_3/V_6	$0.26 + 2.6 \times 10^{-3}{}_{Ndose} - 1.4 \times 10^{-5}{}_{Ndose}{}^2$	*	99
V_3/E	$0.28 + 2.4 \times 10^{-3}{}_{Ndose} - 1.2 \times 10^{-5}{}_{Ndose}{}^2$	*	96
	corn/wheat system (2013 + 2014 + 2015)		
V_3	$0.24 + 1.9 \times 10^{-3}{}_{Ndose} - 8.5 \times 10^{-6}{}_{Ndose}{}^2$	*	89
V_3/V_6	$0.23 + 2.4 \times 10^{-3}{}_{Ndose} - 1.1 \times 10^{-5}{}_{Ndose}{}^2$	*	99
V_3/E	$0.24 + 1.1 \times 10^{-3}{}_{Ndose}$	*	90

V_3 = Full condition (100%) of the nitrogen dose in the third leaf expanded; V_3/V_6 = Fractional condition (70 and 30%) of the nitrogen dose in the third and sixth leaves expanded; V_3/E = fractional condition (70 and 30%) of the nitrogen dose in the third leaf expanded and beginning of the grain filling; R^2 = Coefficient of determination; P (b_{ix}) = Probability of significance of the slope of the line; *Ndose* = dose of nitrogen

Table 4. Identification of potential variables via StepWise for the composition of multiple linear regression model to the simulation of wheat biomass productivity

Source of	Middle Square/StepWise Model		
Variation	V_3	V_3/V_6	V_3/E
	soy/wheat system (2013 + 2014 + 2015)		
Regression	645508750*	723117769*	448795250*
Doses (N) (Ndose)	25524628*	26858344*	21340402*
Thermal Sum (TS)	185376*	275689*	17932755*
Rainfall (Rain)	11466795*	12608601*	13007953*
Error	2053370	3056952	2172296
	corn/wheat system (2013 + 2014 + 2015)		
Regression	381279637*	493176333*	397702003*
Doses (N) (Ndose)	33204366*	55227835*	48673854*
Thermal Sum (TS)	134971*	1587386*	1093195*
Rainfall (Rain)	40916448*	51662350*	76799602*
Error	1570385	1797387	1273198

Days of the cycle (Days) = Days of biomass cuts (30, 60, 90 and 120 days); Thermal sum (TS) degrees day^{-1}; Precipitation (Prec) mm m^{-2}; Doses (N) (Nose) = Nitrogen doses - 0, 30, 60, 120 kg N ha^{-1}; V_3 = Full condition (100%) of the nitrogen dose in the third leaf; expanded V_3/V_6 = Fractional condition (70%/30%) of the nitrogen dose in the third and sixth leaves expanded; V_3/E = Fractional condition (70%/30%) of the nitrogen dose in the third leaf expanded and beginning of grain filling; * = Significant by the F test at 5% of probability of error.

Table 5. Multiple regression equation to estimate biomass productivity under nitrogen supply conditions in cropping systems

Phenological Stage	Equation $\mathrm{BP} = \mathrm{A} \pm \mathrm{B}_{\mathrm{Ndose}} \pm \mathrm{C}_{\mathrm{Ts}} \pm \mathrm{D}_{\mathrm{Rain}}$
	soy/wheat system (2013 + 2014 + 2015)
V_3	$9122.20 + 10.74_{\mathrm{Ndose}}\quad 2.58_{Ts} + 1.13_{\mathrm{Rain}}$
V_3/V_6	$9846.90 + 15.95_{\mathrm{Ndose}}\quad 4.63_{Ts} + 3.95_{\mathrm{Rain}}$
V_3/E	$9236.76 + 18.42_{\mathrm{Ndose}}\quad 2.66_{Ts} + 0.43_{\mathrm{Rain}}$
	corn/wheat system (2013 + 2014 + 2015)
V_3	$10344.76 + 23.08_{\mathrm{Ndose}}\quad 1.69_{Ts}\quad 3.50_{\mathrm{Rain}}$
V_3/V_6	$13899.41 + 30.69_{\mathrm{Ndose}}\quad 4.55_{Ts}\quad 2.90_{\mathrm{Rain}}$
V_3/E	$14031.39 + 23.36_{\mathrm{Ndose}}\quad 4.13_{Ts}\quad 4.03_{\mathrm{Rain}}$

V_3 = Full condition (100%) of the nitrogen dose in the third leaf expanded; V_3/V_6 = Fractional condition (70 and 30%) of the nitrogen dose in the third and sixth leaves expanded; V_3/E = fractional condition (70 and 30%) of the nitrogen dose in the third leaf expanded and beginning of grain filling; Ts = Thermal sum (degrees days^{-1}); Rain = Rainfall (mm); N dose = Nitrogen doses; A, B, C, D = regression coefficients; BP = biomass productivity (kg ha^{-1})

Table 6. Mathematical model for estimating grain productivity in each nitrogen supply condition in cropping systems

Stadium	Dose (N)	Equation $GP = (A \pm B_{Ndose} \pm C_{Ts} \pm D_{Rain}) \times (E \pm F_{Ndose} \pm G_{Ndose})$	GP_O	GP_E
		soy/wheat system (2013 + 2014 + 2015)		
V_3	0	$(9122.20 + 10.74_{Ndose} - 2.58_{Ts} + 1.13_{Rain}) \times (0.27 + 3.1 \times 10^{-3}{}_{Ndose} - 1.6 \times 10^{-5}{}_{Ndose}{}^{2})$	1659	1618
	30		2154	2201
	60		2694	2645
	120		2997	2998
V_3/V_6	0	$(9846.90 + 15.95_{Ndose} - 4.63_{Ts} + 3.95_{Rain}) \times (0.26 + 2.6 \times 10^{-3}{}_{Ndose} - 1.4 \times 10^{-5}{}_{Ndose}{}^{2})$	1479	1533
	30		2358	2074
	60		2540	2505
	120		2950	2843
V_3/E	0	$(9236.76 + 18.42_{Ndose} - 2.66_{Ts} + 0.43_{Rain}) \times (0.28 + 2.4 \times 10^{-3}{}_{Ndose} - 1.2 \times 10^{-5}{}_{Ndose}{}^{2})$	1469	1504
	30		2138	2022
	60		2562	2467
	120		2984	2997
		corn/wheat system (2013 + 2014 + 2015)		
V_3	0	$(10344.76 + 23.08_{Ndose} - 1.69_{Ts} - 3.5_{Rain}) \times (0.24 + 1.9 \times 10^{-3}{}_{Ndose} - 8.5 \times 10^{-6}{}_{Ndose}{}^{2})$	943	1108
	30		1924	1537
	60		2222	1941
	120		2728	2553
V_3/V_6	0	$(13899.41 + 30.69_{Ndose} - 4.55_{Ts} - 2.9_{Rain}) \times (0.23 + 2.4 \times 10^{-3}{}_{Ndose} - 1.1 \times 10^{-5}{}_{Ndose}{}^{2})$	931	952
	30		1728	1477
	60		2304	2000
	120		2739	2812
V_3/E	0	$(14031.39 + 23.36_{Ndose} - 4.13_{Ts} - 4.03_{Rain}) \times (0.24 + 1.1 \times 10^{-3}{}_{Ndose})$	954	950
	30		1658	1272
	60		1889	1640
	120		2706	2515

N dose = Nitrogen doses; V_3 = Full condition (100%) of the nitrogen dose in the third leaf expanded; V_3/V_6 = Fractional condition (70 and 30%) of the nitrogen dose in the third and sixth leaves expanded; V_3/E = fractional condition (70 and 30%) of the nitrogen dose in the third leaf expanded and beginning of grain filling; Ts = Thermal sum (degrees days^{-1}); Rain = Rainfall (mm); GP_O = Observed grain productivity (kg ha^{-1}); GP_E = Estimated grain productivity (kg ha^{-1})

The nitrogen efficiency to the obtention of high productivities in wheat depends on the availability of water in the soil, because water deficiency limits the plant's response to fertilizer application (Martin *et al*., 2006). Therefore, the favorable climate for the cultivation of wheat, described as one with milder temperatures and with quality of radiation in favor of tillering and filling of grains, without occurrence of rains in great quantity and intensity, but promoting an adequate moisture stored in the soil (Pereira *et al*., 2015; Marolli *et al*., 2017). The proposal of simulation of wheat grain productivity per agricultural year does not contemplate efficient models, considering the strong variation between the years of cultivation, interfering in the use of nitrogen to the elaboration of the productivity (Table 1, Figure 1). Therefore, the cumulative effect of the variability among the unfavorable, intermediate and favorable years were considered for the obtention of the values of thermal sum, precipitation and productivity of biomass and grains. Table 2 presents the averages of biomass productivity, grain productivity and wheat harvest index in each nitrogen supply condition in the succession systems, as well as the minimum, medium and maximum values of the meteorological variables. Table 3 shows the models that aim to estimate the wheat harvest index under the conditions of single and fractionated nitrogen supply in the different succession systems. Regardless of the phenological stage and the cultivation system, the models showed a quadratic tendency, except in the fractional condition in V_3/E in the corn/wheat system, which presented a linear behavior. The harvest index of a crop is highly influenced by the sowing density, water availability, nitrogen and temperature (Mantai *et al*., 2015; Romitti *et al*., 2017). The efficient use of nitrogen provides a better use of the biomass for the benefit of the grains, increasing the harvest index (Pimentel *et al*., 2014). A higher harvest index indicates improved targeting and utilization of photoassimilates to the elaboration of grains (Trevizan *et al*., 2015). Table 4 presents the potential variables tested by the StepWise technique for the composition of the multiple linear regression model. In each nitrogen supply condition, the inclusion of thermal sum, nitrogen doses and precipitation were qualified in the simulation of wheat biomass productivity by the multiple model. On the set of independent variables there may be some which have little influence on the set of dependent variables (Padua *et al*., 2015). The StepWise method allows to select these variables with greater explanatory capacity, allowing to achieve a smaller model with efficiency in the simulation (Almeida *et al*., 2016). This method suggests that a variable be considered explanatory considering the increase in the coefficient of determination, resulting from its inclusion in the multiple linear regression model (Mantai *et al*., 2016). The use of this method leads to the exclusion of some variable models initially defined due to the reduced importance they present (Ribeiro and Jorge 2014). Balbinot *et al*. (2005), in corn, selected through StepWise the components spike mass, number of grains per row, number of rows per spike and number of plants and ears per area as the most appropriate in the simulation of grain productivity. Mantai *et al*. (2016), simulated the oat productivity through the multiple model with the variables, selected through the StepWise technique, panicle harvest index, number of grains and spikelets in the panicle and nitrogen. Godoy *et al*. (2015), in rice, selected through the StepWise technique, copper, nitrogen, iron and acid phosphatase for composition of the multiple model to the productivity simulation. Table 5 shows the equations of multiple linear regression for simulation of wheat biomass productivity in the conditions of nitrogen supply with the meteorological elements in the cropping systems. In this simulation were used the values presented in Table 2 along with the potential variables validated by the StepWise technique (Table 4).

The identification of components that influence productivity is decisive in the elaboration of simulation models (Leal *et al*., 2015). The multiple linear regression models make possible to identify these variables with efficiency to compose the simulation model (Silva *et al*., 2016a). Mercante *et al*. (2010), used the multiple linear regression method, considering the NDVI and GVI vegetation indexes, proposing accurate models of soy productivity prediction. Lacerda *et al*. (2015), estimated by multiple linear regression the soy and corn productivity, according to the total amounts of N, P_2O_5 and K_2O. Souza *et al*. (2013), simulated wheat grain productivity through the Jensen model, using the coefficients obtained by multiple linear regression. Through the multiple linear regression model, Pinto *et al*. (2016), estimated the irrigated rice productivity by sprinkling (kg ha^{-1}), considering the water tension and chemical and physical attributes of the soil. Table 6 shows the models for simulation of grain productivity of wheat under the conditions of nitrogen supply in the cropping systems. In this simulation, the model combines multiple linear regression models (Table 5) and polynomial regression (Table 3), which simulate biomass productivity and harvest index, respectively. For such simulation, were used the values presented in Table 2. The grain productivity values observed showed linear increase with the increment of chemical fertilizer, regardless of the succession system. This tendency of grain productivity increase was also obtained through the proposed model. In addition, the results simulated by the model are very close to those observed in real conditions of cultivation. Therefore, it proved to be an accurate model to estimate the productivity of wheat considering the conditions of nitrogen fertilization along with meteorological factors in the systems of high and reduced N-residual release. Due to the importance of estimating crop productivity, mathematical models can provide data to feed crop productivity forecasting systems, allowing the identification of factors that act along the crop cycle (Rosa *et al*., 2009). In addition, simulation models are tools that allow to analyze scenarios, considering the various combinations of factors that influence crop productivity (Gomes *et al*., 2014). However, the possibility of integrating two or more models is a way of obtaining a more efficient model, making possible the estimation of parameters, learning and simulations (Silva *et al*., 2014).

Conclusion

The proposed model that interacts polynomial regression with multiple linear regression is efficient in the simulation of grain productivity of wheat in single and fractionated nitrogen supply with meteorological elements in the systems of high and low N-residual release.

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