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Agronomic performance of wheat cultivars in response to nitrogen fertilization levels

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ABSTRACT. The release of wheat cultivars with different nutritional demands and yield potential hinders generalized recommendations for nitrogen fertilization. This study was designed to evaluate the effects of different nitrogen fertilization levels (0, 60, 120 and 180 kg ha^{-1} of N) on the agronomic performance of six wheat cultivars (*Triticum aestivum* L.) in two harvests. A randomized block factorial design with three replications was used. The response to fertilization levels was evaluated through AMMI (Additive Main effects and Multiplicative Interaction) and GGE (Genotype main effects and Genotype x Environment interaction) biplot graphic methodologies and polynomial regression. There was genetic variability in response to nitrogen fertilization in the cultivars studied. The biggest increases in yield were observed under a more suitable water regime. The higher performance of yield components was associated with higher nitrogen fertilization levels.

Keywords: *Triticum aestivum* L., grain yield, AMMI, GGE biplot.

Desempenho agronômico de cultivares de trigo em resposta a doses de adubação nitrogenada

RESUMO. O lançamento de cultivares, com diferentes exigências nutricionais e potencial produtivo inviabilizam recomendações generalizadas de adubação nitrogenada para a cultura do trigo. O objetivo do presente trabalho foi de avaliar os efeitos de doses de adubação nitrogenada (ausência de fertilização, 60, 120 e 180 kg ha^{-1} de N) sobre o desempenho agronômico de seis cultivares de trigo (*Triticum aestivum* L.), em duas safras agrícolas. O delineamento experimental foi em blocos ao acaso em esquema fatorial, com três repetições. A resposta às doses empregadas foi avaliada através das metodologias em gráfico biplot AMMI (Additive Main effects and Multiplicative Interaction) e GGE (Genotype main effects and Genotype x Environment interaction) e regressão polinomial. Há variabilidade genética quanto à resposta a adubação nitrogenada, no conjunto de cultivares avaliados. Os maiores incrementos em produtividade ocorreram em condições mais adequadas de precipitação pluvial. O maior desempenho dos componentes do rendimento foram associados às maiores doses de adubação nitrogenada.

Palavras-chave: *Triticum aestivum* L., rendimento de grãos, AMMI, GGE biplot.

Introduction

The European Union, China, India and the United States are the four largest wheat producers, in order of importance, with 25, 24, 28 and 19 million hectares of cultivated area, and average yields of 5.3, 4.7, 2.8 and 3.0 t ha^{-1}, respectively (USDA, 2011). In Brazil, the cultivated area in the 2010 harvest was 2.1 million ha, with an average yield of 2700 kg ha^{-1} (CONAB, 2011).

The inadequate management of nitrogen fertilization, its non-use, and other factors have limited the increase in wheat crop yields in Brazil. Nitrogen is a constituent of proteins, enzymes, coenzymes, nucleic acids, phytochromes and chlorophyll; it plays an important role in the biochemical processes of the plant. Therefore, it is one of the most required nutrients by wheat crops (KUTMAN et al., 2011; WENDLING et al., 2007). Nitrogen deficiency affects biomass production and solar radiation use efficiency by the plant, with a great impact on grain yield and its components (HEINEMANN et al., 2006; ZAGONEL et al., 2002).

The variability in soil and climatic conditions associated with processes that affect nitrogen dynamics in the soil and their relationship with the plant may lead to changes in nitrogen availability and its requirement by the plant (SIMILI et al., 2008; ESPINDULA et al., 2010). In addition, the release of new cultivars with different nutritional demands hinders generalized recommendations of nitrogen fertilization for wheat crops (FREITAS et al., 1994; VIEIRA et al., 1995; TEIXEIRA FILHO et al., 2010). These authors emphasized the need to study the response of different cultivars to nitrogen fertilization under specific environmental conditions.

The interest in maximizing wheat yields has encouraged growers to adopt intensive management practices. It should be noted that both an optimized nitrogen management for a less responsive cultivar and a restrictive management for a more demanding cultivar may result in crops with little yield potential. High nutrient levels can also harm crops by making wheat plants more vulnerable to lodging, causing both damages to the environment through leaching (RILEY et al., 2001) and nitrate volatilization (MA et al., 2010) and economic losses to farmers, because only 33% of all nitrogen fertilizers applied to cereal crops are absorbed in harvested grains (RAUN; JOHNSON, 1999). Thus, the use of nitrogen in wheat crops must be optimized to increase yields.

There are reports of nitrogen use in wheat crops, ranging from 90 to 225 kg ha^{-1} of N, without significant responses in grain yield under more favorable environment and management conditions (PENCKOWSKI et al., 2009). For irrigated wheat, Heinemann et al. (2006) observed a positive response of up to 156 kg ha^{-1} of N, with a grain yield of 6472 kg ha^{-1}. The best yields were usually achieved with nitrogen fertilization levels ranging from 70 to 120 kg ha^{-1} (ESPINDULA et al., 2010; FREITAS et al., 1995; TEIXEIRA FILHO et al., 2007, 2010; VIEIRA et al., 1995).

The objective of this study was to evaluate the response in grain yield and other yield components of wheat cultivars to different nitrogen fertilization levels.

Material and methods

The study was conducted in the experimental area of the School of Agronomy at the Universidade Tecnológica Federal do Paraná (UTFPR), Campus Pato Branco, Paraná State, Brazil, at an altitude of approximately 760 m above sea level and a humid subtropical climate (Cfa, Köppen's classification). The soils in this area are LVdf2 – distroferric red latosols, with clayey texture and an alic and undulating profile (BHERING et al., 2008). The chemical analysis of the soil before implementation of the experiment is described in Table 1, while temperature and precipitation levels during the experiment are presented in Figure 1.

The experiments were conducted on July 2, 2007 and July 4, 2008, respectively, via a direct planting system on chaff over soybean crop residues. A randomized block factorial design with three replications was used, with combinations of the following factors: a) wheat cultivars (BRS 179, BRS 248, BRS Guamirim, Fundacep Cristalino, CD 111 and CD 115) and b) nitrogen fertilization levels (0, 60, 120 and 180 kg ha^{-1}). Plots consisted of seven rows, 5.0 m in length, spaced 0.17 m apart, with a density of 350 viable seeds per m^2 in the area formed by the five central rows.

Table 1. Chemical analysis of the soil$^{(1)}$, at 0-20 cm, in the experimental area of the School of Agronomy at UTFPR in 2007 and 2008.

		Exchangeable cations								
Years	pH ($CaCl_2$)	H + Al*	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	P	M.O.	V	M
		-------------- cmol dm^{-3} --------------					mg dm^{-3}	g dm^{-3}	--- % ---	
2007	5.03	4.67	0.00	4.14	2.48	0.36	1.25	50	59	0.00
2008	5.10	4.28	0.00	4.37	2.54	0.35	1.19	59	62	0.00

*H + Al – Potential acidity; Al^{3+} – Aluminum; Ca^{2+} – Calcium; Mg^{2+} – Magnesium; K^+ – Potassium; P – Phosphorus (Melich); O.M. – Organic matter; V – Base saturation; M – Aluminum saturation; $^{(1)}$Performed at the Laboratory of Soil Analyses UTFPR / IAPAR.

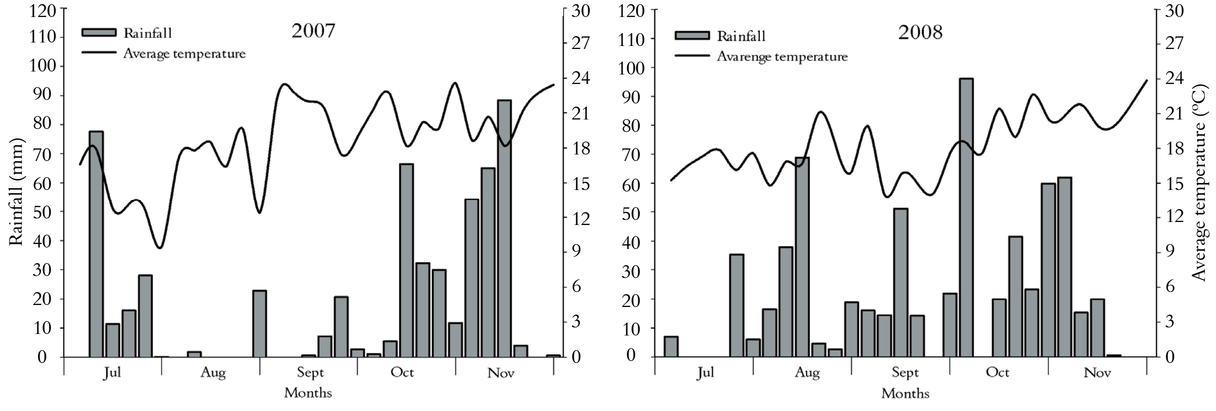

Figure 1. Rainfall and average temperatures for the 2007 and 2008 experimental periods in the city of Pato Branco, with 5-day averages. Source: Agricultural Institute of Paraná.

Base fertilization consisted of applying 250 kg ha^{-1} of 8-20-20 and 0-20-20 (N-P-K) to experimental cultivars with and without nitrogen fertilization, respectively. To complement fertilizer levels in each treatment, urea (45% N) was applied in a single dose (at early tillering, Feekes-Large scale 2) in the 60 kg ha^{-1} treatment and in two doses (at early and late tillering, Feekes-Large scales 2 and 5) in the 120 and 180 kg ha^{-1} treatments. For both years, to avoid interference from other factors in the expression of potential crop yield, pests, diseases and weed control were managed according to technical recommendations for wheat crops.

The following yield components were evaluated: a) plant height, measured as the distance (in cm) from ground level to the tips of the spikes, excluding awns; b) number of fertile tillers per linear meter, obtained by counting tillers with spikes in two linear meters at each experimental unit; c) flag leaf length, obtained by measuring 20 leaves per experimental unit; d) number of grains per spike: prior to harvesting, 15 spikes per experimental unit were collected, and grains were counted; e) weight per 1000 seeds; f) hectoliter weight (kg hL^{-1}); and g) grain yield (in grams), corrected for 13% humidity and converted to kg ha^{-1}.

The variables were submitted for analyses of the homogeneity of variance (Bartlett test) and normality (Lilliefors test). After meeting these assumptions, an individual analysis of variance was performed for each variable in each year. Because the ratio between the highest and lowest residual mean square (RMS$^+$/RMS$^-$) was lower than seven for all parameters evaluated, a pooled analysis could be performed, with genotype as a fixed effect and year as a random effect. A polynomial regression analysis was used for significant effects of nitrogen fertilization levels. Model choice considered significant equations of highest degree and best fit, confirmed by the highest coefficients of determination (r^2). The analyses were performed with Genes software (CRUZ, 2006), and graphs were plotted with the statistical package Sigmaplot 11.0. Maximum agronomic efficiency (MAE) values were calculated from the first derivation of the quadratic polynomial equation, setting the equation equal to zero.

Grain yield response to different nitrogen fertilization levels and its interaction with cultivar type and characteristics were quantified with the package GGE Biplot (YAN, 2001), using the following methodologies: AMMI1 (additive main effects and multiplicative interaction analysis), which combines the analysis of variance from additive effects of genotypes and environment with the principal component analysis from the multiplicative effect of the interaction genotype x environment (ZOBEL et al., 1988), and GGE Biplot (genotype and genotype-by-environment), which considers the effect of genotype and the interaction between genotypes and environment (YAN et al., 2000).

Results and discussion

A significant triple interaction (year x cultivar x nitrogen fertilization level) was observed for grain yield (GY), number of fertile tillers (NFT), plant height (PH) and flag leaf length (FLL). Hectoliter weight (HW) and number of grains per spike (NGS) showed positive interactions only with year and cultivar (Table 2). These results support those obtained by Barraclough et al. (2010) who, in a study to quantify variations in nitrogen absorption and use efficiency, also noted the significant influence of year, nitrogen level and cultivar on the phenotypic traits of wheat. In this study, coefficients of variation were low, indicating good reliability of the inferences tested and high experimental precision.

The contribution of the main effect of the factor nitrogen fertilization level on GY was more significant in the 2007 harvest (25.8%) than in the 2008 harvest (13.6%); in contrast, the contribution of the main effect of genotype was more pronounced in 2008 (79.5%) than in 2007 (55.7%) (Figure 2A and B).

Table 2. Summary of the pooled analysis of variance (including sources of variation, respective mean squares and significance levels) of six wheat cultivars subjected to four nitrogen fertilization levels in the 2007 and 2008 harvests.

Source of variation	D.F	Means squares						
		GY	NFT	PH	FLL	HW	WTS	NGS
(B/G)/Y	24	34836.4	22.3	6.96	0.9	46.1	12.1	19.4
Years (Y)	1	2540166.6★★	437.5★★	5575.1★★	10.7★★	467.9★★	27.3^{ns}	995.1★★
Genotypes (G)	5	4422269.2^{ns}	3073.3★	658.8★	105.2^{ns}	179.4^{ns}	135.8★	211.5★
Rates (R)	3	2186398.4^{ns}	4280.2★★	306.4^{ns}	132.3★★	36.6^{ns}	2.5^{ns}	76.4^{ns}
Y x G	5	3283751.8★★	536.2★★	82.5★★	28.8★★	74.2^{ns}	27.6^{ns}	31.4^{ns}
Y x R	3	336567.7★★	85.8★★	52.9★★	4.1★	63.6^{ns}	13.1^{ns}	60.5★
G x R	15	93219.3^{ns}	120.5^{ns}	6.5^{ns}	7.5^{ns}	31.9^{ns}	13.1^{ns}	16.3^{ns}
Y x G x R	15	180542.9★★	64.6★★	10.4★	7.7★★	34.9^{ns}	8.1^{ns}	16.3^{ns}
Error	72	31214.6	10.1	5.2	1.2	34.4^{ns}	9.8	20.3
Mean		3079.1	94.6	78.6	18.1	72.7	30.3	36.5
CV(%)		5.74	3.36	2.91	5.98	8.06	10.32	12.33

^{ns} – Non-significant ($P > 0.05$); ★ – Significant ($p < 0.05$); ★★ – Significant ($p < 0.01$). D.F. – degrees of freedom; CV (%) – Coefficient of variation; GY – Grain yield (kg ha^{-1}); NFT – Number of fertile tillers; PH – Plant height (cm); FLL – Flag leaf length (cm); HW – Hectoliter weight; WTS – Weight per 1000 seeds; NGS – Number of grains per spike.

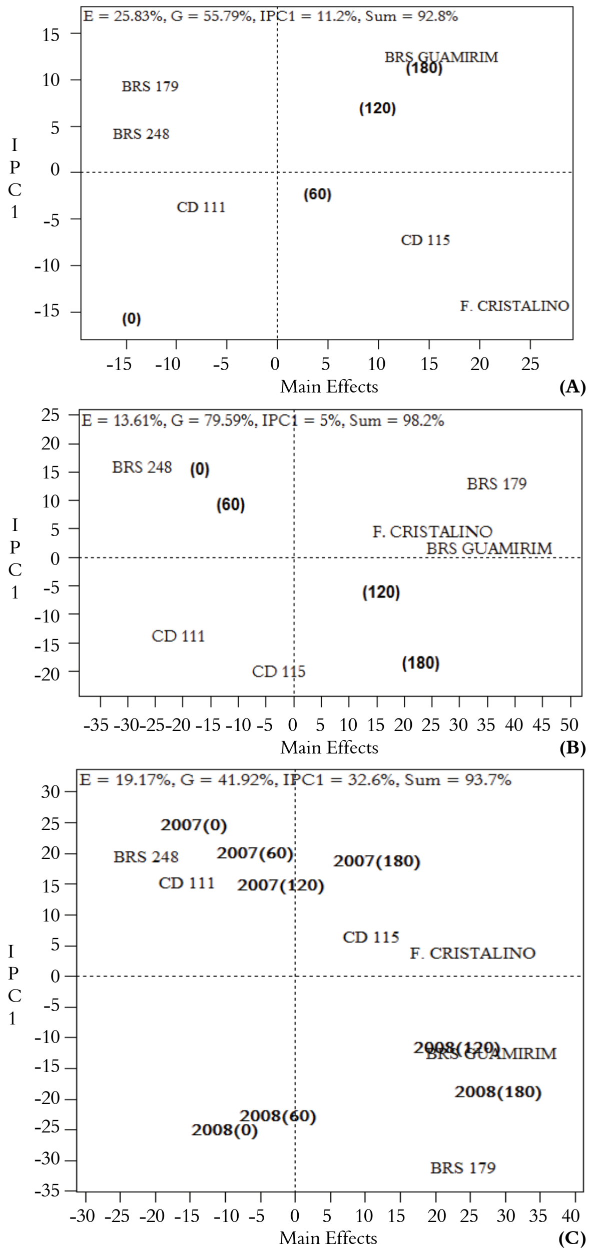

Figure 2. Plot of scores of the principal components from the interactions between genotypes and environment according to the AMMI1 model for the 2007 (A), 2008 (B) and 2007/2008 pooled (C) harvests for grain yield (kg ha^{-1}) of six wheat cultivars in response to four nitrogen fertilization levels in the 2007 and 2008 harvests.

These results indicate that regardless of harvesting year, there was proportionately higher response variability to nitrogen fertilization level among genotypes. In addition, the contribution of the interaction genotype x nitrogen fertilization level was higher in 2007 (11.2%) than in 2008 (5%), possibly due to water stress observed in August and September 2007 (Figure 1). This supports the findings of Anjos and Nery (2005), who identified significant correlations between meteorological variables and grain yield for wheat crops in the state of Paraná.

In the 2007 harvest (Figure 2A), treatments where nitrogen was applied were above the overall average grain yield (indicated by the center of the perpendicular lines); however, in the 2008 harvest (Figure 2B), only the treatments with 120 and 180 kg ha^{-1} of N were above the overall average yield, and a similar behavior was observed in the pooled analysis (Figure 2C). The expression of grain yield was ranked in descending order according to nitrogen fertilization level (180 > 120 > 60 > 0 kg ha^{-1}). Higher average performance and greater response stratification between nitrogen levels were observed in 2008, which can be attributed to more evenly distributed rainfall and milder temperatures in that year (Figure 1). Soil water stress hinders the main processes involved in mineral nutrition: diffusion, mass flow and root absorption (TRINDADE et al., 2006), with negative effects on grain yield.

In the pooled analysis, the interaction between year x nitrogen fertilization level accounted for 19% of the total variation in grain yield (Figure 2C), indicating a proportionally smaller contribution when compared to the variability in genotype response (41.9%), confirming the greater contribution of genotype effects to the determination of grain yield. The cumulative percentage of explanation for the years 2007, 2008, and 2007/2008 combined (Figure 2A, B and C) were 92.8, 98.2 and 93.7%, respectively. These values indicate that the explanation of total variation on genotype performance plus its interaction with environment (G + G x E) was highly reliable. These results are similar to those reported by Ma et al. (2004), who studied the response of wheat genotypes to nitrogen fertilization levels and identified explanation patterns from graphical analyses that were higher than 76%. Multivariate graphical analysis enables the observation of complex interactions and inferences on the performance of genotypes and environment, clarifying the visualization of behavior patterns (YAN et al., 2000; YAN; RAJCAN, 2002; HASSANPANAH, 2010).

Yields of wheat cultivars were either non-significant or adjusted to a linear model, indicating genetic variability in the response to nitrogen fertilization levels (Figure 3). Higher responses to nitrogen application were observed in the 2008 harvest, when the water regime was more suitable to crop growth (Figure 1). In this harvest, according to regression equations, the biggest increases in yield per kilogram of nitrogen applied were observed for cultivars CD 115 (8.17 kg ha^{-1}) and CD 111 (7.02 kg ha^{-1}); these cultivars presented maximum yields of 3974 and 3104 kg ha^{-1} at 180 kg ha^{-1} of N, respectively. However, a higher average grain yield was observed for cultivar BRS 179 (4201 kg ha^{-1}), though it did not exhibit a significant response to increasing nitrogen levels. Similarly, Braz et al. (2006) identified linear increases, quadratic responses or the lack of significant effects in grain yield with nitrogen levels up to 120 kg ha^{-1}. In this context, Freitas et al. (1994) argued that the yield response of wheat to nitrogen depends on factors such as climate, soil and cultivar. In addition, under highly favorable conditions, grain yield might not be responsive to high nitrogen levels (PENCKOWSKI et al., 2009).

The low response (or lack thereof) of some cultivars to nitrogen fertilization, regardless of planting year, is mostly related to high soil organic matter content (Table 1) and the cultivation of wheat subsequent to soybeans. According to Wendling et al. (2007), soils with organic matter levels higher than 4% can supply wheat crops

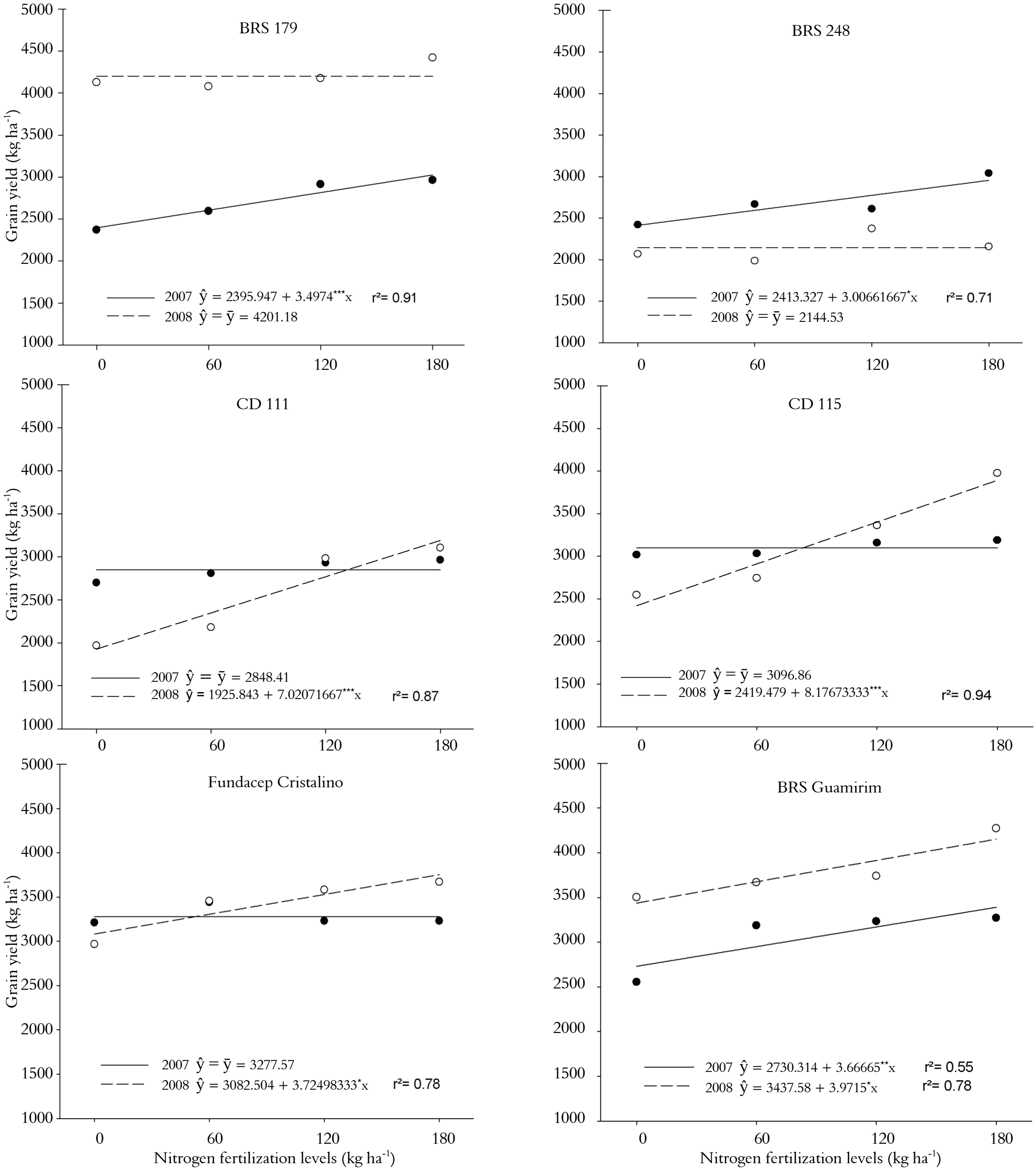

Figure 3. Grain yield response of wheat cultivars to different nitrogen fertilization levels in two harvests in southwestern Paraná state, Brazil. *, **, *** – Statistically significant values according to Student's t-test, with significance levels at 0.05 or 5%, 0.01 or 1% and 0.001 or 0.1%, respectively.

with enough N for yields of up to 2,500 kg ha^{-1}, even in the absence of nitrogen fertilization. Therefore, high yields in the absence of nitrogen fertilization and the lack of response to this nutrient by less demanding cultivars can be explained by soil organic matter levels. Other authors have the attributed low grain yield response of wheat to nitrogen fertilization to the mineralization of organic matter and the cultivation of soybeans over four consecutive years (POTTKER et al., 1984; SILVA, 1991). In addition to providing nitrogen to the system, cultivation of legumes prior to wheat improves the physicochemical characteristics of the soil and reduces the incidence of pests, diseases and weeds (GARRIDO; LÓPEZ-BELLIDO, 2001).

The BRS Guamirim cultivar exhibited maximum agronomic efficiency (MAE) at 152 (137 tillers) and 179 (122 tillers) kg ha^{-1} of N in 2007 and 2008, respectively (Figure 4).

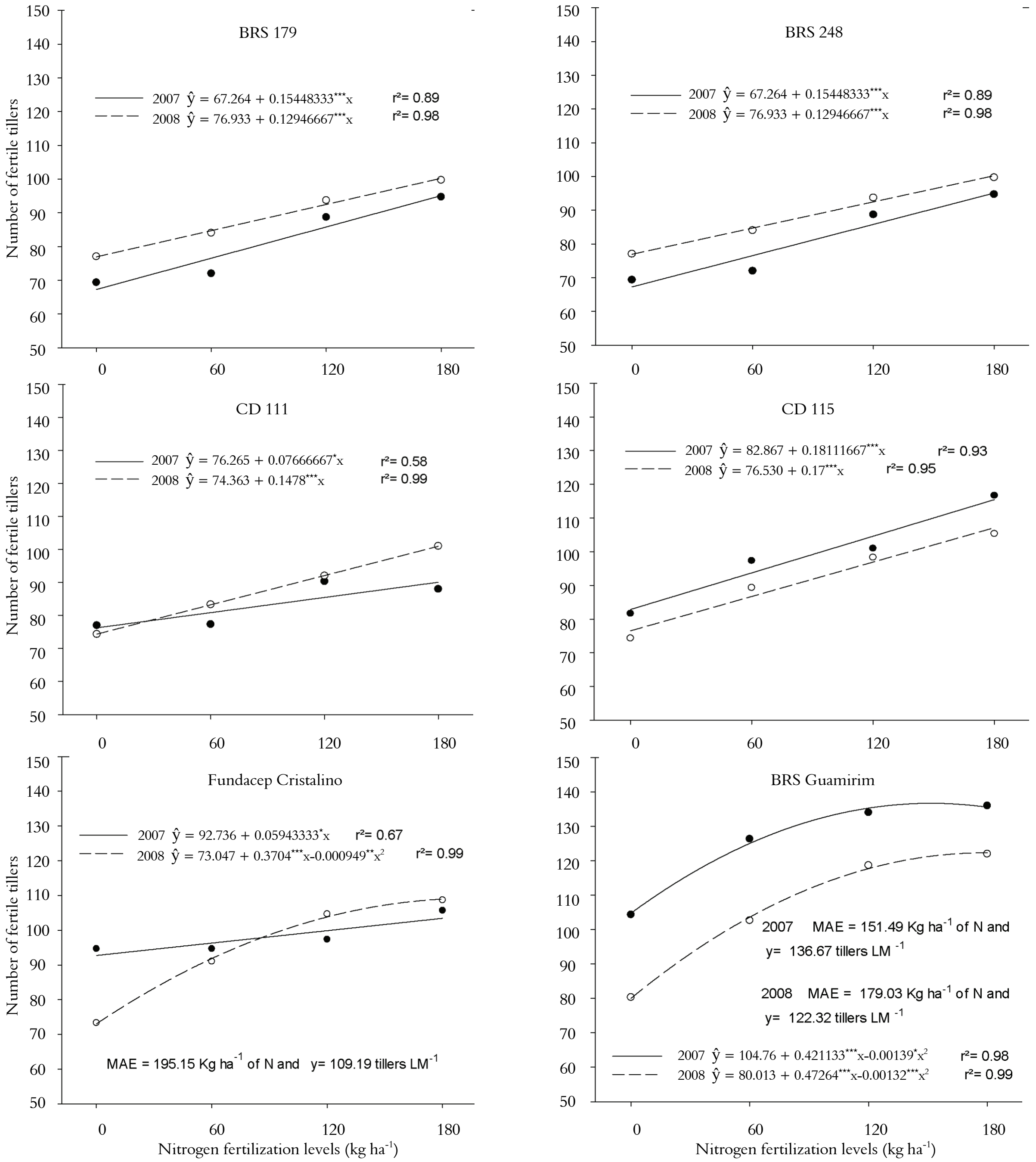

Figure 4. Number of fertile tillers response of wheat cultivars to different nitrogen fertilization levels in two harvests in southwestern Paraná state, Brazil. Maximum agronomic efficiency (MAE); *, **, *** – Statistically significant values according to Student's t-test, with significance levels at 0.05 or 5%, 0.01 or 1% and 0.001 or 0.1%, respectively.

In 2008, the Fundacep Cristalino cultivar exhibited MAE for NFT estimated at 195 kg ha^{-1} of N, with 110 fertile tillers per linear meter. However, that value is outside the range of the nitrogen levels studied; therefore, it can be inferred that the best response was to the 180 kg ha^{-1} of N treatment. The application of nitrogen in coverage promotes greater tiller contributions to grain yield, regardless of the phenotypic traits of the cultivar, leading to an increase in grain yield (ZAGONEL et al., 2002; SANGOI et al., 2007).

The association between traits and cultivars with nitrogen fertilization levels can be observed in Figure 5, where associations are denoted by the angles between vectors: it is a positive association if the angle is lower than 90°, a negative association if the angle is greater than 90° and a null association if the angle is exactly 90° (YAN; TINKER, 2006). Thus, performance of GY, NGS, PH, FLL and NFT were more associated with nitrogen levels of 180 and 120 kg ha^{-1} in both years (Figure 5A, B). Higher GY at higher nitrogen fertilization levels may be explained by better performance of grain yield components, especially NFT, NGS and FLL. Higher nitrogen levels promote greater vegetative vigor, especially during tillering and reproductive meristem differentiation, resulting in increased expressions of yield components (ESPINDULA et al., 2010).

In 2008, PH was positively associated with 0 and 60 kg ha^{-1} of N (Figure 5B). Meteorological conditions during that year were more suitable to the emergence and survival of tillers and development of spikes at higher nitrogen levels. This resulted in increased competition for nutrients and photoassimilates, restricting grain filling and resulting in lower PH values under more restrictive nitrogen fertilization, a fact that was also observed by Coelho et al. (1998). Although it is possible to increase yield components individually, compensatory phenomena have often led to negative associations between components, resulting in the growth of some at the expense of others. Thus, the same yield may be achieved in different ways, hindering an optimal combination of yield components (LAMOTHE, 1998).

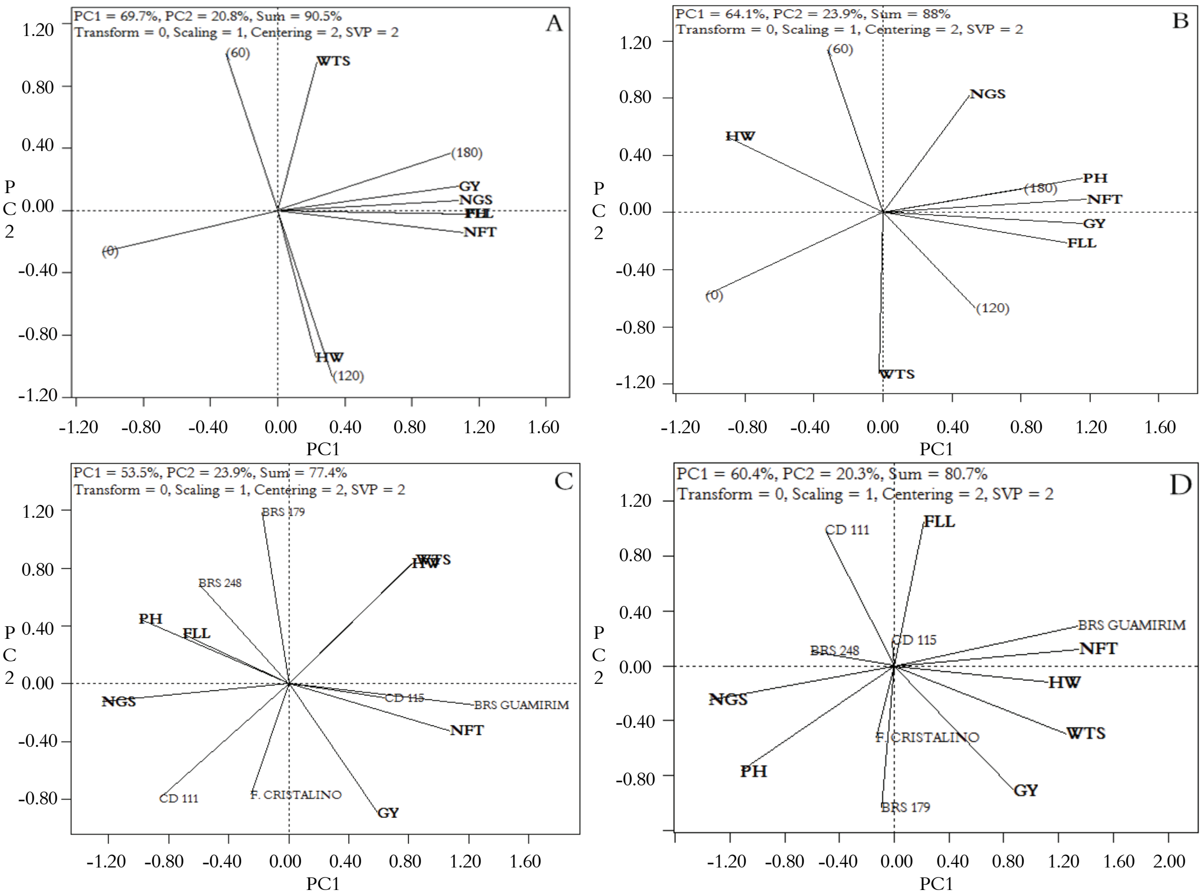

Figure 5. Plot of scores of the principal components, according to the GGE Biplot model, from the association of nitrogen levels (A and B) and cultivars (C and D) with grain yield (GY), hectoliter weight (HW), number of grains per spike (NGS), number of fertile tillers (NFT), flag leaf length (FLL), weight of 1000 seeds (WTS), and plant height (PH) at four nitrogen fertilization levels in 2007 (A and C) and 2008 (B and D).

The performance of cultivar BRS Guamirim was, in large part, accounted for by the number of fertile tillers in both years (Figure 5C and D), a trait highlighted by Scheeren et al. (2007). In fact, better performance of yield components in response to nitrogen fertilization has also been reported by Espindula et al. (2010) and Sangoi et al. (2007), who observed that the emergence and survival of tillers and the number of grains per spike (NGS) were highly associated with an increase in yield potential.

Conclusion

In conclusion, we have observed a yield response variability to nitrogen fertilization in the wheat cultivars evaluated in this experiment. Moreover, a greater response to nitrogen fertilization was noted when meteorological conditions, especially rainfall, were not limiting factors. Finally, we have shown that the positive effect of nitrogen fertilization levels on grain yield was related to better performance of grain yield components

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