Bulgarian Journal of Agricultural Science, 30 (No 3) 2024, 476–481

Nitrogen doses, efficiency, and use in low-altitude hybrid corn cultivars

Rovani Marcos Rossato, Diego Nicolau Follmann*, Cristian Mateus Freiberg, Eduardo Brezolim, Mateus Vendrame and Guilherme Bergeijer da Rosa

Federal University of Santa Maria, Department of Plant Science, CEP 97105-900 Santa Maria, RS, Brazil
**Corresponding author:* diego.follmann@ufsm.br

Abstract

Rossato, R. M., Follmann, D. N., Freiberg, C. M., Brezolim, E., Vendrame, M. & da Rosa, G. B. (2024). Nitrogen doses, efficiency, and use in low-altitude hybrid corn cultivars. *Bulg. J. Agric. Sci., 30*(3), 476–481

Corn is among the main agricultural products produced in Brazil, mainly due to its importance in human and animal food. Corn productivity is mainly related to climatic conditions and nutritional management, especially concerning nitrogen. The study's objective was to evaluate the response of corn hybrids subjected to nitrogen doses in a low-altitude subtropical environment. The experiment was conducted in the agricultural year of 2019/2020 in the municipality of Santa Maria-RS. The experimental design was of completely randomized blocks in a subdivided plot. Four corn hybrids, DKB 240 PRO 3, DKB 290 PRO 3, DKB 345 PRO 3, and Ag 9025 were used as the main plot, and six doses of nitrogen, 0, 50, 100, 150, 200, and 250 kg ha^{-1} in subplots. We evaluated the number of grain rows (NR) per cob, number of grains per row (NGR), cob length (CL, cm), average grain length (GL, cm), total grain weight per cob (GWC, g), thousand-grain mass (TGM, in g), and grain yield (YIE, in kg ha^{-1}). The data were submitted to the analysis of variance (F test), and the means were compared by the Scott-Knott test at 5% of error probability and submitted to regression analysis. Cultivar Ag 9025 had the highest grain yield, associated with the highest CL, GL, GWC, TGM. The higher GL associated with high TGM compensated for the lower averages of NR and NGR for this cultivar. The maximum technical efficiency for the cultivars was 196.22 kg ha^{-1} of nitrogen. The mass economic efficiency with commercial values of the 2019/2020 harvest for the cultivars was 185.84 kg ha^{-1}.

Keywords: Zea mays L.; agronomic performance; technical and economic efficiency

Introduction

Corn (*Zea mays* L.) is the second most-produced agricultural product in Brazil, remaining behind only soybeans, mainly due to its importance in animal and human food. Corn production reached a record of 102.1 million tons of grain in the Brazilian 2019/2020 harvest, representing 40.2% of all grain production in the country (CONAB, 2020). This increase is mainly due to favorable climatic conditions, especially water availability combined with adequate fertilization management, ensuring crop productivity and sustainability (Dantas Junior et al., 2016). Nitrogen fertilization directly influences the yield of corn grains by the availability of nitrogen (N) in the soil during the crop development cycle (Bortolini et al., 2001).

Like grasses in general, corn requires high nitrogen availability in the soil in nitric (NO_3^-) and ammonia (NH_4^+) forms. However, much of the nitrogen found in the soil is in organic form, making it unavailable for plants to absorb in the short term. Nitrogen is the mineral nutrient that exerts the greatest influence on grain productivity, being an essential constituent of proteins, and directly interferes with the photosynthetic process. It is also one of the inputs that most burdens production cost (Silva et al., 2005). However, not applying N causes the reduction of productive and economic potential (Duete et al., 2009).

According to Pauletti & Motta (2019), 14.4 kg of nitrogen is required to produce one ton of corn grains. Nitrogen is the nutrient required in greater quantity by the corn crop and often becomes the most limiting nutrient for grain yield since it plays an important role in the biochemical processes of the plant (Farinelli & Lemos, 2012). Nitrogen in the soil is dynamic and unstable. Thus losses may occur due to various factors. Several coefficients must be considered to define the amount of nitrogen to be applied, such as yield expectation, type of soil to be cultivated, organic matter content, area history, previous crop, and use or not of green fertilizers (Amado et al., 2002), in addition to environmental conditions, such as the average air temperature in the day and night period, which is influenced by altitude and can interfere with the efficiency of the use of photoassimilates.

The corn genotype to be used must also be considered when defining the amount of nitrogen. There are currently several hybrids and varieties of corn available in the market that require different amounts of this nutrient. This consumption is associated with the productive potential (Rodrigues et al., 2014). Another factor that interferes with corn grain productivity is altitude. The temperature is higher in environments with low altitude, especially at night, which accelerates the plant's metabolic process. According to Durães (2007), altitude indirectly affects corn productivity, directly influencing important physiological processes, such as photosynthesis, respiration, and absorption of water and nutrients.

Producers must know the hybrid corn cultivars and the characteristics of the growing environment to adapt the nitrogen investment to be carried out in their crop, optimizing the use of the nutrient. In this context, the work aims to evaluate the agronomic performance and technical and economic viability of hybrid corn cultivars subjected to different doses of nitrogen in low-altitude subtropical environments.

Material and Methods

This study was conducted during the agricultural year of 2019/2020, in the municipality of Santa Maria – RS, located at latitude 29º41'02.31" S, longitude 53º43'57.63" W, and with an altitude of 90 m. The climate is classified as Cfa, according to the Köppen classification, characterized as a humid subtropical climate, with hot summers and no defined dry season throughout the year (Alvares et al., 2013). The soil of the experiment site is classified as 'Argissolo Vermelho Distrófico arênico' (Santos et al., 2018), with slightly undulating topography.

The preparation of the area was carried out with the winter sowing of forage turnip (*Raphanus sativus* L.). The forage turnip was desiccated 30 days before sowing with the herbicide recommended by the technical indications of the corn crop. The fertilization was carried out using a sower, with 450 kg ha^{-1} of the NPK commercial formula 5-20-20, fertilizing in the groove with 22.5 kg ha^{-1} of N, 90 kg ha^{-1} of P_2O_5, and 90 kg ha^{-1} of K_2O. The experiment was installed on September 20th, 2019. Sowing was performed adopting the no-till system. The sowing density used was 3.5 seeds per linear meter, spaced 0.5 m between lines. Sowing was carried out in the fertilized lines of the 72 plots using a manual sower and a template to keep the plants equidistant in the plot, sowing two seeds per pit. Thinning was performed after plant emergence, leaving only one plant per pit, forming a final population of 70 000 plants ha^{-1}.

The experiment was conducted in a randomized blocks design consisting of 24 treatments (4 hybrid cultivars x 6 doses of N) and three replicates, totaling 72 experimental units. The hybrid cultivars (main plot) used were DKB 240 PRO 3, DKB 290 PRO 3, DKB 345 PRO 3, and Ag 9025, associated with six doses of cover nitrogen (subplots): 0 (control without N), 50, 100, 150, 200, and 250 kg ha^{-1}, characterizing a bifactorial experiment with a subdivided plot. The hybrids used have great representativeness, being cultivated by farmers of the region.

The plots consisted of five lines with spacing between lines of 0.5 m and 4 m in length, totaling 10 m². Three central lines were considered for the evaluations, eliminating the rows of the edge and 0.5 m of the ends of the plots, with a total useful area of 4.5 m².

The cultural treatments, weed, insects pests, and disease management were carried out during the crop development following the technical indications for corn for the subtropical region of cultivation of the 2019/2020 harvest. After controlling the weeds, cover nitrogen fertilization with urea (45% N) was performed, at doses equivalent to 0 (control, where urea was not applied), 50, 100, 150, 200, and 250 kg of N ha^{-1}. The doses were fractioned into two applications. The first was performed when the plants were in the vegetative stage V3 (three leaves developed) and the second in V5-V6 (5 to six leaves developed).

Eight plants per plot located within the useful area were used for the evaluations and duly identified with labels from numbers 1 to 8 to carry out the post-harvest yield components' evaluations subsequently. These cobs were collected after the field evaluations when the plants reached physiological maturation. The character evaluations were carried out individually in the laboratory, having marked and identified the cobs of the eight plants in chronological order. The characters evaluated were the number of rows of grains (NR) and the number of grains per row (NGR) of each cob, cob length (CL in cm), grain length (GL in cm), and the grain weight per cob (GWC), and thousand-grain mass (TGM in g) weighed using an electronic scale.

The harvest was carried out on February 11th, 2020, subsequently determining the productivity of the plots. The grain weight of the eight cobs was added with the yield of the useful area of the plots to determine the yield kg ha^{-1} (YIE), with the humidity corrected to 13%.

The data collected from the evaluations were computed and submitted to the analysis of variance (F test). The means of the hybrid factor were compared using the Scott-Knott test at 5% of error probability, and the means of the dose factor were submitted to regression analysis. The maximum technical efficiency was calculated using the formula MTE= -b1/(2*b2), where b1 is the degree of the linear significant polynomial and b2 is the degree of the significant quadratic polynomial. The maximum economic efficiency (MEE) was estimated by the formula MEE= MTE+(u/(2*b2*c)), where ‘u’ is the price of urea per kg and ‘c’ the price of corn in tons. Urea and corn prices were obtained from the Companhia Nacional de Abastecimento – Conab and Emater/ASCAR for the 2019/2020 harvest.

The agronomic efficiency of nitrogen use (N) was determined by the formula AE = (PGcf – PGsf)/(QNa) expressed in kg kg^{-1}, developed by the authors Fageria & Baligar (2005), in which AE is the agronomic efficiency; PGcf, grain yield with nitrogen fertilizer; PGsf, grain yield without nitrogen fertilizer; and QNa, the amount in kg of N applied. The analyses were carried out using the SISVAR statistical program (Ferreira, 2019).

Results and Discussion

There was no significant effect for the variables analyzed based on the analysis of variance and significance of the characters of grain yield and productivity components evaluated from four corn hybrids submitted to six doses of nitrogen, regarding the interaction between hybrids and doses (Table 1). There was a significant effect by the F test at the level of 5% significance for the cultivar source of variation in all variables analyzed. There was a significant effect for the variables CL, NGR, GWC, and YIE regarding the dose source of variation. Variables NGR, GWC, and YIE had a significant effect on the block source of variation, thus making the use of random block design effective, proving that the design was properly planned.

Hybrid DKB 240 had the highest average number of grains per row (33.42), while hybrid DKB 290 had the highest average (16.47) for the number of rows per cob. Hybrids DKB 345 and Ag 9025 showed a good performance only for the variable mass of one thousand grains (449.03 g) (Table 2).

Hybrid Ag 9025 presented the highest average cob length (16.23 cm) and grain length (1.09 cm), and stood out with the highest grain weight per cob (151.58 g), forming the highest average group with hybrids DKB 290 and DKB 240. Hybrid Ag 9025 presented the highest average grain yield (8956.55 kg ha^{-1}), highlighting its performance com-

Table 1. Summary of the analysis of variance with the values of the mean squares of the sources of variation and experimental coefficient of variation (CV) for the evaluated characters, Santa Maria – RS

	CL	NR	NGR	GL	GWC	TGM	YIE
Hybrid (DF = 3)	13.63*	35.74*	441.35*	0.08*	3359.19*	40250.39*	18440329.66*
Dose (DF = 5)	12.20*	0.28 ns	70.93*	0.01 ns	3571.20*	2548.56 ns	6904089.59*
Block (DF = 3)	2.29 ns	1.48 ns	96.50*	0.06*	6542.34*	2051.23 ns	18045419.52*
D*H (DF = 15)	0.71 ns	0.82 ns	7.44 ns	0.01 ns	161.46 ns	1234.67 ns	1348322.03 ns
Error (DF = 46)	1.20	0.53	8.33	0.01	464.99	1096.51	1262574.58
CV (%)	7.27	4.97	10.37	7.76	15.61	8.07	14.20

Characters: CL: cob length, in cm; NR: number of rows; NGR: number of grains per row; GL: grain length, in cm; GWC: Grain weight per cob, in g; TGM: Thousand-grain mass, in g; YIE: Grain yield, in kg ha^{-1}. DF: degrees of freedom. *: Significant effect by the F test at the level of 5% significance. ^{ns}: Not significant.

Table 2. Scott-Knott means clustering test for the characters evaluated in four hybrid corn cultivars in a subtropical low-altitude environment, Santa Maria-RS

	CL	NR	NGR	GL	GWC	TGM	YIE
DKB 240	15.24 b	13.47 c	33.42 a	0.96 c	137.58 a	343.19 c	8224.54 b
DKB 290	14.29 c	16.47 a	25.36 c	1.04 b	143.77 a	411.42 b	7922.3 b
DKB 345	14.52 c	14.99 b	22.32 d	0.95 c	119.50 b	449.03 a	6539.22 c
Ag 9025	16.23 a	13.58 c	30.25 b	1.09 a	151.58 a	436.84 a	8956.55 a
Mean	15.07	14.63	27.84	1.01	138.11	410.12	7910.65

Characters: CL: cob length, in cm; NR: number of rows; NGR: number of grains per row; GL: grain length, in cm; GWC: Grain weight per cob, in g; TGM: Thousand-grain mass, in g; YIE: Grain yield, in kg ha^{-1}. Means not followed by the same letter in the column differ by the *Scott-Knott* test at 5% significance.

pared to hybrids DKB 240 and DKB 290, which presented intermediate yield, while DKB 345 presented the lowest grain yield (Table 2).

The superior cob length can explain the higher yield of hybrid Ag 9025 and grain length compared to the other hybrids. Ag 9025 also stood out concerning the grain weight per cob and high thousand-grain mass, which have a high relationship with the increase in grain yield in this study. Schroeder et al. (2016) also obtained the best values for the thousand-grain mass and yield for the Ag 9025 hybrid. Grain yield is controlled by the expression of many genes and can explain the prominence of some genotypes in specific environments. Additionally, the environmental conditions contribute to this process and, in this sense, any stress to which the plant is subjected, of a biotic or abiotic nature, can significantly affect the grain mass after the flowering of the corn crop (Caires & Milla, 2016).

The agricultural year of 2019/2020 suffered from the scarcity of water availability in the municipality of Santa Maria – RS, as occurred in general for the entire state of Rio Grande do Sul, thus compromising the real productive potential of crops. Performing a water balance allows a better characterization of the corn hybrid performances and their responses to the nitrogen doses used in the experiment.

Water deficiency related to the need for evapotranspiration occurred mainly from November 8th, 2019 to January 9th, 2020 (Figure 1), resulting in 62 days of uninterrupted water deficit, which led to the restriction of productive potential. In this subperiod, the plants were in the VT stages (tasseling, beginning of the reproductive phase), reaching the stages R4-R5, where the culture requires great water availability in the soil. Water deficit reduces the leaf area,

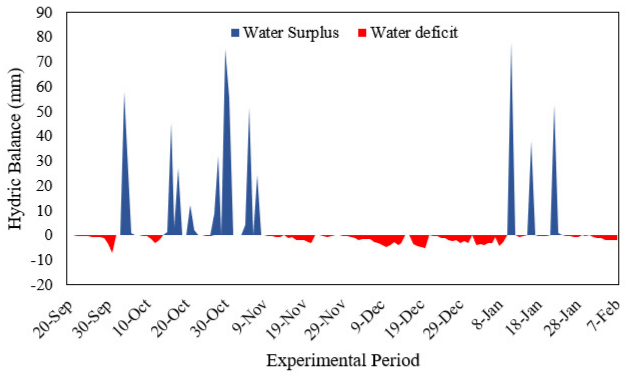

Fig. 1. Sequential water balance for surface (CAD= 75 mm) during the experiment period for the municipality of Santa Maria – RS. Source: Data taken from the National Institute of Meteorology – INMET

decreasing photosynthesis and affecting several other processes. It also changes the physical environment of crops by modifying the system's energy balance (Bergamaschi, 1992).

The regression analysis adjusted the variables cob length, number of grains per row, and grain weight per cob to a quadratic regression model that presented a better fit. The coefficient of determination (R^2) obtained in the quadratic regression model for both variables was greater than 0.84, indicating a high degree of adjustment of the equation. The number of rows per cob, the grain length, and the mass of one thousand grains showed no response means for the N doses used, unlike in work carried out by Portugal et al. (2017), who obtained an increase in the mass of one thousand grains in a positive linear way with the increase in N doses. This fact may have a direct relationship with environmental conditions, especially water restriction during crop development.

Figure 2 shows an increase in cob length, number of grains per row, and grain weight per cob as a function of the increase in N doses applied. The doses with maximum technical efficiency (MTE) were 206.83, 213.03, and 196.22 kg ha^{-1}. The maximum economic efficiencies (MEE) were 203.98, 211.27, and 185.84 kg ha^{-1}. Gazola et al. (2014) found the maximum response of cob length at the dose of 135 kg ha^{-1}. These differences between the work data and the literature may be associated with environmental factors and cultivar genetics.

Regression analysis for grain productivity was better adjusted to the linear model, with $R^2 = 0.7363$ indicating a good fit. Future studies with larger dose intervals and/or a larger number of doses should be performed to verify the maximum technical and economic efficiency of hybrid cultivars in low-altitude locations in subtropical conditions, highlighting that positive responses to the increase in nitrogen dose occurred even with water restriction.

Cândido et al. (2020) also found an increasing linear response for productivity with increasing doses of N applied, indicating that there could be responses to doses greater than 200 kg ha^{-1}. The answers obtained corroborate the fact that nitrogen is the nutrient required in greater quantity by the corn crop, often limiting grain yield and playing an important role in the biochemical processes of the plant (Fernandes et al., 2019). The efficiency of nitrogen use (Figure 3) was reduced with the increase in the dose of N.

The highest efficiency was obtained with the dose of 50 kg ha^{-1} N applied, increasing 20.60 kg in yield with every 1 kg of N applied. Doses of 200 and 250 kg ha^{-1} showed the lowest efficiencies: 5.74 and 9.18 kg kg^{-1} of N applied, respectively (Figure 3). The results of the agronomic efficiency of the use of N collaborate with those found by San-

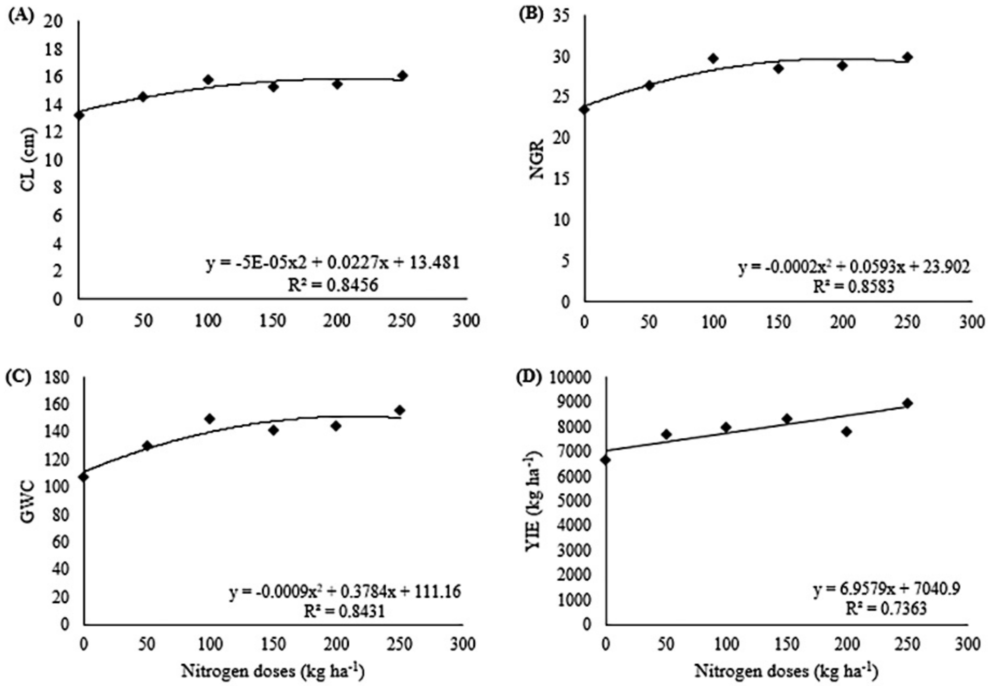

Fig. 2. Linear and quadratic regression curve for the variables cob length (CL) , number of grains per row (NGR), grain weight per cob (GWC), and grain yield (YIE) as a function of the cover N dose response, Santa Maria – RS

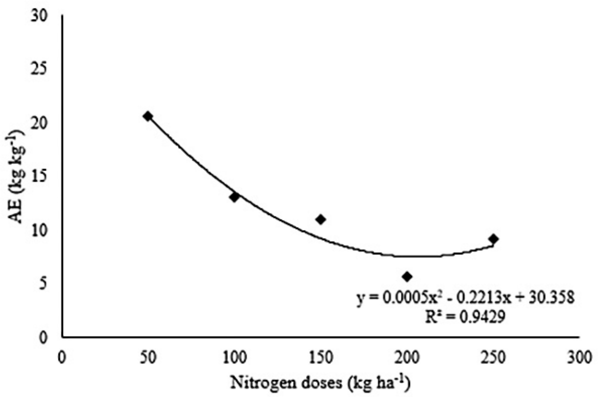

Fig. 3. Agronomic efficiency (AE) of cover nitrogen in response to grain productivity, Santa Maria – RS, 2021

goi et al. (2015), who studied the agronomic performance of corn with *Azospirillum* sp. and application of doses of mineral nitrogen. According to Farinelli & Lemos (2010), this decrease is possibly due to ammonia and nitrate losses by leaching after the nitrification process, which increases with the applied dose, and this increase can be linear or exponential.

Conclusions

Thus study showed a differentiated response for the hybrid corn cultivars for the characters CL, NR, NGR, GL, GWC, TGM, and YIE in low-altitude subtropical environments during an agricultural year with water deficit. There was a linear regression for YIE, with the dose of 250 kg of cover N as the highest average, indicating that the use of nitrogen has a direct response to the increase in corn grain productivity even with water deficit during the grain-filling period.

Cultivar Ag 9025 had the highest grain yield, associated with the highest CL, GL, GWC, TGM. The higher GL associated with high TGM compensated for the lower averages of NR and NGR for this cultivar.

The maximum technical efficiency for the cultivars was 196.22 kg ha^{-1} of nitrogen. The mass economic efficiency with commercial values of the 2019/2020 harvest for these cultivars was 185.84 kg ha^{-1}, highlighting the importance of carrying out annual calculations based on the price of nitrogen inputs and the marketing price of corn.

Acknowledgments

To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES and Conselho Nacional de Desenvolvimento Cientifico e Tecnológico – CNPq, for the financial support.

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Received: **April, 13, 2023**; *Approved*: **November, 22, 2023;** *Published:* **June, 2024**