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Wheat yield obtained from nitrogen dose and fractionation

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It is possible to increase nitrogen for wheat productivity by adjusting the single and fractionated dose based on the condition of the agricultural year. The objective of this work is to study the highest amount of nitrogen used for the production of wheat using single dose or fractionation under favorable and unfavorable cultivation years. The study was conducted in 2012, 2013 and 2014 in Augusto Pestana, Rio Grande do Sul, Brazil. The experimental design was a randomized block in a 4 × 3 factorial scheme with four replications. It consists of N-fertilizer rates (0, 30, 60 and 120 kg ha^{-1}), forms of supply [single (100%), growth stage V_3 (third expanded sheet); fractionated (70%/30%) growth stage V_3/V_6 (third and sixth expanded sheet); fractionated (70%/30%) phonological stage V_3/E (third expanded leaf and early grain filling)]. In favorable, intermediate and unfavorable years, wheat cultivated with single dose of nitrogen is more effective than the grain fractionated, regardless of the succession system. Nitrogen use efficiency can be substantially reduced or increased in wheat based on the condition of the year of cultivation and the use of the optimal dose of the nutrient may not necessarily express maximum grain yield with economic efficiency.

Key words: *Triticum aestivum,* relation C/N, meteorological condition, simulation.

INTRODUCTION

Wheat is one of the most produced cereals in the world. It has large derivatives and used for different types of flour (Stefen et al., 2015; Camponogara et al., 2016). Wheat is used in animal feed as bran, pastures and ensures soil

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coverage in no tillage farming (Rodrigues et al., 2014; Santos, 2016). Wheat cultivation extends from the South to the West Central of Brazil, which subjects the culture to different conditions of climate and soil, hindering stability in productivity (Costa et al., 2013; Chavarria et al., 2015). The high productivity and quality of grain wheat is associated with the performance of cultivars, management technologies, climate and favorable soil of cultivation (Pinnow et al., 2013; Camponogara et al., 2016). Among the management technologies, nitrogen fertilization is the most important for increasing grain yield in cereals (Flores et al., 2012; Arenhardt et al., 2015). Nitrogen is considered essential to plants; it is present in the composition of the most important biomolecules such as adenosine triphosphate (ATP), nicotinamide adenine dinucleotide (NADH), Nicotinamide adenine dinucleotide phosphate (reduced form) (NADPH), chlorophyll, proteins and several enzymes (Bredemeier and Mundstock, 2000). In wheat, the nutrient is responsible for the formation of biological molecules and determinant of productivity and grain quality (Fageria et al., 2006; Silva et al., 2015). On the other hand, nitrogen is the element of greater complexity of action on the environmental conditions, resulting in years of high or low temperature and rainfall, significant losses by leaching and/or volatilization, therefore, compromising nutrient use efficiency, reducing productivity, increasing costs and causing environmental pollution (Benin et al., 2012). Thus, there is a need to optimize food production from technologies that ensure productivity with reduced costs and sustainability in agricultural ecosystems (Sala et al., 2005; Viola et al., 2013). In this context, several authors have reported the possibility of using nitrogen economically adjusted to the condition of the agricultural year using fractionation to obtain greater efficiency of grain yield (Arenhardt et al., 2015; Espindula et al., 2014; Mantai et al., 2016).

Nitrogen dose used for cereals gives the expected desired productivity, considering the percentage of soil organic matter and C/N ratio of residual coverage. In soil, nitrogen in the form of ammonium (NH_4^+) or ammonia (NH_3) is rapidly oxidized to nitrite, which in turn is rapidly oxidized to nitrate (Carvalho and Zabot, 2012). Wheat absorbs and metabolizes inorganic nitrogen present in the soil, especially in the form of NO_3^- and NH_4 (Chagas, 2007). Weather conditions significantly alter the plant remains of the preceding crop and the expected productivity. This indicates the need for more efficient management systems to ensure productivity and reduce costs based on the conditions of the crop year. Thus, nitrogen administered in single or double doses under different conditions of crop year, high succession systems and reduced release of N-residual can provide good input to wheat production in Brazil.

The objective of this work is to study the highest amount of nitrogen used for the production of wheat using single dose or fractionation under favorable and unfavorable cultivation year in high succession systems and reduced release N-residual.

MATERIALS AND METHODS

The field experiments were conducted in 2012, 2013 and 2014, in the municipality of 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. It has hot summer and without dry season. Soil analysis was carried out ten days before the sowing date and subsequently during the middle of the years it was identified with the following chemical characteristics: (i) Maize/wheat system (pH = 6.5, P = 23.6 mg dm^{-3}, K = 295 mg dm^{-3}, MO = 2.9%, Al = 0 cmolc dm^{-3}, Ca= 6.8 cmolc dm^{-3}, and Mg = 3.1 cmolc dm^{-3}), and (ii) soybean/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. The experimental units have 5 rows of 5 m long with 0.20 m space, totaling 5 m^2. 45 and 30 kg ha^{-1} of P_2O_5 and K_2O was applied during sowing based on the P and K levels in the soil, in expectation of grain yield of 3 t ha^{-1} and nitrogen in the form of urea. The seeds were submitted for a germination and vigor test in the laboratory in order to provide the desired density of 300 viable seeds per square meters. During the vegetation period, plants were protected against diseases by using FOLICUR® EC fungicide at the dose of 0.75 L ha^{-1}. In addition, the weeds were controlled with an herbicide named ALLY®, known to have reduced stature, early cycle, resistance to lodging, commercial type "bread" and high yield potential. The cultivar is the standard biotype commonly desired by wheat farmers in southern Brazil.

In each cultivation system with high and low N-residual release (soybean/wheat and maize/wheat systems), the experimental design used was a randomized block in a 4 × 3 factorial scheme with four replications consisting of N-fertilizer rates (0, 30, 60 and 120 kg ha^{-1}), forms of supply [one rate (100%), V_3 phenological stage (third expanded leaf); fractionated (70 and 30%) V_3 and V_6 phenological stages (third and sixth expanded leaf); and fractioned (70 and 30%) V_3 and E phenological stages (third expanded leaf and early grain filling)], respectively, totaling 96 experimental units. It is noteworthy that in all the cultivation years, the application of N-fertilizer in V_3, V_6 and E stages, there were 30, 60 and 90 days of emergence of wheat, respectively.

Harvesting was done to estimate grain yield (PG, kg ha^{-1}). It was done manually by cutting the three central rows of each parcel stage near the harvest point (125 days), with grain moisture of about 15%. After harvesting, the beans were threshed with stationary combine harvester and sent to the laboratory for correction of grain moisture to 13%, after weighing and estimating grain yield (PG, kg ha^{-1}).

After checking the assumptions of normality and homogeneity using Bartlett test (STELL et al., 1997), analysis of variance for detection of the main and interaction effects was carried out. Based on this information, we proceeded to the mean comparison test by Scott & Knott's linear (PG = a ± bx) and quadratic (PG = a ± bx ± cx^2) equations. In conditions where there was a significant quadratic effect, the estimate of the maximum technical efficiency of nitrogen was obtained (MET = - [b/2c]) for the maximum grain yield in the different years and succession systems. Grain yield estimation was also obtained through technical recommendation of N-fertilizer in expectation of 3 t ha^{-1} grain, under the succession culture and MO content of soil. In addition, for combined analysis of the time (days) and N fertilizer dose, response surface analysis regression was performed ($Z_i = \beta_0 + \beta_1 X_j + \beta_2 Y_j + \beta_3 X^2_j + \beta_4 Y^2_j + ... + \beta_n X_j Y_j + \epsilon_j$), where, Z_i = dependent variable (grain yield); β_n = Estimates of regression coefficients; X and Y mean the encoded values of factors [conditions for supplying nitrogen (V_3 = 30 days; V_3/V_6 = 60 days; V_3/E = 90 days) and doses (0, 30, 60, 120 kg of N ha^{-1}), respectively]; $\beta_1 X_j$ and $\beta_2 Y_j$ = are responsible for the main effect (interacted factors); $\beta_3 X_{2j}$ and $\beta_4 Y_{2j}$ are responsible for the effects of curvature; $\beta_n X_j Y_j$ is responsible for the effects of interactions; ϵ_j is error. For their determination, we used the computer program Genes.

RESULTS AND DISCUSSION

In Figure 1, the maximum temperatures observed in 2012, at the beginning of the wheat development were higher (± 28 °C) compared to 2013 and 2014. This condition favors faster elongation and reduces the incentive to produce new tillers, component directly linked to grain yield. Also in 2012, it was observed high temperatures without rain before and after nitrogen fertilization on stage V_3, a condition that favors loss per volatilization of nutrient. Although the total rainfall was lower compared to historical average (Table 1), weather information together with the reasonable productivity obtained characterizes 2012 as year of intermediate (AI) cultivation. In the agricultural year 2013, the maximum temperature observed at the time of N fertilizer application in the V_3 stage was around 15 °C and favorable conditions of soil moisture by rainfall that occurred in the days prior to fertilization (Figure 1). In Table 1, the total rainfall was similar to the historical average, indicating adequate distribution of rainfall throughout the cycle (Figure 1). These conditions were decisive in the highest average grain yield obtained, characterizing 2013 as a favorable year (FY). In 2014 (Figure 1), the nitrogen supplied indicated maximum temperature of around 23 °C. In addition, nitrogen application was followed by significant rainfall (± 30 mm), a condition also observed near the grain crop. These facts justify the low grain yield obtained in the year (Table 1), through nutrient loss by leaching or damage caused by excessive rainfall at maturity (Figure 1), characterizing 2014 as unfavorable year (AD).

Of all the segments of the economy, agriculture is the one with greater reliance on climate variables, generating output fluctuations over the years (Chies; Yokoo, 2012). Rainfall stands as one of the main elements responsible for these variations (Martins et al., 2010). The prior knowledge of the precipitation conditions may indicate ways of management to ensure the success of the agricultural activity (Arf et al., 2015). The availability of nitrogen in soil and fertilizer efficiency is also influenced by the C/N ratio of residue cover, soil type and rainfall, which vary according to year and location (Arenhardt et al., 2015). Temperature, light and solar radiation are also elements that influence productivity (Souza et al., 2013). The temperature acts as a biological processes catalyst, which is why the plants require a minimum and maximum temperature for normal physiological activities (Tonin et al., 2014). In wheat, favorable weather is described as that of milder temperatures, having radiation that favours tillering and grain filling; without excessive rain; and facilitating adequate supply of moisture stored in the soil (Guarienti et al., 2004; Valério et al., 2009).

In Table 2, in each year of cultivation, there was an interaction between dose fractionation and nitrogen regardless of the succession system. In 2012 (IY), for soybean/wheat and corn/wheat and in 2014 (UY) for soybean/wheat, nitrogen fractionation indicated no change on grain yield. The differences promoted by fractionation, regardless of the succession system were obtained only in 2013 (FY). On the average comparison between the years, 2013 had the highest grain yield, followed by 2012 with regular productivity and 2014 with lower productivity. These results qualify the classification established between favorable (2013), intermediate (2012) and unfavorable (2014) years of wheat cultivation (Table 1).

The improvement of the chemical, physical and biological quality of the soil, especially in no-till system is associated with the previous crop, directly interfering with grain yield (Melero et al., 2013). The wide variation of grain yield is associated with variability of crop conditions, and the proper management of critical nitrogen on wheat productivity increased (Storck et al., 2014). Nitrogen is one of the most required nutrients and, in most cases, is not offered at the optimal dose and time to ensure productivity (Camponogara et al., 2016). Fractionation of nitrogen in wheat has been suggested as an alternative to increase efficiency in the assimilation of nutrients, especially when soil moisture conditions are not appropriate in the nutrient application time (Sangoi et al., 2007). To elucidate these issues, Table 3 shows the nitrogen utilized in single and fractionated conditions under favorable, intermediate and unfavorable conditions for wheat cultivation in succession soybean/wheat and corn/wheat.

Table 3 shows the developmental stage of the wheat crop, regardless of N-fertilizer rates. The year 2012 (IY) in the succession systems (soybean/wheat, corn/wheat) indicated no significant slope of the equation, a condition which reports the absence of differences between the mean grain yields. In 2013 (FY) in both cropping systems, the angular coefficient was negative and significant, a condition which shows reduction in grain yield with the use of fractionation. Therefore, from the V3 stage, reduced productivity occurs at 3.87 kg ha^{-1} in day system in soybean/wheat and 6.39 kg ha^{-1} system in maize/wheat. In 2014 (UY) in the soybean/wheat system, the angular coefficient of the equation was not significant, corroborating similar medium in different conditions of supply of fertilizer.

On the other hand, in the slow release system of N-waste, there was a significant reduction in grain yield (3.26 kg ha^{-1}) per day of fractionation. The results obtained in different conditions of agricultural year indicate disadvantages in the use of fractionation.

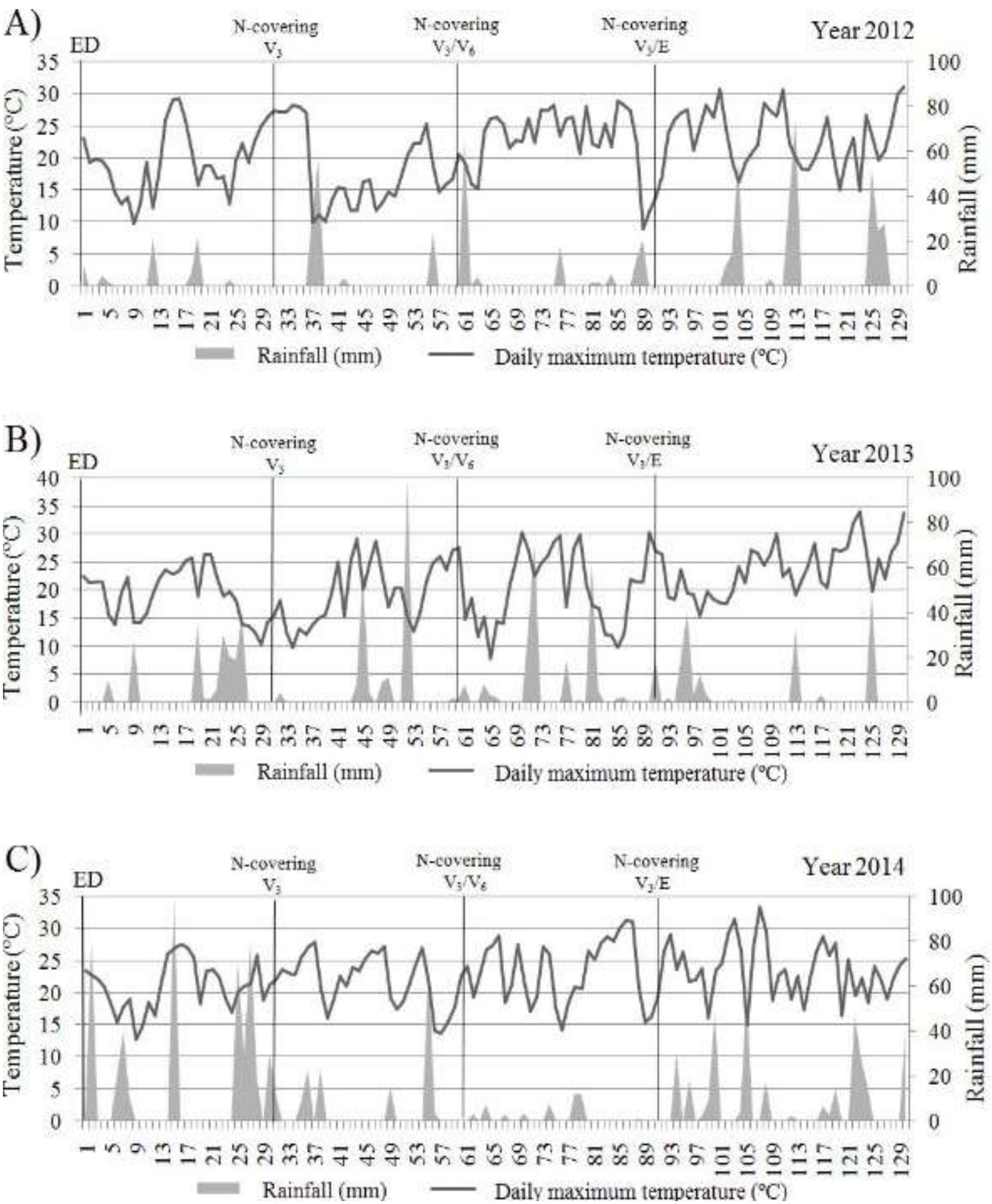

Figure 1. Rainfall and daily maximum temperature in the wheat crop cycle with the days of nitrogen application. ED = emergency date: 2012 (27 June); 2013 (17 June); 2014 (25 June). DAE = days after emergency. V3 = full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth expanded leaf; and V_3/E = fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling.

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

Year	Month	Temperature (°C)			Rainfall (mm)		$GY_{\bar{x}}$ (kg ha^{-1})	Class
		Minimum	Maximum	Average	Average 25 years*	Occurred		
	May	11.1	24.5	17.8	149.7	20.3		
	June	9.3	19.7	14.5	162.5	59.4		
	July	7.4	17.5	12.4	135.1	176.6		
2012	August	12.9	23.4	18.1	138.2	61.4	2441	IY
	September	12	23	17.5	167.4	194.6		
	October	15	25.5	20.2	156.5	286.6		
	Total	-	-	-	909.4	798.9		
	May	10.5	22.7	16.6	149.7	100.5		
	June	7.9	18.4	13.15	162.5	191		
	July	8.3	19.2	13.75	135.1	200.8		
2013	August	9.3	20.4	14.85	138.2	223.8	3357	FY
	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		
	May	10.8	23.6	17.2	149.7	412		
	June	8.6	19	13.8	162.5	412		
	July	9.7	21.82	15.76	135.1	144		
2014	August	8.8	23.66	16.23	138.2	77.8	1414	UY
	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		

*= Average rainfall obtained in the months from May to October 1989-2014; IY = intermediate year; FY = favorable year; UY = unfavorable year; GY_X = average grain yield.

Although the year 2012 (IY) does not show reduced productivity by fractionation, the averages were similar to N-fertilizer application in a unique way, which would reduce costs, time and manpower with only a single application. Espindula et al. (2010) point out that years of favorable and unfavorable climate change the nitrogen availability and use efficiency by the plant reflected in productivity. Ma et al. (2010) described the amount and timing of fertilization should be considered carefully, because high doses and late or early applications can be inefficient, especially in conditions of low soil moisture or high rainfall after fertilization. In this context, the nitrogen fertilization should be highlighted, not only due to the high cost that it represents, but also due to the efficient use with guaranteed sustainability (Costa et al., 2013). Studies by Mundstock (1999) report that the supply of nitrogen in fractionated condition seeks to provide more efficient assimilation of the nutrients by wheat, a condition that was not observed from the results presented in Table 3.

Table 4 shows the models that seek to validate the behavior of wheat grain yield expression for the maximum technical efficiency of nitrogen use and expectation of grain yield of 3 t ha^{-1}, regardless of single supply condition and nitrogen split in years and succession systems. The expected grain yield estimate of 3 t ha^{-1} was obtained due to the content of soil organic matter and the succession system (soybean/wheat = 60 kg N ha^{-1}, corn/wheat = 90 kg N ha^{-1}) according to technical indication for culture. In 2012 (IY), in the soybean/wheat system, the quadratic equation was significant, describing optimal dose of nitrogen with 110 kg ha^{-1} and simulated yield in 2869 kg ha^{-1}. On the other hand, considering the expected dose of 3 t ha^{-1}, the use of 60 kg ha^{-1} of nutrient led to large reduction of cost of fertilization while maintaining optimal dose. The quadratic behavior was also obtained in 2014 (UY) and provided a grain yield of 1704 kg ha^{-1} with 89 kg ha^{-1} N-fertilizer. It is noteworthy that the dose used for the expectation of 3 t ha^{-1} (60 kg ha^{-1}) indicated grain yield of around 1600 kg ha^{-1}.

These facts reinforce that nitrogen can be substantially reduced or increased based on the condition of the year of cultivation and the use of optimal dose may not necessarily express maximum grain yield with economic efficiency. In 2013 (FY), linearity was obtained in the

Table 2. Summary of the analysis of variance of nitrogen dose fractionation and comparison of average year wheat cultivation in succession systems.

Change source	DF	Mean square	
		Grain yield (kg ha^{-1})	
		Soybean/wheat system	Corn/wheat system
2012 (IY)			
Block	3	17877	51477
Fractionation (F)	2	6878[ns]	65216[ns]
Dose (D)	3	3034309*	8554725*
F x D	6	116598*	80829*
Error	33	33347	22162
Total	47		
General average		2613[b]	2270[b]
CV (%)		7.89	7.52
2013 (FY)			
Block	3	183194	8670
Fractionation (F)	2	238388*	609325*
Dose (D)	3	14866902*	38371527*
F x D	6	71559*	297203*
Error	33	35417	23303
Total	47		
General average		3691[a]	3023[a]
CV (%)		5.79	5.91
2014 (UY)			
Block	3	75262	9756
Fractionation (F)	2	41615[ns]	164537*
Dose (D)	3	817841*	1602882*
F x D	6	49807*	37256*
Error	33	15033	15129
Total	47		
General average		1561[c]	1268[c]
CV (%)		8.57	11.0

* = Significant at 5% error probability; ns = not significant at 5% probability of error; DF = degrees of freedom; CV = coefficient of variation; IY = Intermediate Year; FY = favorable year; UY = unfavorable year; Means followed by the same letter in the column do not differ by the Scott Knott model.

behavior of grain yield in high and reduced release of N-waste systems, a condition that reports the benefits of favorable year in using nitrogen to prepare grains. It is noteworthy that 60 kg ha^{-1} dose expressed nitrogen values above the expected 3 t ha^{-1}. In the slow release system of N-residual (Table 4), the nitrogen used for the grain was linear, regardless of intermediate year, favorable and unfavorable conditions for wheat cultivation. The results corroborate the agricultural year classification (Table 1), because at the intermediate condition there was increased grain yield by 15.9 kg ha^{-1} per kilogram of nitrogen applied. In favorable condition (Costa et al., 2013), each kilogram of nitrogen applied per hectare gave 19.4 kg ha^{-1} of grain yield. On the other hand, the unfavorable condition in 2014 exhibited lower nitrogen used for the preparation of grains with 6.7 kg ha^{-1} productivity per kilogram of nitrogen. In this condition, the nitrogen dose expectation of 3 t ha^{-1} (90 kg N ha^{-1}), promoted an estimated yield of 1366 kg ha^{-1}. Therefore, in an unfavorable year, investments in fertilizer should be reduced, noting the cost/benefit ratios.

Espindula et al. (2010) obtained the highest grain yield with doses ranging from 70 to 120 kg ha^{-1} of nitrogen. Heinemann et al. (2006) point out that the wheat under irrigation has a positive response up to 156 kg ha^{-1} with estimated productivity of 6472 kg ha^{-1}. Vianal (2010) claims that nitrogen is the nutrient which interferes mostly with wheat composition and is mostly demanded during its development.

On the other hand, the nitrogen supplied to plants

Table 3. Regression equation to estimate grain yield and average productivity in stages (days) of the supply of nitrogen in cropping systems.

Year	Phenological stage (application day N)	GY (kg ha^{-1})	Equation GY = a ± bx	R^2 (%)	P (b_{ix})
		Soybean/wheat system			
2012 (IY)	V_3 (30)	2294[a]	2272+0.68x	98	ns
	V_3/V_6 (30/60)	2311[a]			
	V_3/E (30/90)	2335[a]			
2013 (FY)	V_3 (30)	3346[a]	3484-3.87x	90	*
	V_3/V_6 (30/60)	3295[a]			
	V_3/E (30/90)	3113[b]			
2014 (UY)	V_3 (30)	1488[a]	1504-1.21x	50	ns
	V_3/V_6 (30/60)	1390[a]			
	V_3/E (30/90)	1415[a]			
		Corn/wheat system			
2012 (IY)	V_3 (30)	1908[a]	1858+2.03x	91	ns
	V_3/V_6 (30/60)	2002[a]			
	V_3/E (30/90)	2030[a]			
2013 (FY)	V_3 (30)	2754[a]	2967-6.39x	96	*
	V_3/V_6 (30/60)	2626[a]			
	V_3/E (30/90)	2371[b]			
2014 (UY)	V_3 (30)	1200[a]	1313-3.26x	93	*
	V_3/V_6 (30/60)	1149[a]			
	V_3/E (30/90)	1005[b]			

V_3 = single condition (100%) of the nitrogen dose in the third expanded leaf (30 days); V_3/V6 = fractional condition (70% / 30%) of the nitrogen dose in the third and sixth expanded sheet (30 and 60 days); V_3/E = fractional condition (70% / 30%) of the amount of nitrogen in the third expanded leaf and early grain filling (30 and 90 days); R^2 = coefficient of determination; IY = intermediate year; FY = favorable year; UY = unfavorable year; GY = grain productivity (kg ha^{-1}); P (b_ix) = slope significance of probability; * = Significant at 5% probability of error for the test; ns = not significant; means followed by the same letter in the column do not differ by the Scott Knott model.

depends, among other factors, on the amount of soil nutrients, the composition of plant residues, the expected desired productivity and humidity, aeration and temperature interaction in cropping systems (Rocha et al., 2008; Romitti et al., 2016). Therefore, the biochemical composition of crop residues used for determining nitrogen mineralization or immobilization may affect the dosages and times of N-fertilizer of the rate of soil nitrogen release and decomposing tissues (Mantai et al., 2016).

The analysis of the grain yield involving dose of interrelations with the N-fertilizer fractionation can be better understood if the mathematical function that simultaneously adds these sources of variation is known. One way to express this function can be obtained by regression analysis using response surface. Therefore, in Table 5, the different models tested are shown as a way of simulating grain yield in different culture conditions. Among the equations obtained, one with the highest coefficient of determination is more efficient to explain the simultaneous behavior between dose and form of nitrogen supply. This condition was obtained using the following mathematical structure:

$$Z = b_0 \pm b_1 X + b_2 Y - b_3 Y^2$$

Table 6 shows the values of simulated grain yield by response surface regression model, the combined dose analysis and condition of nitrogen supply based on agricultural year and succession system. The results obtained in soybean/wheat system and maize/wheat showed increased grain yield with the increase of fertilizer nitrogen mainly in intermediate year (2012) and favorable (2013) cultivation. This increase was significant at succession system with reduced C/N ratio (soybean/wheat), which promotes increased release of this residual N-cultivation system. In all conditions analyzed in the year and nitrogen rate, the use of fractionation showed no increase in the simulated values grain yield.

The results give support when stating that although it occurs favorable years, intermediate and unfavorable to wheat cultivation, the use of single dose of nitrogen is more advantageous. In addition, the optimum dose of the

Table 4. Regression equation of grain yield and average wheat productivity in nitrogen and define the optimal dose with simulation of grain yield.

Year	Dose (N)	GY ($kg\ ha^{-1}$)	Equation $GY= a \pm bx \pm cx^2$	R^2 (%)	P (b_{ix})	$N_{(MET)}$ ($kg\ ha^{-1}$)	$GY_{(MET)}$ ($kg\ ha^{-1}$)	$N_{(PG=3\ t\ ha^{-1})}$ ($kg\ ha^{-1}$)	GY_E ($kg\ ha^{-1}$)
Soybean/wheat system									
2012 (IY)	0	1607[c]	$1659+22x-0.10x^2$	95	*	110	2869	60	2619
	30	2366[b]							
	60	2492[b]							
	120	2787[a]							
2013 (FY)	0	1930[d]	2132+21.3x	96	*	-	-	60	3410
	30	2871[c]							
	60	3665[b]							
	120	4539[a]							
2014 (UY)	0	1069[c]	$1065+14.3x-0.08x^2$	99	*	89	1704	60	1635
	30	1412[b]							
	60	1638[a]							
	120	1605[a]							
Corn/wheat system									
2012 (IY)	0	919[d]	1141+15.9x	94	*	-	-	90	2572
	30	1808[c]							
	60	2264[b]							
	120	2929[a]							
2013 (FY)	0	1263[d]	1564+19.4x	92	*	-	-	90	3310
	30	2467[c]							
	60	2851[b]							
	120	3753[a]							
2014 (UY)	0	647[d]	763+6.7x	84	*	-	-	90	1366
	30	1035[c]							
	60	1298[b]							
	120	1491[a]							

GY = Grain yield ($kg\ ha^{-1}$); N = nitrogen; N (MET) = Maximum technical efficiency of nitrogen use; PG (MET) = Grain yield the maximum technical efficiency of nitrogen use; N (PG = 3 t ha^{-1}) = nitrogen dose for expectation of 3 t ha^{-1} of grain yield; GY_E = estimated grain yield; MET = Maximum technical efficiency; IY = Intermediate Year; FY = Favorable year; UF = Unfavorable year; R^2 = coefficient of determination; P (b_ix) = Probability of slope of significance; * = Significant at 5% probability of error for the test; ns = not significant; Means followed by the same letter in the column do not differ by the Scott Knott model.

N-fertilizer should not always be indicated, especially in unfavorable conditions for cultivation, since the utilization efficiency of the nutrient to the grains preparation is drastically reduced. Although the fertilizer around the phenological stage V_3 is shown to be more appropriate, it is essential that the soil moisture conditions are suitable for enabling greater absorption of nutrients by the plant. Therefore, suggesting that the supply of nitrogen in the growth stage V_4 and V_5 can also be considered, provided that there are suitable conditions for nitrogen supply stage V_3. Even the wheat technical specifications mention the possibility of fertilization with N-fertilizer in a range that goes from 30 to 60 days after emergence of wheat seedlings.

Response surface analysis is a method that comprises a set of mathematical and statistical procedures used in the model to develop, improve and optimize processes (Zhang et al., 2009; Santos et al., 2014). With surface analysis response, the best conditions of hydrothermal pre-treatment in sugarcane were determined (Ferreira et al., 2015). Using this methodology, greater efficiency of live weight ratio of broiler chickens against the feed intake and its feed conversion was achieved. Therefore, an optimization technique that also allows simulations may indicate the behavior of important processes, and the efficient use of natural and biological resources in agriculture.

Conclusion

In favorable, intermediate and unfavorable years of wheat

Table 5. Response surface models on the combined use of doses and conditions of supply of nitrogen to wheat grain yield in cropping systems.

Soybean/wheat system			**Corn/wheat system**		
Model		**R^2**	**Model**		**R^2**
		2012 (IY)			
$Z=2271+0.68749X$		12	$Z=1858+20302X$		13
$Z=1851+8.78936Y$		66	$Z=1141+15.97801Y$		88
$Z=1810+0.68749X+8.78936Y$		66	$Z=1019+2.0302X+15.97801Y$		89
$Z=1822+0.19583X+0.00409X^2+8.78936Y$		66	$Z=908+6.45104X-0.03685X^2+15.97801Y$		89
$Z=1618+0.68749X+22.04781Y-0.10668Y^2$		79	$Z=825+2.0302X+29.36933Y-0.10775Y^2$		94
$Z=1630+0.195X+0.004X^2+22.047Y-0.106Y^2$		78	$Z=714+6.451X-0.036X^2+29.369Y-0.107Y^2$		93
$Z=1875-0.39751X+7.54936Y+0.02066XY$		66	$Z=1180-0.65X+12.91492Y+0.05105XY$		89
X minimum = 30	Y maximum = 120		X minimum = 30	Y maximum= 120	
X maximum = 90	Z minimum = 1332		X maximum = 90	Z minimum= 788	
Y minimum = 0	Z maximum = 3023		Y minimum = 0	Zbmaximum=3364	
		2013 (FY)			
$Z=3483-3.87188X$		9	$Z=2966-6.38855X$		3
$Z=2131+21.31817Y$		90	$Z=1564+19.4169Y$		84
$Z=2364-3.87188X+21.31817Y$		91	$Z=1947-6.38855X+19.4169Y$		87
$Z=2147+4.79062X-0.07219X^2+21.31817Y$		91	$Z=1735+2.09895X-0.07073X^2+19.4169Y$		87
$Z=2155-3.87188X+35.74258Y-0.11606Y^2$		95	$Z=1716-6.38855X+35.34571Y-0.12817Y^2$		92
$Z=1938+4.790X-0.072X^2+35.742-0.116Y^2$		94	$Z=1504+2.098X-0.070X^2+35.345Y-0.128Y^2$		91
$Z=2418-4.78001X+20.28031Y+0.01729XY$		91	$Z=1743-2.99834X+23.29142Y-0.06458XY$		87
X minimum = 30	Y maximum = 120		X minimum = 30	Y maximum = 120	
X maximum = 90	Z minimum = 1678		X maximum = 90	Z minimum =1109	
Y minimum = 0	Z maximum = 5024		Y minimum = 0	Z maximum =4081	
		2014 (UY)			
$Z=1503-1.21146X$		18	$Z=1313-3.26146X$		5
$Z=1212+4.15492Y$		45	$Z=763+6.74873Y$		73
$Z=1285-1.21146X+4.15492Y$		47	$Z=959-3.26146X+6.74873Y$		78
$Z=1492-9.47396X+0.06885X^2+4.15492Y$		48	$Z=805+2.8927X-0.05129X^2+6.74873Y$		78
$Z=1138-1.21146X+14.33761Y-0.08193Y^2$		70	$Z=843-3.26146X+14.73419Y-0.06426Y^2$		87
$Z=1344-9.473X+0.068X^2+14.337Y-0.081Y^2$		69	$Z=689+2.89X-0.051X^2+14.734Y-0.064Y^2$		86
$Z=1335-2.04667X+3.20039Y+0.0159XY$		47	$Z=1028-4.4175X+5.42753Y+0.02201XY$		78
X minimum = 30	Y maximum = 120		X minimum = 30	Y maximum = 120	
X maximum = 90	Z minimum = 891		X maximum = 90	Z minimum =411	
Y minimum = 0	Z maximum = 2048		Y minimum = 0	Z maximum =1773	

Z = Grain yield (kg ha^{-1}); X = nitrogen supply condition [V_3 = single condition (100%) of the nitrogen rate in the third expanded leaf (30 days); V_3/V_6 = fractional condition (70% / 30%) of the nitrogen rate in the third and sixth expanded sheet (60 days); V_3/E = fractional condition (70% / 30%) of the amount of nitrogen in the third expanded leaf and early grain filling (90 days)]; Y = nitrogen doses (0, 30, 60, 120 kg ha^{-1}); IY = Intermediate year; FY = favorable year; UY = unfavorable year; R^2 = coefficient of determination.

cultivation the supply of nitrogen in single dose is more effective than the development of the grain using fractionation, regardless of the succession system.

The nitrogen use efficiency can be substantially reduced or increased in wheat based on the year of cultivation, and the use of optimal dose of the nutrient may not necessarily express maximum grain yield with economic efficiency.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Table 6. Value estimated by the model of response surface regression in predictability of grain yield in cropping systems.

Year	Dose N ($kg\ ha^{-1}$)	Phenological stage (days)	$Z = b_0 \pm b_1X + b_2Y - B_3Y^2$ ($kg\ ha^{-1}$) Soybean/Wheat	Corn/Wheat
2012 (IY)	0	V_3 (30)	1639	886
		V_3/V_6 (60)	1659	947
		V_3/E (90)	1680	1008
	30	V_3 (30)	2204	1670
		V_3/V_6 (60)	2225	1731
		V_3/E (90)	2243	1792
	60	V_3 (30)	2577	2260
		V_3/V_6 (60)	2598	2321
		V_3/E (90)	2619	2382
	120	V_3 (30)	2748	2859
		V_3/V_6 (60)	2769	2920
		V_3/E (90)	2789	2980
2013 (FY)	0	V_3 (30)	2039	1524
		V_3/V_6 (60)	1923	1333
		V_3/E (90)	1807	1141
	30	V_3 (30)	3001	2469
		V_3/V_6 (60)	2891	2278
		V_3/E (90)	2774	2086
	60	V_3 (30)	3766	3184
		V_3/V_6 (60)	3649	2992
		V_3/E (90)	3533	2800
	120	V_3 (30)	4657	3920
		V_3/V_6 (60)	4541	3729
		V_3/E (90)	4424	3537
2014 (UY)	0	V_3 (30)	1102	745
		V_3/V_6 (60)	1065	647
		V_3/E (90)	1029	549
	30	V_3 (30)	1458	1129
		V_3/V_6 (60)	1422	1032
		V_3/E (90)	1385	934
	60	V_3 (30)	1667	1398
		V_3/V_6 (60)	1631	1300
		V_3/E (90)	1594	1202
	120	V_3 (30)	1642	1588
		V_3/V_6 (60)	1607	1490
		V_3/E (90)	1570	1392

N = nitrogen; Z = grain yield ($kg\ ha^{-1}$); X = nitrogen supply condition [V_3 = single condition (100%) of the nitrogen rate in the third expanded leaf (30 days); V_3/V_6 = fractional condition (70% / 30%) of the nitrogen rate in the third and sixth expanded sheet (60 days); V_3/E = fractional condition (70% / 30%) of the amount of nitrogen in the third expanded leaf and early grain filling (90 days)]; Y = nitrogen doses (0, 30, 60, 120 $kg\ ha^{-1}$); IY = Intermediate year; FY = favorable year; UY = unfavorable year.

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