

# Timing and growing conditions of nitrogen topdressing influence the grain yield and protein content of four wheat cultivars

Raphael Rossi Silva<sup>1</sup>, Claudemir Zucareli<sup>1</sup>, Inês Cristina de Batista Fonseca<sup>1</sup>, Carlos Roberto Riede<sup>2</sup>,  
Giovani Benin<sup>3</sup>, Diego Gazola<sup>1,\*</sup>

1. Universidade Estadual de Londrina - Agronomia - Londrina (PR), Brazil.

2. Instituto Agronômico do Paraná - Genética e Melhoramento de Plantas - Londrina (PR), Brazil.

3. Universidade Tecnológica Federal do Paraná - Centro de Ciências Agrárias - Pato Branco (PR), Brazil.

**ABSTRACT:** The application of an adequate rate and splitting of nitrogen is essential for wheat grain yield and protein content. The aim of this work was to adjust nitrogen management approaches regarding agronomic performance and protein content of wheat cultivars in various environments. Field experiments were conducted under no-tillage system on soybean mulch during the 2011 and 2012 growing seasons in Londrina and Pato Branco regions. The experimental design was a randomized block in split plot with four replicates. Four wheat cultivars (IPR Catuara TM, BRS Gaivota, Quartzo, CD 120) were tested with six nitrogen (N) management forms. Were evaluated: number of ears per unit area (NEA); plant height (PH); thousand-kernel weight (TKW); test weight (TW); grain yield (GY); and protein content (PC). The combined ANOVA ( $p \leq 0.01$ ) and

Tukey's test ( $p \leq 0.01$ ) were used. The interaction between cultivars and environments influence all yield components, GY and PC. The interaction management forms of N and environments affected the TKW, NEA, GY and PC. The results showed that in low-rainfall environments, nitrogen topdressing could be suppressed with no negative effects on GY or PC. Under ideal weather conditions, the GY of wheat cultivars was enhanced on application of 60 kg.ha<sup>-1</sup> N of urea at the beginning of tillering as well 20 kg.ha<sup>-1</sup> of N at booting. Matching the appropriate cultivars to the ideal growth environment is essential for achieving high GY values. The nitrogen forms on the topdressing do not influence the PC of cultivars in Pato Branco.

**Key words:** ammonium sulphate, grain yield, nitrogen, *Triticum aestivum* L, urea.

\*Corresponding author: gazolad@gmail.com

Received: May 17, 2018 – Accepted: Dec. 9, 2018



## INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the world's most important cereals with over 700 million tons produced each year. In Brazil, approximately 5.4 million tons, corresponding to 50% of Brazilian consumption of this cereal. Paraná state contributes to 50% the amount of the wheat produced in this country, with an average production of 2700 kg.ha<sup>-1</sup>. Moreover, there are differences in consumer preferences, implying the need for wheat production with suitable quality characteristics for baking (Brum and Müller 2008).

Various factors limit wheat grain yield and grain quality, including the management of nitrogen (N), the environment and the cultivar. N can influence wheat grain yield (Benin et al. 2012a), yield components (Trindade et al. 2006; Benin et al. 2012a) and wheat grain quality (Pinnow et al. 2013). Similarly, the environment has a significant effect on the grain yield (Silva et al. 2011) and aspects of grain quality such as protein content (Silva et al. 2014). The protein content of wheat grain is an important parameter in the analysis of the quality attributes of wheat. Any fluctuation in protein content significantly affects its technological quality (Hrušková and Faměra 2003).

However, the dynamism of N and its tendency to losses creates a challenging environment to manage this nutrient in topdressing efficiently (Fageria and Baligar 2005), mainly due to various reactions and instability in the soil. The low efficiency of N is attributed to ammonia volatilization (Van der Gon and Bleeker 2005), leaching, surface runoff and denitrification (Fageria and Baligar 2005). Therefore, improving the efficiency of N use by plants is crucial to enhance grain yield, reduce production costs and improve environmental quality (Fageria and Baligar 2005).

Amidic N sources (urea) have higher loss by volatilization when applied to soils of low cation exchange capacity (CEC), basic pH, low humidity and high temperature. The flow of ammonia volatilization begins immediately after application of urea by rapid hydrolysis in soil. Moreover, ammonium sulfate and ammonium nitrate do not result in volatilization losses, even when surface-applied. Further, the energy requirement for ammonium assimilation is lower than for nitrate assimilation, because the former does not

need to be reduced for incorporation into amino acids (Magalhães et al. 1993). Nevertheless, urea is one of the most frequently used N sources in Brazil, based on its high N concentration and low cost per unit of nitrogen.

An important practice in crop management is to supply the plant during critical periods by using splitting N fertilizers and applying a suitable amount of N. The correct timing of application mitigates the loss of nutrients and increases the efficiency of nutrient, improving grain yield, yield components (Basso et al. 2010) and grain quality parameters (Fuertes-Mendizábal et al. 2010).

There are conflicting reports on the ideal time to N application or splitting of nitrogen in the wheat crop (Teixeira Filho et al. 2010). In Brazil the late application of N fertilizer to wheat is often criticized because the accumulated protein might not be functional, which implies lower gains in gluten strength. The industrial quality of wheat genotypes for Brazilians is not usually measured based on the protein content in grain (Vázquez et al. 2012).

The efficiency of N also varies depending on the cultivars released year by year, which differ in their response to the N applied in topdressing. Moreover, the response to N relies on the growth environment for each cultivar (Benin et al. 2012a). Therefore, it is technically impracticable to generalize the management of N for wheat cultivars (Teixeira Filho et al. 2010).

Consequently, the integrated study of the management of N fertilization of wheat must consider the distinction between environments, N sources, timing of the application, and especially genetic factor. The aim of this study was to adjust nitrogen management approaches with regard to the agronomic performance and protein content of wheat cultivars under different environmental conditions.

## MATERIALS AND METHODS

Field experiments were performed during the 2011 and 2012 growing seasons in two wheat-growing regions of Paraná state, Brazil: Londrina (23°22'09" S latitude, 51°10'13" W longitude and 549 m elevation) and Pato Branco (26°09'58" S latitude, 52°42'22" W longitude, altitude 749 m elevation). Hence resulting in four different growth conditions. The predominant climate of both locations is the Cfa type and their soil is classified as Oxisol.

→

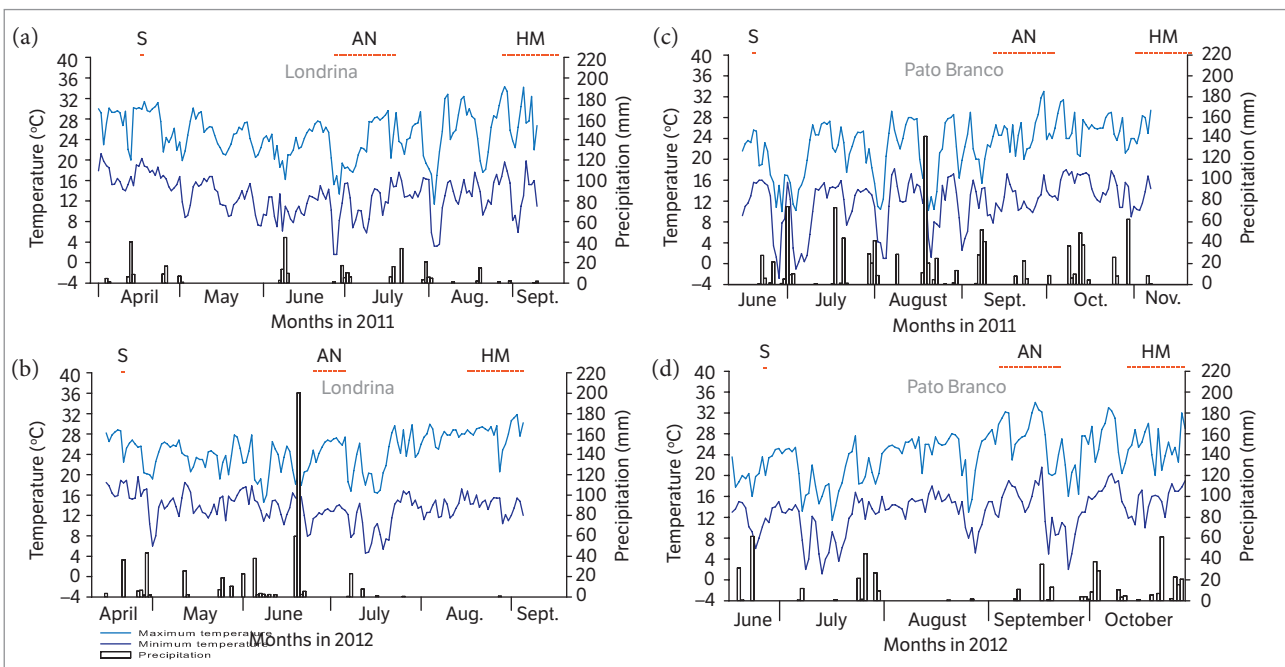
Wheat is grown in three principal regions of Brazil: Central, South Central and South. To evaluate wheat genotypes, these regions are subdivided by water regime, air temperature and elevation above sea level. The categorization of these subdivisions is based on their Value for Cultivation and Use (VCU) categories, as follows: wet, cold and high elevation (VCU 1); wet, moderately warm and low elevation (VCU 2); moderately dry, warm and low elevation (VCU 3); and dry, warm and Cerrado (VCU 4). Londrina is in the VCU 3, and Pato Branco is in the VCU 2.

The experimental design was a randomized block in split plot design with four replicates. Four cultivars of wheat (IPR Catuara TM, BRS Gaivota, Quartzo and CD 120) were tested in six management forms of nitrogen (subplots). The sowing was carried out mechanically under no-tillage system on soybean mulch at both locations. In Londrina the sowing was performed in April 16 (2011) and April 20 (2012). In Pato Branco it was performed in June 20 (2011) and June 26 (2012). Each experimental unit (subplot) consisted of six 5-m long rows spaced 0.17 m apart. The seeds were treated with Imidacloprid (Gaucho FS) at a dose of 70 ml for every 100 kg of seeds. In Londrina, the basal fertilizer was 300 kg·ha<sup>-1</sup> of 10-30-10 formulation (NPK), while in Pato Branco it was 350 kg·ha<sup>-1</sup> of 08-20-20 formulation (NPK). The plant density

was 330 pl·m<sup>-2</sup> in all environments. The environments were coded as A1 (Londrina 2011), A2 (Londrina 2012), A3 (Pato Branco 2011) and A4 (Pato Branco 2012).

The management forms of nitrogen were: N1 – without N topdressing; N2 – 60 kg·ha<sup>-1</sup> of N in the formulation of urea applied at the beginning of tillering; N3 – 80 kg·ha<sup>-1</sup> of N in the formulation of urea splitted into 60 kg·ha<sup>-1</sup> (beginning of the tillering stage) and 20 kg·ha<sup>-1</sup> (booting stage); N4 – 100 kg·ha<sup>-1</sup> of N in the formulation of urea splitted into 60 kg·ha<sup>-1</sup> (beginning of the tillering stage) and 40 kg·ha<sup>-1</sup> (booting stage); N5 – 80 kg·ha<sup>-1</sup> of N splitted into 60 kg·ha<sup>-1</sup> (beginning of the tillering stage) applied in the formulation of urea, and 20 kg·ha<sup>-1</sup> (booting stage) in the formulation of ammonium sulfate; N6 – 100 kg·ha<sup>-1</sup> of N splitted into 60 kg·ha<sup>-1</sup> (beginning of the tillering stage) applied in the formulation of urea, and 40 kg·ha<sup>-1</sup> (booting stage) in the formulation of ammonium sulfate.

The N fertilization was performed on specific dates for each cultivar according to the cultivar cycle. In Environment A1, after N fertilization, the experiment was irrigated with 15 mm due to drought at the time of the nitrogen topdressing application. The climatic conditions of each environment are shown in Fig. 1. The cultivars characteristics are shown in Table 1. The chemical soil characteristics of each environment are shown in Table 2.



**Figure 1.** Rainfall (mm), minimum and maximum temperatures (°C) in (a) A1 environment – Londrina 2011; (b) A2 environment – Londrina 2012; (c) A3 environment – Pato Branco 2011; and (d) A4 environment – Pato Branco 2012. SW = sowing; AN = anthesis; HM = harvest maturation.

**Table 1.** Genealogy, agronomic and technological characteristics of the evaluated cultivars.

Cultivars	Genealogy	Cycle	Gluten strength ( $10^{-4}$ J)	Class commercial
IPR Catuara TM	LD 875/IPR 85	Early	340	Improve
BRS Gaivota	BR 35/Klein H 2860 U 12100//Sonora 64/BR 23	Medium	290	Bread
Quartzo	Onix/Avante	Medium	270	Bread
CD 120	RUBI/CD105	Medium	111	Soft

**Table 2.** Soil chemical properties in the first 20 cm of soil.

Properties	Unit	Environments <sup>1</sup>			
		A1	A2	A3	A4
P	Mg·dm <sup>-3</sup>	21.1	24.5	18.06	16.7
pH (CaCl <sub>2</sub> )		5.1	5.3	5.6	5.2
Al	Cmolc·dm <sup>-3</sup>	0	0	0	0
H+Al	Cmolc·dm <sup>-3</sup>	6.2	5.34	5.01	5.01
Ca	Cmolc·dm <sup>-3</sup>	5.72	5.25	7.56	6.5
Mg	Cmolc·dm <sup>-3</sup>	2.26	2.87	3.45	2.7
K	Cmolc·dm <sup>-3</sup>	0.18	0.88	0.28	0.3
SB	Cmolc·dm <sup>-3</sup>	8.16	9	11.29	9.5
CEC	%	14.36	14.34	16.3	14.51
V	%	56.82	62.76	69.26	65.47
Sal	%	0	0	0	0
Organic matter	%	1.7	1.9	5.36	5.2

<sup>1</sup>A1 (Londrina 2011), A2 (Londrina 2012), A3 (Pato Branco 2011) and A4 (Pato Branco 2012).

The following evaluations were performed:

- Plant height (PH) at crop maturity, defined as the distance from soil level to the apex of the spike excluding awns, considering ten plants at random of each subplot;
- Number of ears per unit area (NEA) at crop maturity, defined as the number of ears per linear meter in the row and estimated per area;
- Thousand-kernel weight (TKW), defined by measuring the mass of 250 grains in triplicate (counted electronically) of each subplot;
- Test weight (TW), corresponding to the mass of grains in 100 L;
- Grain yield (GY), determined after mechanical harvesting of the useful area in each subplot, expressed as kg·ha<sup>-1</sup> and reported on a 13% moisture content basis;
- Protein content in whole meal (PC), determined by near infrared reflectance (NIR).

Data were subjected to joint analysis of variance (p-value ≤ 0.01) and comparison of means by Tukey test (p-value ≤ 0.01).

## RESULTS AND DISCUSSION

The low coefficient of variation values indicate that our inferences are reliable with high experimental precision (Table 3). In the same way, in the literature the optimal coefficient of variation differs between the characteristics evaluated (Benin et al. 2012a). Barraclough et al. (2010) and Benin et al. (2012a) have previously reported the interactions observed in analysis of variance ANOVA (Table 3). Mean squares for the environmental effect were the most important, with high magnitude in all the characteristics evaluated, which is typical for experiments involving different environmental conditions (Benin et al. 2012a).

PH was influenced by the interaction between cultivars and environments (Table 3). The BRS Gaivota and Quartzo cultivars had higher PH in the A1 and A3 environments; whereas that of the IPR Catuara TM and CD 120 cultivars increased in the A1 environment. PH was unaffected by cultivars in environments A1 and A4 (Table 4). In the A2 environment, IPR Catuara TM had the lowest PH, whereas the A3 environment propitiated the smallest PH for the IPR Catuara TM and CD 120 cultivars. All cultivars had the lowest PH in the A4 environment, likely due to water stress. Moreover, in the A1 environment all cultivars showed lodging at the stage of earing, except for BRS Gaivota.

N stimulates vegetative growth and stem elongation. Accordingly Espindula et al. (2010) showed that application of N increases wheat PH. Nevertheless, this study and previous studies found that wheat PH was unaffected by N fertilization (Teixeira Filho et al. 2010). The absence of an effect of N on wheat PH may be due to the N splitted fertilization, mainly because the second N application was performed after the beginning of stem elongation. The occurrence of high temperatures and irregular rainfall in the A4 environment may have contributed to the reduction in PH. Oliveira et al. (2011) reported that high cultivation temperatures negatively affected all plant traits, including PH.

→

**Table 3.** Joint analysis of variance for plant height (PH), the number of ears per area (NEA), thousand-kernel weight (TKW), test weight (TW), grain yield (GY) and protein content (PC) of wheat at different environments, cultivars and form of N management in topdressing.

Variation source	Evaluated variables					
	PH	NEA	TKW	TW	GY	PC
<b>Block (Environment)</b>						
MS (12 <sub>DF</sub> )	1.07E + 02	1.84E + 04	1.13E + 01	9.30E + 00	6.91E + 05	1.21E + 00
p value	< 0.01	< 0.01	0.55	0.24	0.11	0,65
<b>Environment (E) (3<sub>DF</sub>)</b>						
MS (3 <sub>DF</sub> )	4.45E + 03	1.57E + 06	7.70E + 02	5.46E + 02	2.19E + 07	8.37E + 01
p value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<b>Cultivars (C) (3<sub>DF</sub>)</b>						
MS (3 <sub>DF</sub> )	2.32E + 02	2.48E + 05	1.24E + 03	1.95E + 02	8.90E + 06	3.49E + 01
p value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<b>E*C</b>						
MS (9 <sub>DF</sub> )	1.68E + 02	2.92E + 04	1.25E + 02	9.48E + 01	1.02E + 07	1.77E + 01
p value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<b>Error</b>						
MS (36 <sub>DF</sub> )	2.20E + 01	6.21E + 03	1.24E + 01	6.94E + 00	4.05E + 05	1.51E + 00
<b>Nitrogen (N) (5<sub>DF</sub>)</b>						
MS (5 <sub>DF</sub> )	4.70E + 00	3.42E + 04	9.19E + 01	1.10E + 01	1.73E + 06	7.65E + 00
p value	0.56	< 0.01	< 0.01	0.06	< 0.01	< 0.01
<b>E*N</b>						
SM (15 <sub>DF</sub> )	5.18E + 00	5.96E + 04	8.19E + 01	7.40E + 00	9.27E + 05	3.64E + 00
p value	0.60	< 0.01	< 0.01	0.12	< 0.01	< 0.01
<b>C*N</b>						
SM (15 <sub>DF</sub> )	7.42E + 00	7.78E + 03	1.72E + 01	7.13E + 00	2.37E + 05	1.35E + 00
p value	0.24	0.40	0.50	0.14	0.16	0.48
<b>E*C*N</b>						
SM (45 <sub>DF</sub> )	5.59E + 00	1.08E + 04	2.17E + 01	4.55E + 00	2.51E + 05	2.19E + 00
p value	0.58	0.04	0.19	0.66	0.04	0,02
<b>Error</b>						
SM (240 <sub>DF</sub> )	5.94E + 00	7.39E + 03	1.79E + 01	5.07E + 00	1.73E + 05	1.38E + 00
Grand mean	85.13	582.56	34.11	78.81	3,950	19
CV 1 (%)	5.51	13.53	10.34	3.34	16.10	6.47
CV 2 (%)	2.86	14.75	12.40	2.86	10.53	6.19

NEA was influenced by the cultivars × environments and N × environments interactions (Table 3). All cultivars showed the greatest NEA in the A1 and A3 environments (Table 4). Environments A1 and A4 propitiated the lowest NEA for IPR Catuara TM cultivar, which differed from those of other cultivars. Only in the A3 environment the NEA was affected by the form of N; moreover, the effect of environment differed for each form of N management. The IPR Catuara TM cultivar had the lowest NEA regardless of the cultivation environment and did not differ from BRS Gaivotá in environments A2 and A3.

The environmental effect on NEA demonstrates the importance of the suitability of cultivars and nitrogen level to each environment. In the A3 environment, the NEA increased because the fertilizer of N was split at tillering and booting stage (N3, N4 and N6). However, in the A3 environment no significant difference was observed between the sources of N topdressing. Changes in weather, especially under solar radiation, promote changes in stem elongation rate and the internodes of the plant, affecting the development of tillers that will produce ears.

**Table 4.** Mean values for plant height, ears per unit area, test weight and thousand-kernel weight of wheat cultivars in different environments and form of N management in topdressing.

Cultivars	Plant height (cm)				Test weight (kg·hl <sup>-1</sup> )			
	Environments <sup>1</sup>				Environments			
	A1	A2	A3	A4	A1	A2	A3	A4
IPR Catuara TM	92 aA	77 cB	87 bB	78 cA	81 bA	82 abA	76 cA	84 aA
BRS Gaivota	90 aA	84 bA	91 aA	77 cA	81 aA	80 aB	76 bA	74 bC
Quartzo	93 aA	84 bA	95 aA	76 cA	79 aA	81 aAB	75 bA	79 aB
CD 120	92 aA	82 bA	86 bB	77 cA	79 aA	81 aAB	75 bA	79 aB
Cultivars	Ears per unit area (ears·m <sup>-2</sup> )				Thousand-kernel weight (g)			
	Environments				Environments			
	A1	A2	A3	A4	A1	A2	A3	A4
IPR Catuara TM	591 bB	392 cC	671 aB	381 cB	40.4 aA	42.3 aA	31.8 bAB	43.1 aA
BRS Gaivota	708 aA	436 cBC	707 aAB	525 bA	32.8 aB	31.1 aC	32.0 aA	33.4 aC
Quartzo	676 aA	545 bA	699 aAB	481 bA	32.8 bB	34.9 abB	27.9 cC	37.1 aB
CD 120	740 aA	505 bAB	748 aA	509 bA	32.8 aB	31.5 abC	28.5 bBC	33.3 aC
Forms of N management <sup>2</sup>	Ears per unit area (ears·m <sup>-2</sup> )				Thousand-kernel weight (g)			
	Environments				Environments			
	A1	A2	A3	A4	A1	A2	A3	A4
N1	716 aA	463 bA	529 bC	447 bA	34.8 aA	35.1 aA	37.1 aA	36.8 aA
N2	720 aA	469 bA	641 aB	484 bA	33.5 abA	34.8 abA	30.6 bB	37.0 aA
N3	638 bA	451 cA	781 aA	521 cA	33.7 aA	34.6 aA	26.4 bBC	36.5 aA
N4	689 aA	505 bA	750 aA	472 bA	33.6 abA	35.0 abA	31.3 bB	36.7 aA
N5	670 aA	489 bA	732 aAB	466 bA	38.3 aA	35.2 aA	29.7 bBC	36.5 aA
N6	640 bA	438 cA	804 aA	455 cA	34.5 aA	35.0 aA	25.3 bC	36.8 aA

Lowercase letters compare the columns (between environments) and uppercase letters compare the rows (between cultivars or between forms of N management). Distinct letters indicate significant differences according to Tukey test ( $p \leq 0.01$ ). <sup>1</sup> A1 (Londrina 2011), A2 (Londrina 2012), A3 (Pato Branco 2011) and A4 (Pato Branco 2012). <sup>2</sup> N1 (without N in topdressing), N2 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage), N3 (60 kg·ha<sup>-1</sup> of N at beginning tillering stage and 20 kg·ha<sup>-1</sup> of N at booting stage, both using urea), N4 (60 kg·ha<sup>-1</sup> of N at beginning tillering stage and 40 kg·ha<sup>-1</sup> of N at booting stage, both using urea), N5 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage and 20 kg·ha<sup>-1</sup> of N using ammonium sulfate at booting stage) and N6 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage and 40 kg·ha<sup>-1</sup> of N using ammonium sulfate at booting stage).

When the plant has high N concentration, the critical red:far red (lower production of tillers) is smaller than at lower concentration. The application of N at the earing stage may contribute to the increase in leaf area index, which results in greater photosynthetic area (Sparkes et al. 2006). The greater photosynthetic area contributes in increasing the availability of carbohydrates to maintain production of tillers and ears that result in grains (Almeida et al. 2004), which explains the effect of N management in the A3 environment. This supports the necessity of N application in the development stages recommended for wheat crop, which enhances the maximum exploitation of the genetic potential of cultivars.

Although the NEA is an important component of GY there are doubts regarding its use, because it has high

complexity and is influenced by genetics (Benin et al. 2012b), environmental conditions (Benin et al. 2012a), the availability of N (Sparkes et al. 2006; Benin et al. 2012b) and seeding rate (Sparkes et al. 2006). However, the results showed that large NEA increases GY, especially in the dry A4 environment (Table 5), as shown by the cultivar BRS Gaivota. On the other hand, the GY of cultivars with low NEA was negatively influenced under unfavorable environmental conditions (environment A4), as demonstrated by the cultivar IPR Catuara TM.

The TKW was affected by the interaction between environment and cultivars, between N and environments (Table 3). The A3 environment led to a lower TKW for all cultivars except BRS Gaivota, which was not influenced by environment effect (Table 4). IPR Catuara

→

**Table 5.** Mean values for grain yield (GY) of wheat cultivars in different environments and forms of N management.

Cultivars	Grain yield (kg·ha <sup>-1</sup> )			
	Environments <sup>1</sup>			
	A1	A2	A3	A4
IPR Catuara TM	5020 aA	3554 bAB	4055 bA	2520 cC
BRS Gaivota	5057 aA	3174 cB	4138 bA	4794 aA
Quartzo	4505 aA	4165 abA	3810 bA	3945 abB
CD 120	3857 aB	3960 aA	3865 aA	2787 bC

Forms of N management <sup>2</sup>	Environments			
	A1	A2	A3	A4
	N1	4660 aA	3784 bA	3698 bBC
N2	4611 aA	3686 bA	3767 bBC	3577 bA
N3	4495 aA	3630 bcA	3762 bBC	3349 bA
N4	4573 aA	3809 bA	4915 aA	3672 bA
N5	4670 aA	3718 bcA	4142 bB	3600 cA
N6	4649 aA	3652 bA	3519 bC	3439 bA

Lowercase letters compare the columns (between environments) and uppercase letters compare the rows (between cultivars or between forms of N management). Distinct letters indicate significant differences according to Tukey test ( $p \leq 0.01$ ).<sup>1</sup> A1 (Londrina 2011), A2 (Londrina 2012), A3 (Pato Branco 2011) and A4 (Pato Branco 2012).<sup>2</sup> N1 (without N in topdressing), N2 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage), N3 (60 kg·ha<sup>-1</sup> of N at beginning tillering stage and 20 kg·ha<sup>-1</sup> of N at booting stage, both using urea), N4 (60 kg·ha<sup>-1</sup> of N at beginning tillering stage and 40 kg·ha<sup>-1</sup> of N at booting stage, both using urea), N5 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage and 20 kg·ha<sup>-1</sup> of N using ammonium sulfate at booting stage) and N6 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage and 40 kg·ha<sup>-1</sup> of N using ammonium sulfate at booting stage).

TM cultivar had the highest TKW in the A1, A2 and A4 environments. Only management without N topdressing was not influenced by environmental effect. There were no differences in TKW with the increment of N topdressing in the environments A1, A2 and A4. The TKW was reduced with N fertilization topdressing in A3 environment.

The largest TKW for IPR Catuara TM is related to its low tillering capacity and thus lower compensatory effect of the number of ears per unit area, which increases the TKW (Motzo et al. 2004). The lack of increase in TKW might be due to the plants using the available N to promote tillering and leaf growth.

The interaction between cultivars and environments (Table 3) influenced the TW. The A3 environment induced the lowest TW for all cultivars, but did not differ from environment A4 with regard to BRS Gaivota. The IPR Catuara TM cultivar had the highest TW in the A1, A2 and A4 environments. In the A3 environment no meaningful difference between cultivars for TW was

observed. Guarienti et al. (2005) reported that excessive water in the 20 days pre-harvest causes reduction in the TKW; therefore the low TKW in A3 environment. There were successive changes in grain moisture due to rain following a dry period (Fig. 1). Such weather stresses lead to a high respiration rate and an increased consumption of carbohydrate and reserves in the grains (Guarienti et al. 2005).

The cultivar environment interaction and the N environment interaction influenced the GY (Table 3). Only in the A3 environment no meaningful difference was observed in GY between cultivars. The GY of BRS Gaivota and Quartzo cultivars experienced no reduction even when grown in the A4 environment (Table 5). The largest GY for IPR Catuara TM cultivar occurred in the A1 environment. The BRS Gaivota presented adaptability to A1 and A4 environments. There was no significant difference in GY for the CD 120 cultivar in the A1, A2 and A3 environments. The effect of environment influenced the GY regardless of the N management form, and the A1 environment provided the highest GY with all forms of N except at N4. Significant effects were observed in relation to the form of N management only in the A3 environment, in which N4 increased the GY.

Therefore, the cultivars tested had similar responses to N. In three of the four tested environmental conditions, the N management did not change the GY. These results (Table 5) confirm that N depend on environmental conditions and genotype, which makes N a difficult nutrient to manage (Fageria and Baligar 2005; Van der Gon and Bleeker 2005). Furthermore, Barraclough et al. (2010) reported that cultivars that use N efficiently are ideal. N fertilizers are expensive and the applied N might be under utilized in poor growing conditions.

Regardless of the choice of cultivar, the environment influenced the PC. Indeed, the choice of cultivars did not influence the PC in Pato Branco location (A3 and A4 environments) (Table 6). The environment influenced the N management. However N management did not influence the PC in Pato Branco (A3 and A4). The PC in wheat flour mainly gluten is one of the most important parameters in the analysis of quality attributes of wheat (Pirozi et al. 2008). Despite the positive effects of N on the PC, it was observed that the N did not influence the tested cultivars; the result obtained may be because the ability to accumulate proteins in response to N fertilizer depends on the wheat cultivar (Ercoli et al. 2011).

**Table 6.** Mean values for protein content (PC) of wheat cultivars in different environments and forms of N management.

Cultivars	Protein content (%)			
	Environments <sup>1</sup>			
	A1	A2	A3	A4
IPR Catuara TM	18.8 bcAB	20.3 aA	18.0 cA	19.5 bA
BRS Gaivota	19.7 aA	20.6 aA	18.1 bA	19.9aA
Quartzo	16.5 cC	17.9 bB	18.3 bA	20.0 aA
CD 120	18.4 bcB	20.3 aA	17.8 cA	19.5 abA
Forms of N management <sup>2</sup>	Environments			
	A1	A2	A3	A4
	N1	17.0 bB	18.8 aB	18.2 abA
N2	18.4 bcAB	19.6 abAB	18.1 cA	20.3 aA
N3	18.6 bA	20.1 aAB	17.3 cA	19.4 abA
N4	18.6 bA	20.5 aA	18.4 bA	19.5 abA
N5	18.7 abA	19.9 aAB	17.9 bA	20.0 aA
N6	18.7 bA	20.4 aA	18.5 bA	19.6 abA

Lowercase letters compare the columns (between environments) and uppercase letters compare the rows (between cultivars or between forms of N management). Distinct letters indicate significant differences according to Tukey test ( $p \leq 0.01$ ).<sup>1</sup> A1 (Londrina 2011), A2 (Londrina 2012), A3 (Pato Branco 2011) and A4 (Pato Branco 2012).<sup>2</sup> N1 (without N in topdressing), N2 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage), N3 (60 kg·ha<sup>-1</sup> of N at beginning tillering stage and 20 kg·ha<sup>-1</sup> of N at booting stage, both using urea), N4 (60 kg·ha<sup>-1</sup> of N at beginning tillering stage and 40 kg·ha<sup>-1</sup> of N at booting stage, both using urea), N5 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage and 20 kg·ha<sup>-1</sup> of N using ammonium sulfate at booting stage) and N6 (60 kg·ha<sup>-1</sup> of N using urea at beginning tillering stage and 40 kg·ha<sup>-1</sup> of N using ammonium sulfate at booting stage).

The variability in PC due to the environment has been previously described by other researchers and may be explained by temperature and precipitation changes (Motzo et al. 2004). Moreover, the environmental effect on the variability in the PC is significantly higher than the genotypic effect (Vázquez et al. 2012). In fact, in the A4 environment has the highest temperature and water stress during grain filling increased the PC. This relationship between climate variables and PC is very debated and uncertain. However, some results indicate that PC increases under low rainfall conditions (Garrido-Lestache et al. 2004).

The regulation of protein content is complex and the effect of rainfall and temperature are not consistent across sites or years. Despite the increased protein in drought conditions, we emphasize that a rise in protein content in grains does not always result in higher-quality bread, because the synthesis of gliadins usually increases (Hajheidari et al. 2007). These protein subunits do not contribute significantly to gluten strength. Although

the previous crop in the environments in this study was soybean, the analysis of PC also depends on the C/N ratio of mulch straw (Pinnow et al. 2013). Thus, under conditions that limit the availability of N, protein synthesis declines and grain starch increases.

PC was negatively correlated ( $r = -0.90$ ;  $p \leq 0.05$ ) with wheat GY. Previous studies have reported negative relationship between PC and GY (Šíp et al. 2013) and concomitant increase in PC and GY (Pinnow et al. 2013). Therefore, the correlation between PT and GY depends on factors as environment, genotype and management crop (Pinnow et al. 2013; Šíp et al. 2013). It is impossible to make generalizations about this relationship.

Thus, in environments A1, A2 and A4 there are evidences that it is not necessary to use nitrogen topdressing when the cultivars with IPR Catuara TM are used in the environment A1, Quartzo cultivar in A2, environment and BRS Gaivota cultivar in A4. Moreover, in the A3 environment, this study recommends using 100 kg·ha<sup>-1</sup> of splitted N (N4) in the topdressing using urea, regardless of the cultivar. However, due to difficulties related to the recommendation of N fertilization and climate prediction, it is often preferable to use cultivars with high GY without N in topdressing (Barracough et al. 2010). Another important result is that in three of the four tested growth environments, a non-significant difference in GY between the N sources was observed, perhaps associated with good soybean mulch on the soil. Furthermore, when different N sources (booting stage) were applied, the crop lines were already closed reducing the temperature and retaining soil moisture (Da Ros et al. 2005).

## CONCLUSION

The interaction between cultivars and growing conditions influences all yield components grain yield and protein content. The interaction management forms of N and environments influenced the thousand-kernel weight, number of ears per area, grain yield and protein content. In environments where there is low rainfall, N topdressing can be suppressed without influencing grain yield and protein content. In ideal weather conditions the wheat grain yield is enhanced with the application of 60 kg·ha<sup>-1</sup> of N at the beginning of tillering and 20 kg·ha<sup>-1</sup> of N at booting. The use of appropriate cultivars for each environment is essential in achieving high

→



production level. The forms of N applied as topdressing did not influence the protein content of cultivars in Pato Branco location.

## AUTHOR'S CONTRIBUTION

Conceptualization, Silva R. R., Zucareli C., Fonseca I., Riedi C., Benin G. and Gazola D.; Methodology, Silva R. R., Zucareli C., Fonseca I., Riedi C. and Benin G.; Writing – Original Draft, Silva R. R. and Zucareli C.; Writing – Review and Editing, Silva R. R. and Gazola D.; Resources, Zucareli C., Fonseca I., Riedi C. and Benin G.; Supervision, Silva R. R., Zucareli C. and Fonseca I.

## ORCID IDs

R. R. Silva

 <https://orcid.org/0000-0003-4960-6954>

C. Zucareli

 <https://orcid.org/0000-0002-5260-0468>

I.C.B. Fonseca

 <https://orcid.org/0000-0003-0129-8534>

C.R. Riede

 <https://orcid.org/0000-0002-9932-6689>

G. Benin

 <https://orcid.org/0000-0002-7354-5568>

D. Gazola

 <https://orcid.org/0000-0002-1375-6179>

## REFERENCES

- Almeida, M. L., Sangoi, L., Merotto Jr., A., Alves, A. C., Nava, I. C. and Knopp, A. C. (2004). Tiller emission and dry mass accumulation of wheat cultivars under stress. *Scientia Agricola*, 61, 266-270. <https://doi.org/10.1590/S0103-90162004000300004>
- Barraclough, P. B., Howarth, J. R., Jones, J., Lopez-Bellido, R., Parmar, S., Shepherd, C. E. and Hawkesford, M. J. (2010). Nitrogen efficiency of wheat: genotypic and environmental variation and prospects for improvement. *European Journal of Agronomy*, 33, 1-11. <https://doi.org/10.1016/j.eja.2010.01.005>
- Basso, B., Cammarano, D., Troccoli, A., Chen, D. and Ritchie, J. T. (2010). Long-term wheat response to nitrogen in a rainfed Mediterranean environment: Field data and simulation analysis. *European Journal Agronomy*, 33, 132-138. <https://doi.org/10.1016/j.eja.2010.04.004>
- Benin, G., Bornhofen, E., Beche, E., Pagliosa, E. S., Silva, C. L. and Pinnow, C. (2012a). Agronomic performance of wheat cultivars in response to nitrogen fertilization levels. *Acta Scientiarum Agronomy*, 34, 275-283. <https://doi.org/10.1590/S1807-86212012000300007>
- Benin, G., Pinnow, C., Silva, C. L., Pagliosa, E. S., Beche, E., Bornhofen, E., Munaro, L. B. and Silva, R. R. (2012b). Análises biplot na avaliação de cultivares de trigo em diferentes níveis de manejo. *Bragantia*, 71(1), 28-36. <https://doi.org/10.1590/S0006-87052012000100005>
- Brum, A. L. and Müller, P. K. (2008). A realidade da cadeia do trigo no Brasil: o elo produtores/cooperativas. *Revista de Economia e Sociologia Rural*, 46, 145-169. <https://doi.org/10.1590/S0103-20032008000100007>
- Da Ros, C. O., Aita, C. and Giacomini, S. J. (2005). Volatilização de amônia com aplicação e ureia na superfície do solo, no sistema plantio direto. *Ciência Rural*, 35, 799-905. <https://doi.org/10.1590/S0103-84782005000400008>
- Ercoli, L., Lulli, L., Arduini, I., Mariotti, M. and Masoni, A. (2011). Durum wheat grain yield and quality as affected by S rate under Mediterranean conditions. *European Journal of Agronomy*, 35, 63-70. <https://doi.org/10.1016/j.eja.2011.03.007>
- Espindula, M. C., Rocha, V. S., Souza, M. A., Grossi, J. A. S. and Souza, L. T. (2010). Doses e formas de aplicação de nitrogênio no desenvolvimento e produção da cultura do trigo. *Ciência e Agrotecnologia*, 34, 1404-1411. <https://doi.org/10.1590/S1413-70542010000600007>
- Fageria, N. K. and Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. In D. L. Sparks (Ed.), *Advances in Agronomy* (p. 97-185). New York: Academic Press. [https://doi.org/10.1016/S0065-2113\(05\)88004-6](https://doi.org/10.1016/S0065-2113(05)88004-6)
- Fuertes-Mendizábal, T., Aizpurua, A., González-Moro, M. B., Estavillo, J. M. (2010). Improving wheat breadmaking quality by splitting the N fertilizer rate. *European Journal Agronomy*, 33, 52-61. <https://doi.org/10.1016/j.eja.2010.03.001>
- Garrido-Lestache, E., López-Bellido, R. J. and López-Bellido, L. (2004). Effect of N rate, timing and splitting and N type on bread-making quality in hard red spring wheat under rainfed Mediterranean conditions. *Field Crops Research*, 85, 213-236. [https://doi.org/10.1016/S0378-4290\(03\)00167-9](https://doi.org/10.1016/S0378-4290(03)00167-9)

- Guarienti, E. M., Ciacco, C. F., Cunha, G. R., Del Luca, L. J. A. and Camargo, C. M. O. (2005). Efeitos da precipitação pluvial, da umidade relativa do ar e de excesso e déficit hídrico do solo no peso do hectolitro, no peso de mil grãos e no rendimento de grãos de trigo. *Ciência e Tecnologia de Alimentos*, 25, 412-418.
- Hajheidari, M., Eivazi, A., Buchanan, B. B., Wong, J. H. Majidi, I. and Salekdeh, G. H. (2007). Proteomics uncovers a role for redox in drought tolerance in wheat. *Journal of Proteome Research*, 6, 1451-1460. <https://doi.org/10.1021/pr060570j>
- Hrušková, M. and Faměra, O. (2003). Prediction of wheat and flour Zeleny sedimentation value using NIR technique. *Czech Journal of Food Sciences*, 21, 91-96. <https://doi.org/10.17221/3482-CJFS>
- Magalhães, J. R., Machado, A. T., Fernandes, M. S. and Silveira, J. A. G. (1993). Nitrogen assimilation efficiency in maize genotypes under ammonia stress. *Revista Brasileira de Fisiologia Vegetal*, 5, 163-166.
- Motzo, R., Giunta, F. and Deidda, M. (2004). Expression of a tiller inhibitor gene in the progenies of interspecific crosses *Triticum aestivum* L. x *T. turgidum* subsp. *durum*. *Field Crops Research*, 85, 15-20. [https://doi.org/10.1016/S0378-4290\(03\)00123-0](https://doi.org/10.1016/S0378-4290(03)00123-0)
- Oliveira, D. M., Souza, M. A., Rocha, V. S. and Assis, J. C. (2011). Desempenho de genitores e populações segregantes de trigo sob estresse de calor. *Bragantia*, 70(1), 25-32. <https://doi.org/10.1590/S0006-87052011000100005>
- Pinnow, C., Benin, G., Viola, R., Silva, C. L., Gutkoski, L. C. and Cassol, L. C. (2013). Qualidade industrial do trigo em resposta à adubação verde e doses de nitrogênio. *Bragantia*, 72(1), 20-28. <https://doi.org/10.1590/S0006-87052013005000019>
- Pirozi, M. R., Margiotta, B., Lafiandar, D. E. and MacRitchie, F. (2008). Composition of polymeric proteins and bread-making quality of wheat lines with allelic HMW-GS differing in number of cysteines. *Journal of Cereal Science*, 48, 117-122. <https://doi.org/10.1016/j.jcs.2007.08.011>
- Silva, R. R., Benin, G., Almeida, J. L., Fonseca, I. C. B. and Zucareli, C. (2014). Grain yield and baking quality of wheat under different sowing dates. *Acta Scientiarum Agronomy*, 36, 201-210. <https://doi.org/10.4025/actasciagron.v36i2.16180>
- Silva, R. R., Benin, G., Silva, G. O. L., Marchioro, V. S., Almeida, J. L. and Matei, G. (2011). Adaptabilidade e estabilidade de cultivares de trigo em diferentes épocas de semeadura, no Paraná. *Pesquisa Agropecuária Brasileira*, 46, 1439-1447. <https://doi.org/10.1590/S0100-204X2011001100004>
- Šíp, V., Vavera, R., Chrpová, J., Kusá, H. and Růžk, P. (2013). Winter wheat and quality related to tillage practice, input level and environmental conditions. *Soil and Tillage Research*, 132, 77-85. <https://doi.org/10.1016/j.still.2013.05.002>
- Sparkes, D. L., Holme, S. J. and Gaju, O. (2006). Does light quality initiate tiller death in wheat? *European Journal of Agronomy*, 24, 212-217. <https://doi.org/10.1016/j.eja.2005.08.003>
- Teixeira Filho, M. C. M., Buzetti, S., Andreotti, M., Arf, O. and Benett, C. G. S. (2010). Doses, fontes e épocas de aplicação de nitrogênio em trigo irrigado em plantio direto. *Pesquisa Agropecuária Brasileira*, 45, 797-804. <https://doi.org/10.1590/S0100-204X2010000800004>
- Trindade, M. G., Stone, L. F., Heinemann, A. B., Cánovas, A. D. and Moreira, J. A. A. (2006). Nitrogênio e água como fatores de produtividade do trigo no cerrado. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 10, 24-29.
- Van der Gon, H. and Bleeker, A. (2005). Indirect N<sub>2</sub>O emission due to atmospheric N deposition for the Netherlands. *Atmospheric Environment*, 39, 5827-5838. <https://doi.org/10.1016/j.atmosenv.2005.06.019>
- Vázquez, D., Berger, A. G., Cuniberti, M., Bainotti, C., Miranda, M. Z., Scheeren, P. L., Jobet, C., Zúñiga, J., Cabrera, G., Verges, R. and Peña, R. J. (2012). Influence of cultivar and environment on quality of Latin American wheats. *Journal of Cereal Science*, 56, 196-203. <https://doi.org/10.1016/j.jcs.2012.03.004>