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The efficiency of wheat yields by nitrogen dose and fractionation

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The biomass productivity and wheat grains efficiency is determined by nitrogen dose adjustment (full or fractioned), environmental conditions, and cropping system. The aim of this study was to improve the efficiency of N-fertilizer usage on wheat to maximize the biomass productivity and grain yield by adjusting the full or fractioned nitrogen dose in favorable and unfavorable year conditions, in succession systems with high and reduced N-residual release. In this study, two experiments were conducted between 2012 and 2014. One was to quantify the biomass productivity rate and another to determine grain yield. The experimental design was a complete randomized block, with four replications, in a 4 × 3 factorial scheme to N fertilizer rates (0, 30, 60 and 120 kg ha^{-1}) and supply forms of the nutrient [full dose (100%) in the V_3 phenological stage (third expanded leaf); fractioned (70 and 30%) at the V_3 and V_6 phenological stages (third and sixth expanded leaf, respectively) and; fractionated (70 and 30%) at the V_3 and E phenological stages (third expanded leaf and early grain filling),] respectively, in soybean/wheat and maize/wheat cultivation systems. The nitrogen supply in wheat through single dose or fraction indicates linear tendency over the productivity biomass daily rate-1 with the increase of N-fertilizer, regardless of a favorable and unfavorable year and system of a succession of the high and reduced N-residual release. However, in favorable years, the use of full dose on V_3 stage is indicated. In the maize/wheat system, the full dose at V_3 stage is more efficient, especially with higher doses of the nutrient. For grain yield, the N-fertilizer fractioning was adjusted in intermediate cropping years, while the full dose became suitable at the V_3 stage in favorable years. However, in unfavorable years, nitrogen investments should be minimized, regardless of the supply form and succession system.

Key words: *Triticum aestivum* L., succession system, optimization, regression.

INTRODUCTION

The supply of N-fertilizer for plants depends, among other factors, on the amount of soil organic matter, the decomposition of plant residues and yield expectation, which interact with each other in cropping systems (Costa et al., 2013; Mantai et al., 2015a). The management technologies and weather conditions act under the nitrogen use efficiency in productivity (Benin et al., 2012; Mantai et al., 2015a). Therefore, the climatic conditions of each year (favorable or unfavorable) and the succession systems, with high or reduced N-residual release, can alter the nitrogen use efficiency in wheat yield (Arenhardt et al., 2015).

The quantity and the proper time of nitrogen application should be better exploited since high doses and/or applications in early/late crop development stages may be too little advantageous (Arenhardt et al., 2015; Ma et al., 2010), in addition to the environmental losses caused by leaching and volatilization (Ma et al., 2010; Mantai et al., 2015b). Therefore, nitrogen fertilization should not be characterized by its high cost, but by the efficient use to provide productivity and sustainability (Costa et al., 2013). In this context, the possibility of splitted application of N fertilizers with adjusted doses can result in increased utilization efficiency by wheat (Espindula et al., 2010). This management can be better understood and feasible, taking into account the environmental conditions and succession systems with the high and reduced release of N-residual.

The aim of this study is to improve the N-fertilizer use efficiency of wheat to maximize the biomass productivity and grain yield by dose adjustment for wheat plant development under conditions of favorable and unfavorable years of cultivation, and crop rotations with high and reduced N-residual release.

MATERIALS AND METHODS

The field experiments were conducted in the years 2012, 2013 and 2014, at 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, with hot summer and without a dry season. Soil analysis was carried out ten days before the sowing date and subsequently in the average of the years 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}, OM= 2.9%, Al= 0 $cmol_c$ dm^{-3}, Ca= 6.8 $cmol_c$ dm^{-3}, and Mg= 3.1 $cmol_c$ 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 $cmol_c$ dm^{-3}, Ca= 6.3 $cmol_c$ dm^{-3} and Mg= 2.5 $cmol_c$ dm^{-3}). The sowing was carried out according to the wheat technical indications, mechanically, with experimental units using 5 rows of 5 m long and spaced 0.20 m apart, totaling 5 m^2. The quantity of 60 and 50 kg ha^{-1} of P_2O_5 and K_2O, respectively, was applied during sowing based on the P and K levels in the soil, considering the expected grain yield of 3 t ha^{-1} and urea nitrogen form to contemplate the proposed dose in this study.

The seeds were submitted to a germination and vigor test in the laboratory in order to provide the desired density of 300 viable seeds per m^{-2}. During vegetation period, plants were protected against diseases by FOLICUR® EC fungicide at the dose of 0.75 L ha^{-1}. In addition, the weeds were controlled with named ALLY® used, which is 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), two experiments were conducted. One was to quantify the biomass productivity rate (DB, kg ha-1) by cuts in every 30 days to physiological maturity, and the other to estimate grain yield (GY, kg ha-1). The experimental design used for all the experiments was a randomized block with four replications, in a factorial 4 × 3 scheme for N-fertilizer rates (0, 30, 60 and 120 kg ha-1) and for nitrogen supply ways [one rate (100%) in the V3 phenological stage (third expanded leaf); fractionated (70 and 30%) in the V3 and V6 phenological stages (third and sixth expanded leaf); and fractioned (70 and 30%) in the V3 and E phenological stages (third expanded leaf and early grain filling)], respectively.

The harvest of wheat for estimations of the biomass productivity and grain yield was performed manually by cutting the three central rows of each experimental unit, close to harvest stage (125 days after sowings), with approximately 15% moisture content of grain. The harvest of grains is also defined as the last cut in the experiment directed for analyzing biomass productivity. The plants designed for grain harvest were threshed and dried to 13% grain moisture, and estimating the grain yield (GY, kg ha^{-1}). The plants for biomass analysis were dried in the kiln at 65°C until constant weight for weighing and estimating biomass productivity (DB, kg ha^{-1}).

After checking the assumptions of normality and homogeneity using Bartlett test, analysis of variance for detection of the main and interaction effects was carried out. Based on this information, the adjustment was made using the linear equation (DB= b0 ± bix) to estimate the daily biomass production $rate^{-1}$ ha^{-1} and averages by the Scott and Knott test in the analysis of grain yield in each dose and N-fertilizer supply condition. In conditions where there was a significant quadratic effect ($GY= b_0 \pm b_1x \pm b_2x^2$), the estimated maximum technical efficiency ($MTE = -[(b_1)/(2b_2)]$) of nitrogen use for grain yield was obtained. On the other hand, when there was a significant linear effect ($GY=b_0 \pm b_ix$) the grain yield was obtained by N-fertilizer technical recommendation accordingly with the succession of culture for the estimated 3 t ha^{-1}. All statistical procedures were performed using the Genes software.

RESULTS AND DISCUSSION

In 2012, the maximum temperatures observed in the beginning of wheat development was higher (± 27°C) in relation to 2013 and 2014 (Figure 1). The condition improved faster elongation and decreased the stimulus to the production of new tillers, a determinant component for biomass productivity and grain yield. After fertilization, variations of temperature were observed close to flowering time. Although rainfall was less in comparison with historic average (Table 1), the association between meteorological information and reasonable productivity

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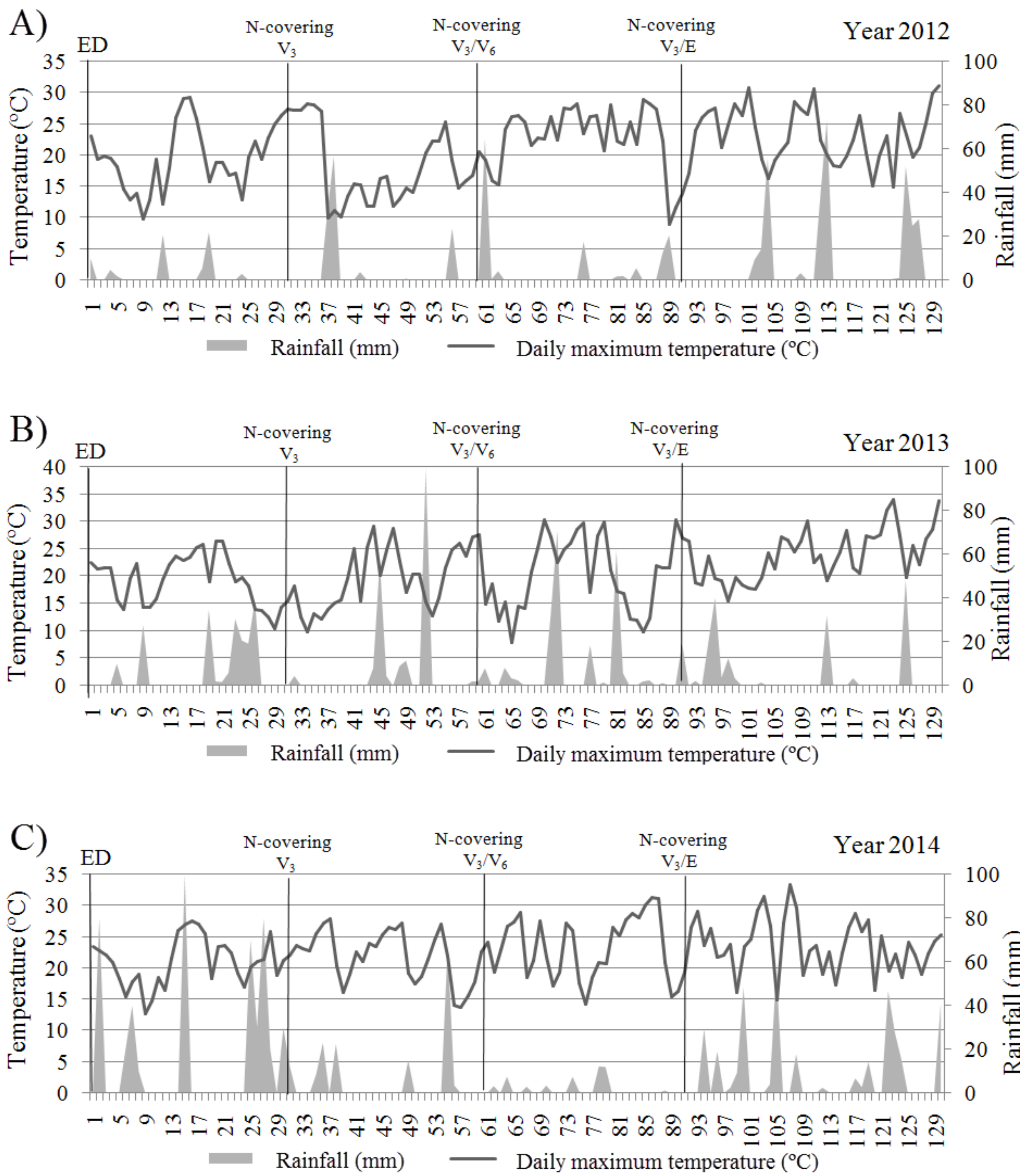

Figure 1. Rainfall and daily maximum temperature in the wheat crop cycle with the days of nitrogen application. ED= emergency date: 2012 (27 June); 2013 (17 June); 2014 (25 June). DAE= days after emergency. V_3= full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = fractioned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

obtained characterize 2012 as an intermediate year (IY) of cultivation.

In 2013, the maximum temperatures observed at the moment of N-fertilizer application was around of 15°C, and with favorable conditions of soil moisture for rain that occurs before fertilizing (Figure 1). According to Table 1, the total volume of rain was similar to historic average, indicating the adequate distribution of rainfall along the cycle (Figure 1). These conditions were decisive for a higher average of grain yield, characterizing 2013 as a

Table 1. Temperature, rainfall per month and average productivity.

Year	Month	Temperature (ºC)			Rainfall (mm)		$GY_{\bar{x}}$ (kg ha^{-1})	Class
		Minimum	Maximum	Average	Historical average*	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	12.0	23.0	17.5	167.4	194.6		
	October	15.0	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	191.0		
	July	8.3	19.2	13.75	135.1	200.8		
2013	August	9.3	20.4	14.85	138.2	223.8	3358	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	412.0		
	June	8.6	19.0	13.8	162.5	412.0		
	July	9.7	21.8	15.8	135.1	144.0		
2014	August	8.8	23.7	16.2	138.2	77.8	1414	UY
	September	13.33	23.6	18.5	167.4	274.8		
	October	16.02	27.5	21.8	156.5	230.8		
	Total	-	-	-	909.4	1551.4		

*= Average rainfall obtained the months from May to October 1989-2014; IY= intermediate year; FY= favorable year; UY= unfavorable year; $GY_{\bar{x}}$= average grain yield.

favorable year (FY) of cultivation. In 2014, the moment of N-fertilizer application indicated maximum temperature next to 23°C (Figure 1). Although there were adequate conditions of soil moisture due to rains that occurred before fertilizing, the moment of nutrient supply was characterized by significant rain volume (30 mm), allowing a high loss of nitrogen for leaching. In addition, the big frequency and rain volume were observed between 90 days after an emergency and the harvest date. This period coincides with low light and high temperatures, these conditions reduced the efficiency photosynthesis. The elevated rainfall in relation to historic average and the reduced productivity obtained in this crop season (Table 1) characterize 2014 as an unfavorable year of cultivation.

One way to improve the nitrogen absorption by plants is the mutation of soil humidity. The nitrogen supply depends on humidity, aeration, and temperature that interrelate with each other in cropping systems (Rocha et al., 2008; Silva et al., 2015). The rainfall is the main meteorological variable that affects the productivity of cultivated species (Benin et al., 2012; Battisti et al., 2013). In this sense, stress caused by lack of water affects plant development negatively with direct effect in productivity (Guarientiet al., 2005; Arenhardt et al., 2015).

The soil and weather variability alter the nitrogen disponibility and demand of plant, thereby restricting productivity (Simili et al., 2008). Weather favorable to wheat is described as more mild temperatures and of solar radiation quality, improving tillering and grain filling, and without high volume and intense rainfall, but one that improves the adequate supply of soil moisture (Guarientiet al., 2004; Valério et al., 2009). Mild temperatures improve the number and filling of grains, while high temperatures on tillering cause infertility of spikelets, which lead to low productivity (Ribeiro et al., 2009).

In the analysis of the variation source of the main effects of nitrogen doses, the condition of supply, cultivate years, and the significant triple interaction was obtained on daily biomass productivity rate^{-1}, total biomass and grain yield (not shown); justifying the way of table presentation in interaction developments. The soybean/wheat system with the high liberation of N-residual, in 2012 (intermediate year) indicated that fractionation condition promotes expressive values on daily biomass productivity rate^{-1}, total biomass and grain yield (Table 2). The dose of 30 kg of N ha^{-1} was more

Table 2. Linear regression equation of dry biomass and wheat average grain yield by dose and nitrogen fractionation in the soybean/wheat system.

Dose	Condition of N	Equation	R^2	P	Average (kg ha^{-1})	
(N)	Stage (DAE)	DB= $b_0 \pm b_i x$	(%)	($b_i x$)	DB	GY
		2012 (IY)				
0	-	1371+68x	80	*	3730	1607
	V_3 (30)	1134+68x	75	*	4021 a	2256 b
30	V_3/V_6 (60)	1811+83x	83	*	4432 a	2570 a
	V_3/E(90)	1614+77x	61	*	4190 a	2273 b
	V_3(30)	1570+78x	68	*	4349 a	2330 b
60	V_3/V_6(60)	1307+74x	73	*	4283 a	2453 b
	V_3/E(90)	1763+82x	72	*	4401 a	2686 a
	V_3 (30)	1434+75x	74	*	4194 b	2875 a
120	V_3/V_6 (60)	1327+78x	75	*	4562 a	2638 a
	V_3/E(90)	2244+85x	83	*	4172 b	2846 a
		2013 (FY)				
0	-	1977+71x	95	*	3352	1930
	V_3 (30)	1823+73x	99	*	3686 a	2860 a
30	V_3/V_6 (60)	2805+82x	96	*	3342 a	2990 a
	V_3/E(90)	2393+77x	86	*	3393 a	2763 b
	V_3 (30)	1908+84x	91	*	4412 a	3952 a
60	V_3/V_6 (60)	2179+84x	93	*	4193 a	3591 b
	V_3/E(90)	2019+75x	97	*	3653 b	3450 c
	V_3 (30)	1903+95x	91	*	5268 a	4501 a
120	V_3/V_6 (60)	2754+108x	88	*	5355 a	4676 a
	V_3/E (90)	2351+88x	99	*	4306 b	4438 a
		2014 (UY)				
0	-	442+53x	67	*	3560	1069
	V_3 (30)	701+68x	67	*	4402 b	1345 a
30	V_3/V_6 (60)	882+80x	56	*	5163 a	1514 a
	V_3/E(90)	1968+81x	86	*	3715 c	1376 a
	V_3 (30)	843+77x	59	*	4954 b	1798 a
60	V_3/V_6 (60)	1161+90x	57	*	5611 a	1566 a
	V_3/E(90)	1005+75x	69	*	4656 b	1549 a
	V_3 (30)	1021+86x	69	*	5500 a	1613 a
120	V_3/V_6 (60)	1027+91x	62	*	5844 a	1536 a
	V_3/E(90)	851+86x	64	*	5780 a	1665 a

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= 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; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); DB= dry biomass (kg ha^{-1}); R^2= determination coefficient; P ($b_i x$)= significance probability of slope line; *= significant at 5% probability level. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

efficient when fractionation was employed in V_3/V_6 stages. However, 60 kg dose of N ha^{-1} indicated that the fractionating in V_3/E stages was more responsive. In elevated nutrient dose, the V_3/V_6 fractionating indicated more efficiency, similar to the reduced condition of N-fertilization.

In 2013 (favorable year), the fertilizing in V_3 stage showed more significant results with all doses of N-fertilizing. Although the V_3/V_6 condition can increase the daily biomass productivity rate^{-1}, the total biomass productivity and grain yield was inferior or similar to the full dose provided. As a result, one single application in nitrogen management in the field became more advantageous, reducing the production costs and work time by using machinery. In 2014 (unfavorable year), the condition of N-fertilizing use in full dose or fractionated raised questions, mainly, in years of rain becoming more intense close to harvest (Table 2). In doses of 30 and 60 kg of N ha^{-1}, the fractioned condition showed more interest on daily biomass productivity rate^{-1} and total biomass, however, it does not occur differences on grain yield. This suggests that when seeking maximum productivity straw for summer crops in the no-tillage system, it is indicated with the fractioning shown. On the other hand, at the higher dose of N-fertilizer, a single application promoted similar results on grain yield and biomass. While analyzing only the grain yield, the use of full dose stands out as the most appropriate management, regardless of nutrient dose.

The maize/wheat system, with reduced N-residual release, in the year 2012 (intermediate year) showed advantages over nitrogen use in full dose in the condition of 30 and 60 kg N ha^{-1} (Table 3). Only in the highest condition of N-fertilizer the V_3/E fractioning proved advantageous on grain yield. In 2013 (favorable year), the nitrogen management in full dose also showed positive results in grain yield, regardless of N-fertilizer dose. It may represent a reduction of time and costs in the machinery used for soil fertilization.

The doses of 60 and 120 kg N ha^{-1} may increase the straw productivity in the field when fractionated in V_3/V_6 growth stages, in comparison with the single dose at V_3 growth stage (Table 3). In the year 2014 (unfavorable year), the full dose condition in this system also showed more effective results on daily biomass productivity rate^{-1}, total biomass and grain yield. The results of conjoint analysis of biomass productivity and grain yield indicated that, in the high N-residual condition (Table 2), the intermediate year (2012) and unfavorable year (2014) suggested the use of N fractionation. However, in the favorable year (2013) the use of full dose is the most indicated. In the condition of high C/N ratio (Table 3), the results suggest that the lower N-residual release for corn straw requires the need for the most intensive use of N-fertilizer, with direct application of full dose at V_3 stage.

The favoring of cultivation year is decisive on the productivity potential, due to the volume and rainfall distribution, temperature, and solar radiation (Benin et al., 2012). Nitrogen deficiency reduces the uptake of solar radiation by wheat, with direct effects on the biomass production and grain yield (Heinemann et al., 2006). The N-fertilizer stimulates the vegetative and root growth, affecting the absorption of nutrients and productivity (Flores et al., 2012). The description of N-fertilizer dose in wheat is realized according to the soil organic matter content, the species cultivated previously, and the yield expectations (Siqueira-Neto et al., 2010). The correct use of nitrogen in favorable weather conditions can increase the grains productivity, overcoming the expected yield by nitrogen dose. On the other hand, it can also facilitate the lodging, with negative effects on productivity and grain quality (Bredemeier et al., 2013; Arenhardt et al., 2015). The appropriate time for N-fertilizer supply in coverage focuses on plant phenology associated with the scarcity period of the nutrient (Bredemeier et al., 2013). For wheat, the biggest scarcity of nitrogen is defined between the period of emission of the third and sixth leaf (Arenhardt et al., 2015; Rissini et al., 2015). Nitrogen fractionation in wheat has been suggested to provide greater efficiency in the assimilation of nutrient, especially when soil moisture conditions are not appropriate at the moment of N application (Sangoi et al., 2007). Therefore, the fractioning can reduce leach losses in wet years and volatilization in dry years (Costa et al., 2013; Mantai et al., 2015b). In addition, the biochemical composition of the waste affects the dose and timing of nitrogen supply in relation to the nutrient release in soil and decomposing tissues (Siqueira-Neto et al., 2010).

The expression of grain yield by the maximum technical efficiency of nitrogen use and nutrient dose, for productivity expectation of 3 t ha^{-1}, in different growing conditions (unfavorable year, favorable year and intermediate year), are presented in tables 4 and 5. Thus, in linear behavior conditions, grain yield estimate for the expectation of 3 t ha^{-1} was obtained according to the wheat recommendations and the nutrient dose in function of succession system (soybean/wheat = 60 kg de N ha^{-1}; maize/wheat = 90 kg de N ha^{-1}). Considering the soybean/wheat system in the year 2012 (intermediate year), only the fractioned condition showed a quadratic behavior with 90 to 100 kg N ha^{-1} for the maximum grain yield of 2809 and 2932 kg ha^{-1}, respectively (Table 4). In this condition, the dose to the expectation of 3 t ha^{-1} showed the highest yields in fractioned condition. In an intermediate year, the reduction of N-fertilizer from optimum estimated dose of 60 kg N ha^{-1} showed great benefits. Among these benefits is the drastically reduced dose, close grain yield values, and reduction of production costs and environmental damages.

In 2013 (favorable year), the linear behavior was obtained either by full or fractioned N-fertilizer dose. In this year, the dose of 60 kg N ha^{-1} expressed greater values than the expectation of 3 t ha^{-1}, especially in full dose condition of the nutrient. In 2014 (unfavorable year), the fractionated condition showed similar behavior to the year 2012 (intermediate year), however, with low efficiency of N-fertilizer use. It is noteworthy that the nutrient optimal doses of 80 and 112 kg N ha^{-1} indicated maximum productivity of 1685 and 1702 kg ha^{-1}, respectively. Furthermore, the dose of 60 kg N ha^{-1} for the expected yield of 3 t ha^{-1} indicated mean grain yield approximately 1500 kg ha^{-1}. These facts reinforce that nitrogen use efficiency can be high or low depending on the weather conditions of the environment. Moreover, it shows that the N-fertilizer investment in restrictive conditions of cultivation must be minimized.

Considering the maize/wheat system in 2012 (intermediate year), only the fractioned condition in V_3/V_6 stages indicated a quadratic behavior, with an optimum nutrient dose of 118 kg N ha^{-1} for the expected 2918 kg

Table 3. Linear regression equation of dry biomass and wheat average grain yield by dose and nitrogen fractionation in the maize/wheat system.

Dose	Condition of N	Equation	R^2	P	Average (kg ha^{-1})	
(N)	Stage (DAE)	DB= $b_0 \pm b_i x$	(%)	($b_i x$)	DB	GY
		2012 (IY)				
0	-	1322+50x	91	*	2474	918
30	V_3 (30)	1734+74x	69	*	3858 a	1745 a
	V_3/V_6 (60)	2214+75x	84	*	3448 b	1912 a
	V_3/E(90)	1765+67x	83	*	3297 b	1764 a
60	V_3 (30)	2714+93x	86	*	4260 a	2237 a
	V_3/V_6 (60)	2543+84x	88	*	4165 a	2357 a
	V_3/E(90)	1754+73x	77	*	3740 b	2197 a
120	V_3 (30)	2288+87x	84	*	4239 a	2782 b
	V_3/V_6 (60)	2220+85x	77	*	4203 a	2795 b
	V_3/E(90)	2167+83x	79	*	4077 a	3211 a
		2013 (FY)				
0		1350+43x	95	*	1938	1262
30	V_3 (30)	2608+76x	97	*	3162 a	2892 a
	V_3/V_6 (60)	2600+76x	93	*	3165 a	2265 b
	V_3/E(90)	2927+80x	94	*	3100 a	2243 b
60	V_3 (30)	2432+75x	98	*	3203 b	3083 a
	V_3/V_6 (60)	3449+97x	94	*	3848 a	3077 a
	V_3/E(90)	2573+73x	95	*	2969 b	2392 b
120	V_3 (30)	2735+92x	88	*	4206 b	3871 a
	V_3/V_6 (60)	3355+108x	96	*	4760 a	3939 a
	V_3/E(90)	3030+95x	94	*	4155 b	3448 b
		2014 (UY)				
0	-	577+34x	87	*	1974	647
30	V_3 (30)	968+58x	76	*	3430 a	1133 a
	V_3/V_6 (60)	733+46x	76	*	2744 b	1027 a
	V_3/E(90)	745+39x	86	*	2236 c	944 a
60	V_3 (30)	641+62x	72	*	4024 a	1343 a
	V_3/V_6 (60)	1187+66x	75	*	3769 a	1476 a
	V_3/E(90)	744+43x	73	*	2499 b	1075 b
120	V_3 (30)	1116+71x	81	*	4211 a	1432 a
	V_3/V_6 (60)	1184+63x	85	*	3580 b	1483 a
	V_3/E(90)	1065+57x	90	*	3237 b	1457 a

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= 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; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); DB= dry biomass (kg ha^{-1}); R^2= determination coefficient; P ($b_i x$)= significance probability of slope line. *= significant at 5% probability level. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

ha^{-1} (Table 5). In this condition, the dose employed for 3 t ha^{-1} (90 kg N ha^{-1}) promoted 2809 kg ha^{-1}. Therefore, it considerably reduced the nitrogen use and maintained similar productivities. In 2013 (favorable year), similar behavior was obtained in full and fractioned dose. The expected dose for 3 t ha^{-1} (90 kg N ha^{-1}) promoted approximately 4 t ha^{-1} in the full dose condition at V_3 stage. Moreover, although the years 2012 and 2014 showed the same behavior, the optimal nutrient dose of 93 kg N ha^{-1} in 2014 promoted expected productivity of 1535 kg ha^{-1}, with the similar expectation of 3 t ha^{-1}. These results support the proposal that in unfavorable years, investments with fertilizer should be reduced, noting the cost and benefit. However, the behavior observed in the soybean/wheat and maize/wheat systems on the N-fertilizer efficient use was similar with the

Table 4. Summary of regression variance analysis in the estimate of wheat grain yield by dose and nitrogen fractionation in the soybean/wheat system.

Condition (N) Stage (DAE)	Source of variation	Equation $GY= b_0 \pm b_1x \pm b_2x^2$	P (b_ix)	R^2 (%)	$N_{(MTE)}$ (kg ha^{-1})	$GY_{(MTE)}$ (kg ha^{-1})	$N_{(3\ t\ ha^{-1})}$ (kg ha^{-1})	$GY_{(3\ t\ ha^{-1})}$ (kg ha^{-1})
2012 (IY)								
V_3 (30)	L	1821+9x	*	94	-	-	60	2361 b
	Q	$1761+13.1x-0.03x^2$	ns	95	-	-		
V_3/V_6 (60)	L	1936+7.1x	*	54	-	-	60	2683 a
	Q	$1675+25.2x-0.14x^2$	*	83	90	2809		
V_3/E(90)	L	1797+10.2x	*	80	-	-	60	2712 a
	Q	$1542+27.9x-0.14x^2$	*	99	100	2932		
2013 (FY)								
V_3 (30)	L	2276+20.4x	*	91	-	-	60	3500 a
	Q	$1999+39.4x-0.14x^2$	ns	98	-	-		
V_3/V_6 (60)	L	2131+22.1x	*	97	-	-	60	3457 a
	Q	$1956+34.3x-0.1x^2$	ns	99	-	-		
V_3/E(90)	L	1988+21.4x	*	97	-	-	60	3272 b
	Q	$1814+33.5x-0.1x^2$	ns	99	-	-		
2014 (UY)								
V_3 (30)	L	1292+3.7x	*	50	-	-	60	1514 a
	Q	$1140+14.2x-0.08x^2$	ns	83	-	-		
V_3/V_6 (60)	L	1177+4x	*	48	-	-	60	1641 a
	Q	$981+17.6x-0.11x^2$	*	93	80	1685		
V_3/E(90)	L	1169+4.7x	*	85	-	-	60	1567 a
	Q	$1075+11.2x-0.05x^2$	*	99	112	1702		

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= 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; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); R^2= determination coefficient; P (b_ix) = inclination significance probability; *= significant at 5% probability level; ^{ns}= non-significant; L= linear equation; Q= quadratic equation; $N_{(MTE)}$= maximum technical efficiency of nitrogen use; $GY_{(MTE)}$= grain yield by the maximum technical efficiency of nitrogen use; $N_{(3\ t\ ha^{-1})}$= expected nitrogen dose for 3 t ha^{-1} of grain yield; $GY_{(3\ t\ ha^{-1})}$= grain yield obtained with the expected nitrogen dose for 3 t ha^{-1}. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

suffering of major changes by agricultural year conditions. The interaction between the climate and nitrogen use results in grain yield variations in wheat from year to year, being that water availability is the most decisive factor (Benin et al., 2012). Favorable weather conditions and cultivation techniques act on N-fertilizer efficient use, which is reflected in grain yield (Arenhardt et al., 2015). Nitrogen fertilization should be performed in order to provide adequate plant nutrition, with a possible increase in productivity components (Carvalho et al., 2001; Rissini et al., 2015). Independent of the application season, the increase up to 120 kg N ha^{-1} has positive effects on productivity (Teixeira Filho et al., 2010). The maximum nitrogen use efficiency in wheat ranged from 90 to 120 kg ha^{-1}, being that higher doses showed no significant responses in grain yield in favorable growing conditions (Penckowski et al., 2009). In irrigated wheat, a positive response was obtained with up to 156 kg N ha^{-1}, with grain yield of 6472 kg ha^{-1} (Heinemann et al., 2006). In oats, favorable growing conditions showed maximum nitrogen efficient use with 66 kg ha^{-1}, with grain yield of 3874 kg ha^{-1}. On the other hand, in unfavorable conditions, the maximum use efficiency was obtained with 92 kg N ha^{-1} with grain yield of 3172 kg ha^{-1}. These results show that favorable growing conditions associated with the optimum nitrogen dose can provide higher grain yield than expected (Mantai et al., 2015b). The fractionation of nitrogen fertilization in conditions of high rainfall can favor the increased wheat productivity and reduce losses by leaching (Espindula et al., 2010). This fractionation in wheat favors the biomass production, but not satisfactory in the expression of grain yield (Yano et al., 2005). According to Barbosa Filho et al. (2005), applying nitrogen two or three times results in significantly higher grain yield than when done at a single time. In the same sense, Sangoi et al. (2007) found that nitrogen

Table 5. Summary of regression variance analysis in the estimate of wheat grain yield by dose and nitrogen fractionation in the maize/wheat system.

Condition (N) Stage (DAE)	Source of variation	Equation $GY= b_0 \pm b_1x \pm b_2x^2$	P (b_ix)	R^2 (%)	$N_{(MTE)}$ (Kg ha^{-1})	$PG_{(MTE)}$ (Kg ha^{-1})	$N_{(3\ t\ ha^{-1})}$ (Kg ha^{-1})	$PG_{(3\ t\ ha^{-1})}$ (Kg ha^{-1})
		2012 (AI)						
V_3 (30)	L	1109+15.2x	*	91	-	-	90	2477 b
	Q	886+30.5x-0.12x^2	ns	99	-	-		
V_3/V_6 (60)	L	1243+14.5x	*	87	-		90	2809 a
	Q	973+33x-0.14x^2	*	99	118	2918		
V_3/E(90)	L	1070+18.2x	*	98	-	-	90	2708 a
	Q	981+24.4x-0.04x^2	ns	99	-	-		
		2013 (AF)						
V_3 (30)	L	1700+20.1x	*	81	-	-	90	3833 a
	Q	1304+47x-0.21x^2	ns	94	-	-		
V_3/V_6 (60)	L	1471+21.9x	*	95	-	-	90	3442 b
	Q	1235+38.2x-0.13x^2	ns	99	-	-		
V_3/E(90)	L	1520+16.1x	*	95	-	-	90	2969 c
	Q	1460+20.3-0.03x^2	ns	95	-	-		
		2014 (AD)						
V_3 (30)	L	891+5.9x	*	91	-	-	90	1422 a
	Q	797+12.4x-0.05x^2	ns	99	-	-		
V_3/V_6 (60)	L	774+7.4x	*	76	-	-	90	1534 a
	Q	580+20.5x-0.11x^2	*	98	93	1535		
V_3/E(90)	L	687+7.2x	*	95	-	-	90	1335 a
	Q	566+11.3x-0.03x^2	ns	98	-	-		

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= 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; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); R^2= determination coefficient; P (b_ix) = inclination significance probability; *= significant at 5% probability level; ^{ns}= non-significant; L= linear equation; Q= quadratic equation; $N_{(MTE)}$= maximum technical efficiency of nitrogen use; $GY_{(MTE)}$= grain yield by the maximum technical efficiency of nitrogen use; $N_{(3\ t\ ha^{-1})}$= expected nitrogen dose for 3 t ha^{-1} of grain yield; $GY_{(3\ t\ ha^{-1})}$= grain yield obtained with the expected nitrogen dose for 3 t ha^{-1}. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

supply in divided doses acts significantly in grain yield. On the other hand, Silva et al. (2008) found no difference in wheat productivity when submitted to full or fractioned nitrogen dose. Coelho et al. (1998) contradict the advantageous effects of fractionation, reporting that this practice can be significant if there are losses of nitrogen in the application in full dose due to heavy rains.

Conclusions

To improve the nitrogen use efficiency by the conjoint analysis of the biomass productivity and grain yield in the soybean/wheat system, both unfavorable and intermediate years of cultivation suggest the utilization of fractioned nitrogen fertilization. However, during favorable years, the use of full dose in V_3 stage is more suitable. In the maize/wheat system, the full dose of N-fertilizer at V_3 stage is more efficient, especially at higher doses of nutrient. For grain yield, the nitrogen fertilizer fractioning is adjusted during the intermediate years of cultivation, while the full dose in V_3 stage is indicated in favorable years. During unfavorable years, nitrogen investments should be minimized regardless of the supply form and succession system.

Conflict of Interests

The authors have not declared any conflict of interests.

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