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Simulation of wheat biomass yield by thermal time, rainfall and nitrogen

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Key words:

Triticum aestivum

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ABSTRACT

Wheat biomass yield focused on the production of quality silage is dependent on rainfall, temperature and nitrogen (N). The objective of the study was to validate the use of rainfall, thermal time and N as potential variables for the composition of the multiple linear regression model and simulation of wheat biomass yield for silage production under N supply conditions during the cycle, in the systems of succession. The study was conducted in 2012, 2013 and 2014, in randomized blocks with four replicates in 4 x 3 factorial, for N-fertilizer doses (0, 30, 60, 120 kg ha⁻¹) and forms of N supply [single application (100%) in the stage V₃ (third expanded leaf); split application (70%/30%) in the stages V₃/V₆ (third and sixth expanded leaves); split application (70%/30%) in the stages V₃/E (third expanded leaf and beginning of grain filling)], respectively, in the systems soybean/wheat and maize/wheat. Rainfall and N are potential variables in the composition of the multiple linear regression model. Multiple linear regression models are efficient in the simulation of wheat biomass yield for silage under the N supply conditions during the cycle in the succession systems.

Palavras-chave:

Triticum aestivum

N-dose

N-fracionamento

N-residual

silagem

Simulação da produtividade de biomassa do trigo pela soma térmica, precipitação e nitrogênio

RESUMO

A produção de biomassa de trigo voltada para a elaboração de silagem de qualidade é dependente da precipitação, da temperatura e do nitrogênio. O objetivo no estudo foi validar o uso da precipitação, soma térmica e nitrogênio como variáveis potenciais para composição do modelo de regressão linear múltipla e a simulação da produtividade de biomassa do trigo na elaboração de silagem nas condições de fornecimento de nitrogênio durante o ciclo, nos sistemas de sucessão. O estudo foi conduzido em 2012, 2013 e 2014 em blocos ao acaso com quatro repetições em fatorial 4 x 3, para doses de N-fertilizante (0, 30, 60, 120 kg ha⁻¹) e formas de fornecimento [único (100%) no estágio V₃ (terceira folha expandida); fracionado (70%/30%) no estágio V₃/V₆ (terceira e sexta folha expandida) e fracionado (70%/30%) no estágio V₃/E (terceira folha expandida e início do enchimento de grãos)] respectivamente, no sistema soja/trigo e milho/trigo. A precipitação e o nitrogênio são variáveis potenciais na composição do modelo de regressão linear múltipla. Os modelos de regressão linear múltipla são eficientes para simulação da produtividade de biomassa do trigo para silagem nas condições de fornecimento de nitrogênio durante o ciclo nos sistemas de sucessão.



INTRODUCTION

Silage is a product of forage conservation through anaerobiosis, in which soluble carbohydrates are converted into organic acids by acid-lactic bacteria, preserving the nutritional value (Zamarchi et al., 2014). Ensilage of grasses is an alternative to supply quality silage in period of pasture scarcity (Paris et al., 2015). In southern Brazil, wheat silage has gained attention for the high nutritional value existing in the whole plant (Rosário et al., 2012).

The high biomass yield of wheat is associated with weather conditions, genetic performance of the cultivars and management techniques, including phytosanitary control and nitrogen supply (Silva et al., 2015).

Nitrogen (N) is the nutrient that most stimulates shoot and root growth, with expressive effects on yield (Wrobel et al., 2016); however, it is the most easily lost by environmental conditions, which can compromise efficiency, reduce yield and cause environmental pollution (Viola et al., 2013).

Higher N efficiency is dependent on adequate soil moisture, not always obtained at the moment of fertilization (Silva et al., 2016). Therefore, studies have suggested the use of single or split N dose according to the weather conditions of the cultivation (Ferrari et al., 2016).

In this context, the relationships between weather elements and N can favor the construction of models to simulate wheat yield for silage production and contribute to a more efficient management in nitrogen use.

This study aimed to validate the use of rainfall, thermal time and N as potential variables to compose the multiple linear regression model and simulate wheat biomass yield for silage production under N supply conditions during the cycle, in the systems of succession.

MATERIAL AND METHODS

The study was carried out in 2012, 2013 and 2014 in Augusto Pestana, RS, Brazil. The soil was classified as typic dystroferic Red Latosol and the climate, according to Köppen's classification, as Cfa, with hot summer without dry season (Kuinchtner & Buriol, 2001). Ten days prior to sowing, soil analysis was performed (Tedesco et al., 1995) and, on the average of the years, the following characteristics were identified: i) soybean/wheat system (pH = 6.1, P = 49.1 mg dm⁻³, K = 424 mg dm⁻³, OM = 30 g kg⁻¹, Al = 0 cmol_c dm⁻³, Ca = 6.3 cmol_c dm⁻³ and Mg = 2.5 cmol_c dm⁻³) and; ii) maize/wheat system (pH = 6.5; P = 23.6 mg dm⁻³; K = 295 mg dm⁻³, OM = 29 g kg⁻¹, Al = 0 cmol_c dm⁻³, Ca = 6.8 cmol_c dm⁻³ and Mg = 3.1 cmol_c dm⁻³). Sowing was made using a seeder-fertilizer machine to compose the plots with five 5-m-long rows spaced by 0.20 m, forming the experimental unit with 5 m². Population density was 400 viable seeds m⁻². The fungicide Tebuconazole was applied at dose of 0.75 L ha⁻¹ and weeds were controlled using the herbicide Metsulfuron-methyl at dose of 4 g ha⁻¹. At sowing, 45 and 30 kg ha⁻¹ of P₂O₅ and K₂O, respectively, were applied based on the contents of P and K present in the soil for an expected grain yield of 3 t ha⁻¹.

In each crop system (soybean/wheat, maize/wheat), the experimental design was randomized blocks with

four replicates in a 4 x 3 factorial scheme, for N-fertilizer doses (0, 30, 60, 120 kg ha⁻¹) and forms of supply [single application (100%) in the stage V₃ (third expanded leaf); split application (70%/30%) in the stages V₃/V₆ (third and sixth expanded leaves); split application (70%/30%) in the stages V₃/E (third expanded leaf and beginning of grain filling)], respectively, using the wheat cultivar 'BRS Guamirim', totaling 96 experimental units. Biomass was manually harvested by cutting 1 m² of each plot every 30 days. Plants were dried in an oven at temperature of 65 °C, until constant weight, and then weighed to estimate biomass yield (BY, kg ha⁻¹). The mean values of biomass yield, temperature and rainfall were used to classify the years as intermediate, unfavorable and favorable to wheat cultivation.

To meet the assumptions of homogeneity and normality through Bartlett's tests, analysis of variance was made to detect main and interaction effects and then Scott-Knott test to compare the means. Potential variables for the multiple linear regression model were selected using the StepWise technique, which iteratively constructs a sequence of regression models through the addition and removal of variables, selecting those with highest correlation with the main variable (y) using the partial F statistics, according to Eq. 1:

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

where:

QS_R - quadratic sum of the regression; and,

QM_E(x_j, x₁) - quadratic mean of the error in the model containing the variables x_j and x₁.

The variables selected via StepWise were used to determine the multiple linear regression equation, for the simulation of wheat biomass yield to generate an equation of the following type:

$$y = b_0 \pm b_1 x \pm b_2 x_2 \pm b_3 x_3 \pm \dots \pm b_n x_n \quad (2)$$

Described in the matrix form as:

$$y = \begin{bmatrix} Y_1 \\ Y_2 \\ M \\ Y_n \end{bmatrix} \quad (3.1)$$

$$X = \begin{bmatrix} 1 & X_{11} & X_{12} & \dots & X_{p1} \\ 1 & X_{21} & X_{22} & \dots & X_{p2} \\ M & M & M & \dots & M \\ 1 & X_{1n} & X_{2n} & \dots & X_{pn} \end{bmatrix} \quad (3.2)$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ M \\ \beta_n \end{bmatrix} \quad (3.3)$$

and

$$\varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ M \\ \vdots \\ \varepsilon_n \end{bmatrix} \quad (3.4)$$

These matrices were used to obtain the regression coefficients,

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

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

$$\text{Cov}(\hat{\beta}) = (X'X)^{-1} \hat{\sigma}^2 \quad (5)$$

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

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:

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

These analyses were made using the computer program Genes (Cruz, 2013).

RESULTS AND DISCUSSION

For N application in the V_3 stage, in 2012, the mean maximum temperature showed the highest value compared with the other years (Figure 1A). High temperatures without occurrence of rainfall were observed before and after fertilization, favoring losses of the nutrient through volatilization. Soil moisture conditions for the fertilization in V_3/V_6 and V_3/E were adequate, because of rainfalls during the previous days. Although the rainfall volume was the lowest one compared with the historical average (Table 1), meteorological data, along with the reasonable yield, characterize 2012 as an intermediate year (IY) of cultivation. In 2013, maximum temperature for the N-fertilizer application in V_3 was approximately 15 °C and with favorable conditions of soil moisture, because of rainfalls during the days prior to fertilization (Figure 1B). This condition was also observed in the fertilization in V_3/V_6 and V_3/E . According to Table 1, the total volume of rainfall was similar to the historical average, indicating adequate rainfall distribution along the cycle (Figure 1B). These conditions were decisive for the highest mean yield, characterizing 2013 as a favorable year (FY) for cultivation. In 2014, maximum temperature around 23

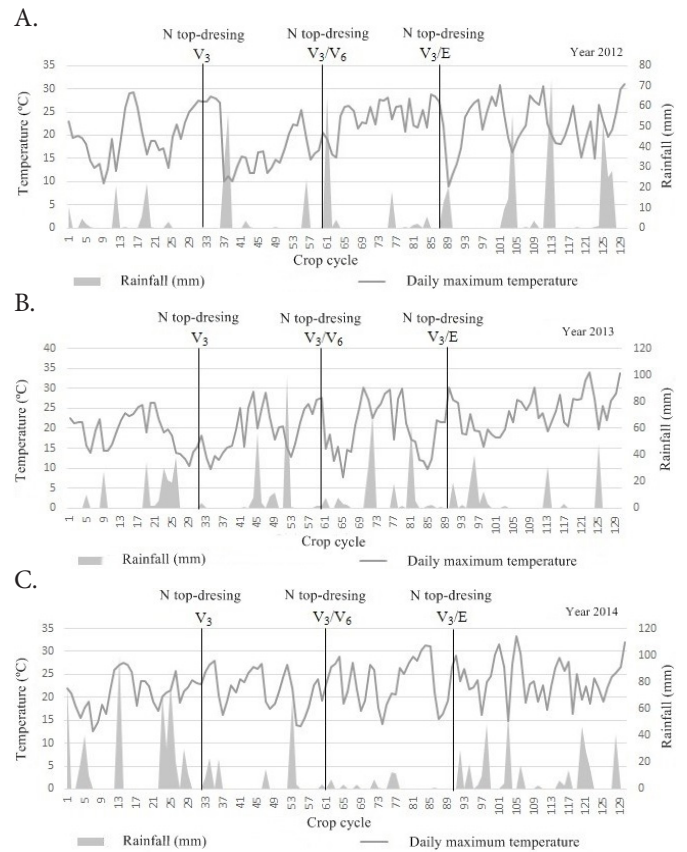


Figure 1. Rainfall, maximum temperature and days of nitrogen application in the wheat cycle (A) 2012, (B) 2013 and (C) 2014

°C (Figure 1C) occurred during N-fertilizer application in V_3 . N application was followed by a significant volume of rainfalls (± 30 mm), a condition also observed close to grain harvest. When N was applied in V_3/E , soil moisture was not adequate for fertilization. These facts justify the lower yield (Table 1), either by N loss through leaching in V_3 , reduced soil moisture in V_3/E or damages caused by rainfalls during maturation (Figure 1C), characterizing 2014 as unfavorable year (UY) for cultivation.

Agriculture is one of the most important segments and the most dependent on natural conditions (Silva et al., 2008). Temperature and rainfall are the meteorological elements that most influence crop yield (Cordeiro et al., 2015). In wheat, a favorable climate is that with mild temperatures, good radiation index to favor tillering and grain filling, with occurrence of rains in small amounts and adequate soil moisture (Pereira et al., 2015).

The proposal of wheat biomass yield simulation per agricultural year does not contemplate efficient models, due to the strong variation between the cultivation years, interfering with N use for yield (Table 1 and Figure 1). Therefore, the cumulative effect of variability between unfavorable, intermediate and favorable years was considered to obtain the values of thermal time, rainfall and biomass yield in the crop cycle and the multiple linear regression coefficients for yield simulation. Thus, Table 2 shows the sum of meteorological values in each moment of cut, along with the mean biomass yields in each N supply condition in the systems of succession. In the soybean/wheat system, biomass yield was altered by the single and split N application at 60, 90 and 120 days after emergence at doses of 30 and 60 kg ha⁻¹. In the maize/wheat

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

Year	Month	Temperature (°C)			Rainfall (mm)		BY _x (kg ha ⁻¹)	Class
		Minimum	Maximum	Mean	Mean 25 years*	Occurred		
2012	May	11.1	24.5	17.8	149.7	20.3	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		
2013	May	10.5	22.7	16.6	149.7	100.5	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	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		

*Mean rainfall obtained from May to October from 1989 to 2014; Means followed by the same letter in the column do not differ at 0.05 probability level by Scott-Knott test; IY - Intermediate year; FY - Favorable year; UY - Unfavorable year; BY_x - Biomass yield

Table 2. Meteorological variables and biomass yields at different moments of cut under the nitrogen supply conditions

Selected variables	N dose (kg ha ⁻¹)	Phenological stage	Moment of cut (DAE)			
			30	60	90	120
Thermal time (degree d ⁻¹)	-	-	322	692	1075	1593
Rainfall (mm m ⁻²)	-	-	280	426	613	867
Soybean/wheat system (2012+2013+2014)						
Biomass yield (kg ha ⁻¹)	0	V ₃	433 a	2152 a	5043 a	6874 a
		V ₃ /V ₆	411 a	1972 a	5467 a	7187 a
		V ₃ /E	411 a	1940 a	5144 a	6734 a
	30	V ₃	455 a	2765 a	6812 a	7215 a
		V ₃ /V ₆	464 a	2349 a	6496 a	7496 a
		V ₃ /E	438 a	1735 b	5876 b	6717 b
	60	V ₃	440 a	2833 a	6623 a	7393 a
		V ₃ /V ₆	437 a	2868 a	6639 a	7841 a
		V ₃ /E	395 a	2351 b	5869 b	7033 b
	120	V ₃	446 a	3564 a	7080 a	7961 a
		V ₃ /V ₆	458 a	3362 a	7212 a	8185 a
		V ₃ /E	416 a	3271 a	6825 a	7998 a
Maize/wheat system (2012+2013+2014)						
Biomass yield (kg ha ⁻¹)	0	V ₃	274 a	1281 a	3157 a	5521 a
		V ₃ /V ₆	201 a	1286 a	3430 a	5278 a
		V ₃ /E	214 a	1053 a	3596 a	5140 a
	30	V ₃	253 a	1761 a	5053 a	5848 a
		V ₃ /V ₆	250 a	1602 a	4871 a	5703 a
		V ₃ /E	212 a	1187 b	4212 b	5283 b
	60	V ₃	279 a	2170 a	5283 a	6586 a
		V ₃ /V ₆	270 a	1989 a	5735 a	6117 a
		V ₃ /E	249 a	1432 b	4788 b	5311 b
	120	V ₃	261 a	2245 a	6061 a	6600 a
		V ₃ /V ₆	257 a	2184 a	6111 a	6584 a
		V ₃ /E	237 a	1975 a	5957 a	6324 a

DAE - Days after emergence; N - Nitrogen (kg ha⁻¹); V₃ - Full (100%) N dose on third expanded leaf; V₃/V₆ - Split (70%/30%) N dose on third and sixth expanded leaves; V₃/E - Split (70%/30%) N dose on third expanded leaf and beginning of grain filling; Means followed by the same letter in the column do not differ statistically at 0.05 probability level by Scott-Knott test

system, biomass yield also showed a similar behavior to the previously mentioned. Regardless of cultivation system, split N application in V₃/E was the least efficient, but the supply in a single dose (V₃) and split in V₃/V₆ did not cause alteration. Highest biomass yields were obtained in the soybean/wheat system, strengthening the benefits of the vegetal cover with higher residual-N release on crop yield.

The chemical composition of the residues affects the dose and period of N supply (Siqueira Neto et al., 2010). Split application with the adjusted dose of N-fertilizer can increment wheat yield, provided that the conditions in the first application are not favorable (Espindula et al., 2010). Silva et al. (2008) observed no differences in wheat grain yield between the conditions of single and split N application, suggesting a single

application under more-favorable conditions of soil moisture, to reduce the operating costs of the application.

In the indication of potential variables for inclusion in the multiple linear regression models, the mean square significance of the variables analysed by the StepWise technique is presented (Table 3). In each N supply condition, the inclusion of days of cycle, N doses and rainfall were applied in the simulation of wheat biomass yield through the multiple model.

The identification of components that influence crop yield is decisive in the elaboration of efficient simulation models (Leal et al., 2015). The StepWise technique allows to select potential components for simulation through multiple linear regression (Balbinot Júnior et al., 2005; Mantai et al., 2016). Dalchiavon et al. (2012) selected through StepWise technique the number of panicles, panicle weight, number of spikelets per panicle and thousand-grain weight of rice to compose the multiple linear regression model in the simulation of grain yield. Mantai et al. (2016) simulated oat yield using the multiple model with the variables panicle harvest index, number of grains and spikelets per panicle and N.

Table 4 shows the multiple linear regression equations for the simulation of wheat biomass yield under the N supply conditions in the cultivation systems. This simulation used the values presented in Table 2 and the potential variables validated by the StepWise technique (Table 3). The observed values of biomass yield increased with the increment of N-fertilizer, regardless of system of succession. This trend of biomass growth was also obtained by the model of simulation through multiple regression. On the other hand, the results of biomass yield simulated by the proposed models in each N-fertilizer condition are very close to those observed in the actual cultivation conditions, thus validating an innovative proposal of simulation of wheat biomass yield for silage production.

Simulation through multiple linear regression can allow an efficient estimate of yield (Tsukahara et al., 2016). Mantai et al. (2016) estimated oat yield through multiple linear regression based on panicle harvest index, number of grains and spikelets per panicle and N use. Leilah & Al-Khateeb (2005) simulated through multiple regression wheat yield under drought

Table 3. Identification of potential variables via StepWise technique to compose the multiple linear regression model for wheat biomass yield simulation

Source of variation	Mean square/StepWise Model		
	V ₃	V ₃ /V ₆	V ₃ /E
Soybean/wheat system (2012 + 2013 + 2014)			
Regression	645508750*	723117769*	448795250*
Days of cycle (days)	1899534826*	2129886363*	1742899874*
N doses (Ndose)	25524628*	26858344*	21340402*
Thermal time (TT)	185376 ^{ns}	275689 ^{ns}	17932755 ^{ns}
Rainfall (P)	11466795*	12608601*	13007953*
Error	2053370	3056952	2172296
Maize/wheat system (2012 + 2013 + 2014)			
Regression	381279637*	493176333*	397702003*
Days of cycle (days)	1443593169*	1372638813*	1067642552*
N doses (Ndose)	33204366*	55227835*	48673854*
Thermal time (TT)	134971 ^{ns}	1587386 ^{ns}	1093195 ^{ns}
Rainfall (P)	40916448*	51662350*	76799602*
Error	1570385	1797387	1273198

Days of cycle (Days) - Days of biomass cut (30, 60, 90 and 120 days); Thermal time (TT) degree d⁻¹; Rainfall (P) mm m⁻²; Ndose - Nitrogen doses - 0, 30, 60, 120 kg N ha⁻¹; V₃ - Full (100%) N dose on third expanded leaf; V₃/V₆ - Split (70%/30%) N dose on third and sixth expanded leaves; V₃/E - Split (70%/30%) N dose on third expanded leaf and beginning of grain filling; *Significant by F test at 0.05 probability level; ^{ns}Not significant by F test at 0.05 probability level

Table 4. Multiple linear regression for the estimate of total biomass yield based on nitrogen doses, rainfall and days in each cultivation system

Stage	Dose (N)	Equation Y = f ₁ (x ₁ , x ₂ , ...)	BY _o (kg ha ⁻¹)	BY _e (kg ha ⁻¹)
Soybean/wheat system (2012+2013+3014)				
V ₃	0	BY = - 682.46 + 79.28 _{days} + 8.02 _{Ndose} - 2.29 _P	6874	6846
	30		7215	7086
	60		7693	7327
	120		7961	7808
V ₃ /V ₆	0	BY = - 758.39 + 83.88 _{days} + 8.23 _{Ndose} - 2.40 _P	7187	7226
	30		7496	7473
	60		7841	7720
	120		8185	8214
V ₃ /E	0	BY = - 2146.75 + 83.49 _{days} + 12.26 _{Ndose} - 1.44 _P	6734	6624
	30		6717	6991
	60		7033	7359
	120		7998	8095
Maize/wheat system (2012+2013+3014)				
V ₃	0	BY = - 756.28 + 86.15 _{days} + 8.79 _{Ndose} - 4.56 _P	5421	5628
	30		5848	5892
	60		6586	6156
	120		6600	6683
V ₃ /V ₆	0	BY = - 838.08 + 87.99 _{days} + 11.34 _{Ndose} - 5.17 _P	5278	5238
	30		5703	5579
	60		6117	5919
	120		6584	6599
V ₃ /E	0	BY = - 201.04 + 88.77 _{days} + 10.65 _{Ndose} - 6.21 _P	5140	5073
	30		5283	5387
	60		5311	5706
	120		6324	6345

V₃ - Full (100%) N dose on third expanded leaf; V₃/V₆ - Split (70%/30%) N dose on third and sixth expanded leaves; V₃/E - Split (70%/30%) N dose on third expanded leaf and beginning of grain filling; Ndose - Nitrogen dose (0, 30, 60, 120 kg ha⁻¹); P - Rainfall (mm); BY - Biomass yield (kg ha⁻¹); BY_o - Observed biomass yield (kg ha⁻¹); BY_e - Estimated biomass yield (kg ha⁻¹)

condition, using the variables grain weight per panicle, panicle harvest index and panicle length. Using this model, Godoy et al. (2015) analysed soil attributes to simulate rice grain yield in the use of copper, nitrogen, iron and acid phosphatase.

CONCLUSIONS

1. Rainfall and nitrogen are potential variables to compose the multiple linear regression model.
2. Multiple linear regression models are efficient to simulate wheat biomass yield for silage during the cycle in the systems of succession.

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