Evaluation of top-dressing fertilization with nitrogen for the morphophysiology of wheat crops

Evaluación de la fertilización de cobertura con nitrogeno sobre la morfofisiología de cultivos de trigo

Fernanda Maria Mieth[1*], Emilso Damm dos Santos[1], Diego Nicolau Follmann[1], Anderson Crestani Pereira[1], and Ricardo Ismael Raddatz[1]

ABSTRACT

The aim of this study was to evaluate the influence of different management of nitrogen fertilization in top dressing on the morphophysiology of spring wheat cultivars in a low-altitude subtropical environment of Brazil. The experiment was carried out in 2022 in a greenhouse. The experiment had a randomized block design. We evaluated 10 wheat cultivars with two different applications of nitrogen with three replicates. The variables evaluated included the number of fertile tillers, plant height, length of the main spike and tiller, number of spikelets in the main spike and tiller, number of grains in the main spike and tiller, number of grains per plant and mass of grains in the main spike and tiller. For wheat cultivated in a low-altitude subtropical environment, nitrogen installments have no influence on the number of fertile tillers, plant height, or crop yield components. It was possible to infer that the difference obtained in the tillering pattern of the cultivars tested was due to their genetic potential.

Key words: *Triticum aestivum* L., plant physiology, tillering, plant height.

RESUMEN

El objetivo de este estudio fue evaluar la influencia de diferentes manejos de fertilizantes nitrogenados de superficie sobre la morfofisiología de cultivos de trigo de primavera en un ambiente subtropical de baja altitud de Brasil. El experimento se llevó a cabo en 2022 en un invernadero. El diseño experimental utilizado fue de bloques al azar, 10 cultivos de trigo y dos momentos de aplicación de nitrógeno fueron evaluados, con tres repeticiones. Las variables evaluadas incluyeron número de macollos fértiles, altura de la planta, longitud de la espiga principal y del macollo, número de espiguillas en la espiga principal y del macollo, número de granos en la espiga principal y en el macollo, número de granos por planta y peso de granos en la espiga principal y el macollo. Cuando se cultiva trigo en un ambiente subtropical de baja altitud, los aportes de nitrógeno no influyen en el número de macollos fértiles, la altura de la planta o los componentes del rendimiento del cultivo. Se pudo inferir que la diferencia obtenida en el patrón de macollamiento de los cultivos ensayados se debió a su potencial genético.

Palabras clave: *Triticum aestivum* L., fisiología de plantas, macollamiento, altura de planta.

Introduction

Wheat (*Triticum aestivum* L.) is an annual grass grown in southern Brazil mainly during the winter period during the months of June, July, August, and September. It is an important crop of sustainable agricultural production systems as an alternative to winter crop rotation in production systems (Barro *et al*., 2017).

The use of management practices that optimize resources contributes to increasing wheat yields in Brazil. Among the determining factors in establishing the crop productive potential are genetics and fertilization; these boost grain yields, since wheat is one of the main cereal crops that provides protein, carbohydrates, minerals, and vitamins for most of the world population (Conab, 2017). Wheat grain is used to make flour and is used in different ways depending on the quality of the grain, grain yield, endosperm content, the proportion of protein in the flour and the quality of the protein; all of these determine the quality of the wheat cultivar (Ahmed & Fayyaz-ul-Hassan, 2015). The genetic improvement of any crop is a fundamental tool, as it provides the launch of cultivars with different characteristics such as high production potential, wide adaptation to contrasting soils and environments, and tolerance to disease.

Received for publication: April 10, 2024. Accepted for publication: April 30, 2024.
Doi: 10.15446/agron.colomb.v42n1.113430

[1] Departamento de Fitotecnia, Universidade Federal de Santa Maria, Santa Maria, RS (Brazil).
[*] Corresponding author: fernanda.mieth@acad.ufsm.br

To increase productivity in wheat, it is necessary to increase the yield potential in tillage conditions, where cultivars need to interact with different environmental and management situations; it is necessary to identify cultivars that respond to specific environmental stimuli (Benin *et al.*, 2012; Scheeren, 1999). In order to obtain high yields, the following aspects are important: management adjustments and rational use of available resources among which nitrogen fertilization and the choice of cultivars best adapted to the growth environment stand out as important aspects (Ecco *et al.*, 2020; Silva *et al.,* 2024). From a nutritional point of view, nitrogen (N) is one of the most important elements, fundamental for plant metabolism and development, acting in the expansion and cell division of the photosynthetic area, in addition to being an essential component of proteins, nucleic acids, and chlorophyll (Silva *et al.,* 2024; Taiz *et al.*, 2017).

One way in which various nitrogen management strategies can help to achieve high grain yields is by increasing the number of tillers per plant (Ecco *et al.*, 2020). This means that the final number of fertile tillers is related to the number of ears and an increase in grains per area, leading to higher yields from wheat in a subtropical environment. The emergence and survival of tillers is associated with factors such as plant population density, N availability, temperature, salinity, and other factors (Shang *et al.*, 2021).

In order to obtain high productive potential of wheat crops, monitoring soil fertility and plant nutrition are also essential issues, considering that N is the nutrient that has greater requirement and uptake by wheat plants. This element also has a strong influence on the productivity of wheat (Prando *et al.*, 2013). Deficiencies in N can cause a reduction in evapotranspiration and water use efficiency and a decrease in leaf size related to solar radiation use efficiency that causes a drop in the photosynthetic rate, as well as a limitation in the number of tillers that also reduce the number of stalks and ears per area and, consequently, wheat yield (Ferreti & Fernandes, 2011). The use of N fertilization contributes to an increase in tillering, as well as an increase in the growth of the wheat canopy (Pietro-Souza *et al.*, 2013). Therefore, mineral N fertilization represents a significant cost in wheat yield (Cui *et al.*, 2014). Moreover, good N agronomic practices that help farmers increase productivity, reduce production costs, and diversify wheat production should be studied to guarantee the sustainability and viability of wheat crops, as well as lowering Brazilian independence from the import of this cereal (Kaneko *et al.*, 2010; Pires *et al.*, 2019).

Studies evaluating the morphophysiology of wheat cultivars associated with N management are limited to cultivars that have only been launched in the Brazilian market for a short time. It is necessary to verify whether and which of the moments of N fertilization in top dressing provide better tillering conditions and, consequently, greater grain yields. The objective of this study was to evaluate the influence of N fertilizer management strategies on the morphophysiology of spring wheat cultivars in a low-altitude subtropical environment.

Materials and methods

The experiment was carried out in the 2022 crop season in a greenhouse at the Phytotechnics Department of the Universidade Federal de Santa Maria - RS. The climate, according to Köppen classification system, is Cfa, humid subtropical, with warm summers during the months of December, January, February, and March, and no defined dry season. The crop was sown on June 22, 2022, within the recommended sowing period according to the Agricultural Risk Zoning (Zoneamento Agrícola de Risco Climático - ZARC) (Ministério da Agricultura e Pecuária, 2021). We planted the crop in 20 L pots with 16 plants per pot, filled with a soil classified as Arenic Profondic Rhodic Acrisol (ISSSWG RB, 1998). The pots were placed on benches under a Van der Hoeven greenhouse made with a galvanized iron and polycarbonate structure with temperatures ranging from 10ºC to 32ºC and irrigation according to the crop's demand.

The experiment used a randomized block design, in a bifactorial arrangement 10x2, consisting of ten wheat cultivars and two periods of N application with three replicates. The following cultivars were used: TBIO Audaz, TBIO Aton, TBIO Toruk, TBIO Ello, TBIO Calibre, TBIO Fusão, TBIO Ponteiro, TBIO Duque, TBIO Astro and TBIO Trunfo (Tab. 1). The trial consisted of 60 experimental units made up of 20 L white pots distributed on 3 benches, each with 20 pots, representing each block. The population used in the trial was 16 plants per pot, and the adjustment was made based on the cultural value of the seeds, so that the recommended population for wheat was 300 plants m^{-2}.

To fertilize the soil in pots, we sampled and analyzed the soil and corrected the pH before the pots were filled using limestone in coverage and applied two months before sowing, based on the recommendations of the fertilization and liming manual for the states of Rio Grande do Sul and Santa Catarina (Comissão de Química e Fertilidade do Solo

TABLE 1. Description of cultivars tested for cycle and industrial quality.

Cultivars	Cycle	Classification
TBIO Audaz	Precocious	Improver
TBIO Aton	Medium	Bread/improver
TBIO Toruk	Medium	Bread/improver
TBIO Ello	Medium	Bread
TBIO Calibre	Super precocious	Bread/improver
TBIO Fusão	Precocious	Improver
TBIO Ponteiro	Mid-late	Bread
TBIO Duque	Precocious	Bread/whitener
TBIO Astro	Super precocious	Improver
TBIO Trunfo	Precocious	Bread

Commercial cultivars were obtained from the holder BIOTRIGO Genética (Brazil).

– RS/SC, 2016). Base fertilizer was applied on the surface at a dose of 200 kg ha^{-1} of 5-20-20 (N-P_2O_5-K_2O) formulation, equivalent to 1.2 g of fertilizer per pot.

When N top dressing fertilizer was applied to meet the N crop requirement during its production cycle, N was spread with two different methods. The first was to apply 50% of the recommended dose in installments, when the wheat was at the beginning of tillering (V3/V4 vegetative stage) and the remaining 50% was spread at the beginning of elongation (V7/V8 vegetative stage) according to the Zadoks Decimal Scale by Zadoks (1974). The second strategy for applying N was to apply 100% of the recommended dose at the beginning of tillering (vegetative stage V3/V4). For crop management, physical weed control was carried out; and, for pests and diseases affecting the crop, we followed the technical recommendations for wheat (Comissão Brasileira de Pesquisa de Trigo e Triticale, 2022).

On June 28, 2022 the seedling emergence rate was assessed in each pot and thinning was performed where necessary. Four plants in the useful area of the experimental unit were marked with colored wire. Beginning from July 15, 2022 some of the cultivars began to be tillered and weekly evaluations began: we counted the number of tillers and checking the plant height of the four plants previously marked in each pot.

Before the plants were harvested, we collected the four marked plants to assess the number of fertile shoots and other crop yield components. We harvested the crop manually on October 26, 2022, when the plants were mature, taking into account the difference in cycle between the cultivars. Later, in the laboratory of the Research Group on Ecophysiology and Management of Annual Crops (Grupo de Pesquisa em Ecofisiologia e Manejo de Culturas Anuais - GEMCA), we evaluated the yield components and characters related to grain yield using a measuring tape and precision scale as follow: number of fertile tillers = tillers that had spikelets with grain formation (NFT), plant height (PH), main spike length (SL_main), tiller spike length (SL_til.), number of spikelets on the main spike (NSS_main), number of spikelets on the tiller spike (NSS_til.), number of grains in the main spike (NGS_main), number of grains in the tiller spike (NGS_til.), number of grains per plant (NG), main spike grain mass fresh (MGS_main) and tiller spike grain mass fresh (MGS_til.).

Statistical analysis

We subjected the characters evaluated to a two-way analysis of variance; and for the crop yield components we grouped the means of the treatments using the Scott-Knott test with a significance level of 5% probability of error. For these analyses, we used the Sisvar statistical software and the Microsoft Office Excel® software to insert the data and draw up the tables.

Results and discussion

The different moments of N application did not differ statistically (P>0.05) for the factor number of fertile tillers (Tab. 2). Similar results were also identified for plant height and some yield components, such as SL, NSS, NGS, and MGS. For the environmental conditions of the experiment, the N installment did not influence the number of fertile tillers, plant height, and crop yield components. Due to adequate irrigation and temperature control in the greenhouse, the difference in the tillering pattern of the evaluated cultivars could be due to their genetic potential, which corroborates the data obtained by Orso *et al.* (2014). The wide variety of cultivars currently available on the market allows the producer to choose the genetic material most adapted to

TABLE 2. Average number of fertile tillers per plant produced by different nitrogen managements applied to the wheat crop, Santa Maria/RS, Brazil.

Nitrogen management	Number of fertile tillers
50% of the recommended N dose applied at vegetative stage V3/V4 (beginning of tillering) and the remaining 50% applied at vegetative stage V7/V8 (full tillering)	2.28 ns*
100% of the recommended N dose applied at vegetative stage V3/V4 (beginning of tillering)	2.40
Overall average	2.34
CV (%)	29.93

CV – coefficient of variation. * ns – not significant using the Scott-Knott test at 5% significance level.

the production system, level of technology, and investment capacity (Pires *et al*., 2005).

In relation to the analysis of variance of the characters evaluated (Tab. 3), we found a low coefficient of variation (CV %) for PH, SL_main, and NSS_main indicating good experimental precision (CV less than 10%), demonstrating the reliability of the tests (Pimentel-Gomes, 1990). The other characters, NFT, SL_til., NSS_til., NGS_main, NGS_til., MGS_main, and MGS_til., had a high coefficient of variation, which may indicate difficulties in measuring these characters. This indicates a lower reliability of results, therefore, in future experiments, a greater number of plants per experimental unit or a greater number of replicates should be used.

The average MGS_til. of each cultivar were presented separately for each type of N fertilizer management (Tab. 4).

Only for the cultivar TBIO Audaz did we observe a significant difference between management A in relation to nitrogen management B. For this cultivar, the application of 50% of the N dose recommended at the beginning of tillering and 50% of the recommended dose applied at the beginning of elongation provided higher MGS_til. values compared to management B, where 100% recommended dose of N was applied at the beginning of tillering of the crop. Similar results are reported by Costa *et al.* (2013) and by Mattuela *et al.* (2018).

TABLE 4. Fresh grain weight of tiller spike (MGS_til.) averages for each cultivar presented separately for the two types of nitrogen fertilizer management, Santa Maria/RS, Brazil.

Cultivar	N fertilizer management	MGS_til.
TBIO Audaz	A	0.87 a
	B	0.26 b
TBIO Aton	A	0.41 a
	B	0.47 a
TBIO Toruk	A	0.43 a
	B	0.64 a
TBIO Ello	A	0.53 a
	B	0.81 a
TBIO Calibre	A	0.57 a
	B	0.62 a
TBIO Fusão	A	0.6 a
	B	0.83 a
TBIO Ponteiro	A	0.55 a
	B	0.54 a
TBIO Duque	A	0.65 a
	B	0.51 a
TBIO Astro	A	0.55 a
	B	0.61 a
TBIO Trunfo	A	0.65 a
	B	0.55 a

CV – coefficient of experimental variation in %. N fertilizer management A - 50% of the recommended N dose applied at vegetative stage V3/V4 (beginning of tillering) and the remaining 50% applied at vegetative stage V7/V8 (full tillering), B - 100% of the recommended N dose applied at vegetative stage V3/V4 (beginning of tillering). * Averages followed by the same letter in the column do not differ by the Scott-Knott test at a 5% significance level.

TABLE 3. Mean squares of the analysis of variance (ANOVA) for productive and morphological characters evaluated in ten wheat cultivars, Santa Maria/RS, Brazil.

SV	DF	NFT	PH	SL_main	SL_til.	NSS_main	NSS_til.
Cultivar	9	0.73	81.75	2.89	1.59	3.28	1.50
Nitrogen	1	0.23	1.58	1.70	0.33	0.65	4.11
Cult X Nitrog	9	0.22	8.60	0.73	0.52	3.37	2.97
Error	40	0.49	22.13	0.87	0.99	2.53	2.99
Mean	-	2.34	62.80	8.71	7.40	15.43	11.15
CV (%)	-	29.93	7.49	10.69	13.45	10.31	15.51

SV	NGS_main	NGS_til	MGS_main	MGS_til.
Cultivar	41.59	41.57	0.13	0.03
Nitrogen	4.00	0.02	0.12	0.00
Cult X Nitrog	51.25	34.48	0.04	0.10
Error	35.95	28.79	0.05	0.04
Mean	36.98	16.66	1.53	0.58
CV (%)	16.22	32.20	15.23	36.17

CV – coefficient of variation. NFT - number of fertile tillers, PH -plant height, SL _ main - main spike length, SL _ til. -tiller spike length, NSS _ main - number of spikelets on the main spike, NSS _ til. - number of spikelets on the tiller spike, NGS _ main - number of grains in the main spike, NGS _ til. - number of grains in the tiller spike, NG - number of grains per plant, MGS _ main - main spike grain mass, and MGS _ til. - tiller spike grain mass.

The results of the averages of the plant traits (Tab. 5) show that a balance is needed between NGS and MGS, both in the main ear and in the tillers. Despite having a considerable number of grains per ear, they may not have a high mass. The quantity of grains produced per area verified in the NGS_main does not directly express high MGS_main; productivity will end up being influenced by other factors. The MGS_main was segregated into two groups according to the average grain weight. In the group with the highest MGS_main averages made up of TBIO Toruk, TBIO Calibre, TBIO Fusão, TBIO Duque and TBIO Trunfo there was no interaction with NGS_main where cultivars that showed the highest value for this variable did not necessarily show the highest MGS_main values.

The TBIO Duque cultivar had the highest NGS_main, and MGS_main also fell into the group with the highest MGS_main averages. Meanwhile, TBIO Audaz and TBIO Astro have the lowest NGS and MG values for the main ear. For NGS_til., TBIO Toruk has the lowest averages and TBIO Ello has the highest averages, but they do not make up the highest MGS_til. Direct selection using the number of grains per ear, considering the thousand-grain mass, is the best strategy for obtaining superior genotypes in terms of grain yield (Vesohoski *et al*., 2011). Indirect selection for grain yield, when it comes to ear weight, considering the number of grains per ear and/or grain mass, is the best indirect selection strategy for choosing superior genotypes (Caierão *et al*., 2001).

For the SL, NSS and NGS characters, despite there being no statistical difference for the cultivar factor, the greater length of ears does not imply a greater number of spikelets per ear or number of grains per ear (Tab. 5) in absolute values. An example of this is the performance of the TBIO Ponteiro cultivar that, despite having the highest SL_main and the highest NSS_main, has the lowest NGS_main. Meanwhile, although TBIO Calibre has one of the lowest SL_main and NSS_main values, it had one of the highest NGS_main values. This differs from Silva *et al*. (2005), who observe that the higher the number of grains per spike (NGS), the greater spike length (SL) and the greater the number of spikelets per spike (NSS).

One of the reasons for the low average yield of spring wheat crops is attributed to the small share of fertile tillers in the final yield (Mundstock, 1999). This can be seen by observing the lower contribution of the tillers to the yield components when compared to the main ear (Tab. 5). There was no statistical difference for the cultivar factor in NFT, but TBIO Ello was superior in the final number of fertile tillers, and TBIO Duque was inferior for the same variable (Tab. 6). However, TBIO Duque stands out in terms of NGS and MGS when compared to TBIO Ello and the other cultivars analyzed. In this case we can infer that the greater number of fertile tillers did not interfere with higher grain yields, but we can consider it a safety mechanism; in years with lower than ideal production, the compensation of fertile tillers can help maintain grain yields.

TABLE 5. Plant characters, SL_main, SL_til., NSS_main, NSS_til., NGS_main, NGS_til., MGS_main and MGS_til., associated with grain yield in ten wheat cultivars, Santa Maria/RS, Brazil.

Cultivar	SL_main (cm)	SL_til. (cm)	NSS_main	NSS_til.	NGS_main	NGS_til.	MGS_main (g)	MGS_til. (g)
TBIO Audaz	8.76 b*	7.09 ns	15.79 ns	10.98 ns	32.29 ns	14.42 ns	1.51 b	0.56 ns
TBIO Aton	7.97 b	6.93	14.88	10.63	38.38	14.64	1.38 b	0.44
TBIO Toruk	9.47 a	7.68	15.92	11.58	37.79	13.69	1.73 a	0.53
TBIO Ello	8.10 b	7.03	14.75	10.61	36.13	21.58	1.33 b	0.67
TBIO Calibre	8.25 b	7.15	14.79	11.00	38.33	15.23	1.66 a	0.59
TBIO Fusão	8.94 a	7.78	16.25	11.39	37.67	17.20	1.65 a	0.71
TBIO Ponteiro	9.12 a	7.98	15.63	12.03	36.25	17.20	1.41 b	0.55
TBIO Duque	8.44 b	6.80	15.13	10.72	40.17	16.06	1.65 a	0.58
TBIO Astro	7.98 b	7.18	14.46	10.83	32.96	20.73	1.36 b	0.58
TBIO Trunfo	10.05 a	8.35	16.70	11.73	39.79	15.86	1.60 a	0.60
Mean	8.71	7.40	15.43	11.15	36.98	16.66	1.53	0.58
CV (%)	10.69	13.45	10.31	15.51	16.22	32.20	15.23	36.17

CV - coefficient of experimental variation in %. * Averages followed by the same letter in the column do not differ by the Scott-Knott test at a 5% significance level. ns – not significant according to the Scott-Knott test at 5% significance level. SL _ main - main spike length, SL _ til. - tiller spike length, NSS _ main - number of spikelets on the main spike, NSS _ til. - number of spikelets on the tiller spike, NGS _ main - number of grains in the main spike, NGS _ til. - number of grains in the tiller spike, MGS _ main - main spike grain mass, and MGS _ til. - tiller spike grain mass.

These contrasts with Camponogara *et al*. (2016). They show that treatments with greater tillering also have greater significance for yield. This leads to an indirect relationship between these characters, possibly meaning that the greater magnitude of yield in these treatments can be explained by greater tillering. However, when NFT is compared with the variables MGS_main and MGS_til., there is no association between these variables in relation to the weight of grains produced in the main ear of the plant. However, in relation to MGS_til., there is a greater weight of grains produced by the cultivars TBIO Ello, TBIO Calibre and TBIO Fusão, which have higher absolute values of NFT, despite the absence of a statistical difference for NFT and MGS_til. Factors such as the incidence of solar radiation and competition for nutrients result in a higher population of fertile tillers per unit area (Ozturk *et al*., 2006).

The application of N in top dressing is not capable of increasing the number of tillers (Ecco *et al*., 2020; Penckowski *et al*., 2009). So, this is probably a genetic characteristic of the cultivar linked to population management and the thermal conditions arising during its development. In production terms, genotypes with lower tillering potential are subject to greater dependence on sowing density and this characteristic is also related to tiller senescence (Valério *et al*., 2008). Plants should ideally have two or three tillers in addition to the main stem, to minimize possible environmental damage (Common & Klinck, 1981). The number of tillers is determined based on the population of plants in the crop, where the number of tillers changes to compensate for the lack or excess of plants (Orso *et al*., 2014).

Despite the fact that there was statistical differentiation for the cultivar factor, according to the PH character (Tab. 6), the averages were segregated into two groups. The group with the highest average PH is made up of the cultivars TBIO Audaz, TBIO Ello, TBIO Calibre and TBIO Duque, while the others had lower values. We can infer that the higher the PH, the lower the NFT, except for the TBIO Astro cultivar that, despite having a lower NFT, also has a low PH average. However, the higher the PH, the greater the possibility of the crop lodging in the face of more intense winds; lodging is one of the factors that most limits the maximization of wheat grain production (Costa *et al.*, 2013).

When growing wheat in a low-altitude subtropical environment, N installments have no influence on the number of fertile tillers, plant height, or crop yield components. If environmental conditions are favorable, nitrogen can be applied in a single application. For the experimental condition, the higher number of fertile tillers is not related to an increase in grain yield. However, this can be considered an important agronomic trait for regulating the number of spikes per area when there is a lower crop density after the crop is established.

TABLE 6. Plant height (PH) and number of fertile tillers (NFT) per plant of ten wheat cultivars, Santa Maria/RS, Brazil.

Cultivar	PH (cm)		NFT
TBIO Audaz	65.13	A*	2.08 ns
TBIO Aton	57.08	B	2.38
TBIO Toruk	59.00	B	2.58
TBIO Ello	64.25	A	3.04
TBIO Calibre	68.25	A	2.50
TBIO Fusão	62.08	B	2.50
TBIO Ponteiro	60.46	B	2.38
TBIO Duque	63.46	A	1.88
TBIO Astro	60.42	B	2.00
TBIO Trunfo	67.92	A	2.04
Mean	62.80		2.33
CV (%)	7.49		29.93

CV – coefficient of experimental variation in %. * Averages followed by the same letter in the column do not differ by the Scott-Knott test at a 5% significance level; ns – not significant according to the Scott-Knott test at 5% significance level.

In addition to the data generated in a controlled environment (greenhouse), it is important to carry out studies in field conditions in order to have a greater number of potentially troubling environmental characteristics such as temperature fluctuations and stress due to excess or deficit water. In this context, we suggest a more in-depth study on the interference of N fertilization management on the tillering and height of wheat plants. The study should also be further developed in a greenhouse that includes more genotypes and nitrogen top dressing, including different N sources, doses, and times of application in order to obtain a significant interaction between N fertilization and the analyzed characters of the number of fertile tillers, plant height, and yield components.

Conclusions

The nitrogen installments had no influence on the number of fertile tillers, plant height or crop yield components.

The difference obtained in the tillering pattern of the cultivars tested could be a function of their genetic potential.

For the experimental condition, an elevated number of fertile tillers was not related to an increase in grain yield.

Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

FMM, EDS, and DNF designed the experiments, DNF obtained financial support for the project that gave rise to this publication. FMM and RIR carried out the experiments in a greenhouse; FMM, RIR, EDS, and ACP assisted in data collection and processing. EDS contributed to the data analysis and FMM and EDS wrote the article. All authors reviewed the final version of the manuscript.

Literature cited

Ahmed, M., & Fayyaz-ul-Hassan. (2015). Response of spring wheat (*Triticum aestivum* L.) quality traits and yield to sowing date. *PLoS ONE*, *10*(4), Article e0126097. https://doi.org/10.1371/journal.pone.0126097

Barro, J. P., Forte, C. T., Trentin, D., Scariot, M., & Milanesi, P. M. (2017). Effectiveness of different fungicide formulations and number of applications in controlling wheat leaf rust. *Summa Phytopathol*ogica, *43*(4), 276–280. https://doi.org/10.1590/0100-5405/174240

Benin, G., Pinnow, C., Silva, C. L., Pagliosa, E. S., Beche, E., Bornhofen, E., Munaro, L. B., & Silva, R. R. (2012). 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

Caierão, E., Carvalho, F. I. F., Pacheco, M. T., Lonrecetti, C., Marchioro, V. S., & Silva, J. G. (2001). Seleção indireta em aveia para o incremento no rendimento de grãos. *Ciência Rural, 31*(2), 231–236. https://doi.org/10.1590/S0103-84782001000200007

Camponogara, A. S., Oliveira, G. A., Georgin, J., & Rosa, A. L. D. (2016). Avaliação dos componentes de rendimento do trigo quando submetido a diferentes fontes de nitrogênio. *Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental*, *20*(1), 524–532. https://www.researchgate.net/publication/341528467_Avaliacao_dos_Componentes_de_Rendimento_do_Trigo_quando_Submetido_a_Diferentes_Fontes_de_Nitrogenio

Common, J. C., & Klinck, H. R. (1981, July 22–29). *Sequence and synchrony of culm development: Implications in breeding for limited tillering barleys* [Conference presentation abstract]. Fourth international barley genetics symposium, Edinburgh. https://www.cabidigitallibrary.org/doi/full/10.5555/19831621827

Companhia Nacional de Abastecimento (Conab). (2017). *A cultura do trigo*. Superintendência de Marketing e Comunicação – Sumac / Gerência de Eventos e Promoção Institucional – Gepin https://www.conab.gov.br/uploads/arquivos/17_04_25_11_40_00_a_cultura_do_trigo_versao_digital_final.pdf

Costa, L., Zucareli, C., & Riede, C. R. (2013). Parcelamento da adubação nitrogenada no desempenho produtivo de genótipos de trigo. *Revista Ciência Agronômica*, *44*(2), 215–224. https://doi.org/10.1590/S1806-66902013000200002

Cui, Z., Wang, G., Yue, S., Wu, L., Zhang, W., Zhang, F., & Chen, X. (2014). Closing the N-use efficiency gap to achieve food and environmental security. *Environmental Science and Technology*, *48*(10), 5780–5787. https://doi.org/10.1021/es5007127

Ecco, M., Perin, R. F., Duarte, R. P., Barbosa, A. P., & Gabriel, A. M. (2020). Respostas biométricas de plantas de trigo submetidas a diferentes doses de nitrogênio em cobertura. *Revista Científica Rural*, *22*(1), 169–184. https://doi.org/10.30945/rcr-v22i1.3074

Ferreti, K., & Fernandes, F. S. C. (2011). Avaliação da produtividade da cultura do trigo (*Triticum aestivum* L.) a aplicação de nitrogênio em cobertura. *Revista Cultivando o Saber*, *4*(3), 47–53. https://cultivandosaber.fag.edu.br/index.php/cultivando/article/view/356

ISSSWG RB. International Society of Soil Science Working Group RB. (1988). *World reference base for soil resources*. Food and Agriculture Organization of the United Nations.

Kaneko, F. H., Arf, O., Gitti, D. C., Arf, M. V., Chioderoli, C. A., & Kappes, C. (2010). Manejo do solo e do Nitrogênio em milho cultivado em espaçamentos reduzido e tradicional. *Bragantia*, *69*(3), 677–686. https://www.scielo.br/j/brag/a/9S4HzLPFK5WrH8LWY49dj3t/?lang=pt

Mattuella, D., Simioni, S. P., Segatto, C., Cigel, C., Adams, C. R., Klein, C., Lajus, C. R., & Sordi, A. (2018). Eficiência agronômica da cultura do trigo submetida a doses de nitrogênio em diferentes estádios ontogênicos. *Revista Ciência Agrícola*, *16*(3), 1–9. https://doi.org/10.28998/rca.v16i3.5176

Ministério da Agricultura e Pecuária (MAPA). (2021). Portaria: Aprova o Zoneamento Agrícola de Risco Climático – ZARC para a cultura do trigo de sequeiro no Estado do Rio Grande do Sul, ano safra 2021/2022 (PORTARIA SPA/MAPA Nº 609, de 16 de dezembro de 2021). https://www.gov.br/agricultura/pt-br/assuntos/riscos-seguro/programa-nacional-de-zoneamento-agricola-de-risco-climatico/portarias/safra-vigente/rio-grande-do-sul/word/PORTN609TRIGODESEQUEIRORS.pdf

Mundstock, C. M. (1999). *Planejamento e manejo integrado da lavoura de trigo*. Porto Alegre: Evnagraf.

Orso, G., Villetti, H. V., Krenchinski, F. H., Albrecht, A. J. P., Albrecht, L. P., Rodrigues, D. M., & Moraes, M. F. (2014). Comportamento da cultura do trigo sob efeito de fontes e doses de nitrogênio. *Revista do Centro Universitário de Patos de Minas*, *5*, 44–52.

Ozturk, A., Caglar, O., & Bulut, S. (2006). Growth and yield response of facultative wheat to winter sowing, freezing sowing and spring sowing at different seeding rates. *Journal of Agronomy and Crop Science*, *192*(1), 10–16. https://doi.org/10.1111/j.1439-037X.2006.00187.x

Penckowski, L. H., Zagonel, J., & Fernandes, E. C. (2009). Nitrogênio e redutor de crescimento em trigo de alta produtividade. *Acta Scientiarum Agronomy*, *31*(3), 473–479. https://doi.org/10.4025/actasciagron.v31i3.1048

Pietro-Souza, W., Bonfim-Silva, E. M., Schlichting, A. F., & Silva, M. C. (2013). Desenvolvimento inicial de trigo sob doses de nitrogênio em Latossolo Vermelho de Cerrado. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *17*(6), 575–580. https://doi.org/10.1590/S1415-43662013000600001

Pimentel-Gomes, F. (1990). *Curso de estatística experimental* (13th ed.). Livraria Nobel S.A.

Pires J. L. F., Lima, M. I. P. M., Voss, M., Scheeren, P. L., Wiethölter, S., Cunha, G. R., Ignaczak, J. C., & Caierão, E. (2005). *Avaliação de cultivares de trigo em sistema de manejo tradicional e otimizado, Passo Fundo, 2004*. Embrapa Trigo.

Pires, J. L. F., Pires, P. C. V., Lemainski, J., Acosta, A. S., Caierao, E., Guarienti, E. M., Lau, D., Vieira, V. M., Klein, M. A., Zeni, M., Manfron, A. C. A., Feltraco, S. L., Richter, R., Kuntzler, L., Pilecco, M., Dezordi, J., Reginatto, T. I., Oerlecke, D., & Corassa, G. (2019). *Trigo exportação: alternativa para sustentabilidade da cultura do trigo no Rio Grande do Sul*. *Embrapa Trigo* [Conference presentation abstract]. Reunião da comissão brasileira de pesquisa de trigo e triticale. https://www.alice.cnptia.embrapa.br/alice/handle/doc/1123108

Prando, A. M., Zucareli, C., Fronza, V., Oliveira, F. A., & Oliveira Júnior, A. (2013). Características produtivas do trigo em função de fontes e doses de nitrogênio. *Pesquisa Agropecuária Tropical*, *43*(1), 34–41. https://doi.org/10.1590/S1983-40632013000100009

Scheeren, P. L. (1999). Trigo no Brasil. In G. R. Cunha, & M. F. Trombini (Eds.), *Trigo no Mercosul: Coletânea de artigos* (pp. 122–133). Embrapa Trigo.

Shang, Q., Wang, Y., Tang, H., Sui, N., Zhang, X., & Wang, F. (2021). Genetic, hormonal, and environmental control of tillering in wheat. *The Crop Journal*, *9*(3), 986–991. https://doi.org/10.1016/j.cj.2021.03.002

Silva, M. H., Silva, M. A. A., Duarte, E. R., Bonetti, R. A. T., Paludetto, A., & Miyashiro, C. F. (2024). A relação do nitrogênio com o desenvolvimento das plantas e suas formas de disponibilidade. *RECIMA21 - Revista Científica Multidisciplinar, 5*(1), Article e514762. https://doi.org/10.47820/recima21.v5i1.4762

Silva, S. A., Carvalho, F. I. F., Nedel, J. L., Cruz, P. J., Silva, J. A. G., Caetano, V. R., Hartwig, I., & Sousa, C. S. (2005). Análise de trilha para os componentes de rendimento de grãos em trigo. *Bragantia*, *64*(2), 191–196. https://doi.org/10.1590/S0006-87052005000200004

Taiz, L., Zeiger, E., Moller, I. M., & Murphy, A. (2017). *Fisiologia e desenvolvimento vegetal* (6th ed.). Artmed.

Valério, I. P., Carvalho, F. I. F., Oliveira, A. C., Benin, G., Maia, L. C., Silva, J. A. G., Schmidt, D. M., & Silveira, G. (2008). Fatores relacionados à produção e desenvolvimento de afilhos em trigo. *Semina: Ciências Agrárias*, *30*(4sup1), 1207–1218. https://doi.org/10.5433/1679-0359.2009v30n4Sup1p1207

Vesohoski, F., Marchioro, V. S., Franco, F. A., & Cantelle, A. (2011). Componentes do rendimento de grãos em trigo e seus efeitos diretos e indiretos na produtividade. *Revista Ceres*, *58*(3), 337–341. https://doi.org/10.1590/S0034-737X2011000300014

Zadoks, J. C., Chang, T. T., & Konzak, C. F. A. (1974). A decimal code for the growth stages of cereals. *Weed Research*, *14*(6), 415–421.