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GROWTH, GRAIN YIELD, AND FORAGE YIELD OF MAIZE HYBRIDS FERTILIZED WITH DIFFERENT NITROGEN DOSES

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ABSTRACT

The objective of this study is to evaluate the effect of fertilization with different doses of nitrogen on the growth and yield of six maize hybrids by determining initial growth, forage fresh matter yield (FFMY), forage dry matter yield (FDMY), grain dry matter content (GDMC), and total grain yield (TGY). The study was carried out in an experimental area of ESALQ/USP in the municipality of Piracicaba/SP, between November and March 2017, using a subsurface drip irrigation system. The experimental design was of completely randomized blocks in a 6 x 4 factorial scheme (hybrids x nitrogen doses) with four replicates. Hybrids Dow 2B587, DeKalb 175 Pro, Pioneer 30F53VYHR, Dow 2B587 PW, Dow 2B633PW C4M Cruiser, and Santa Helena SHS7930 PRO2 were used. The nitrogen concentrations used were 0 , 60, 120, and 180 kg ha^{-1}. At the end of 40 days of evaluation of plant height, the best results were found for hybrids H2, H3, and H6. There was a significant interaction effect between hybrids and nitrogen doses on GDMC. The H1 hybrid presented the lowest GDMC (26.26%). All the studied variables increased linearly as nitrogen doses increased. The overall mean FFMY and FDMY were 81,953.87 and 23,993.10 kg ha^{-1}, respectively.

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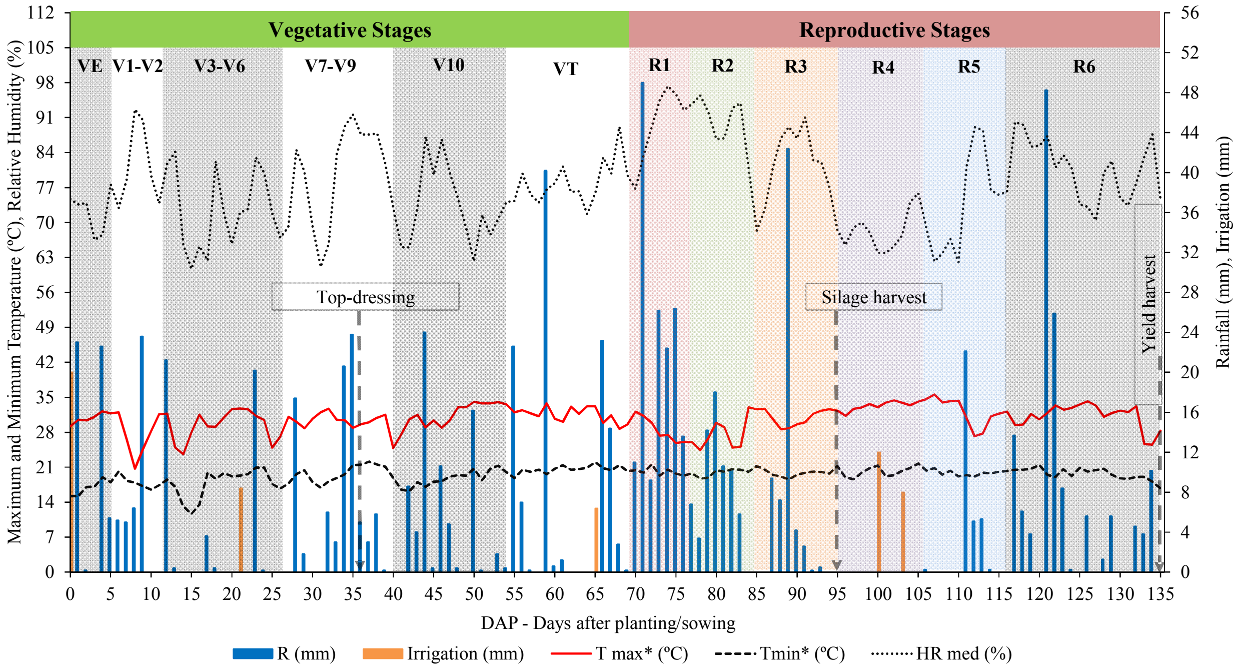
INTRODUCTION

Maize is one of the most important crops worldwide and, although Brazil is the third largest producer of maize globally, grain yield is still limited (Lima *et al*., 2016). The factors that affect yield are genetic (hybrids), soil fertility, soil nutrition, and fertilization (Lujan *et al*., 2015).Irrigated maize cultivation has increased significantly in recent years, leading to changes in crop management and creating a more intensive production system to compensate for the high costs (Garcia *et al*., 2017). However, higher grain yields can be achieved in maize using hybrids adapted to different environmental conditions and by the intensive use of nitrogen fertilizers, which improve the nutritional quality of the product (Guedes *et al*., 2017). In addition, irrigation is used to reduce the costs per unit produced (Al-Ghobari & Dewidar, 2018).Nitrogen contributes significantly to the increase in grain yield in maize crops because it assumes important function in the structural part of cytochromes and chlorophyll (Wang *et al*., 2016). The average amount of nitrogen used in maize in Brazil, United States, and



Legend: E, emergence; V1–V2, initial growth; V3-V6, establishment of plant growth; V7-V9, establishment of the number of kernel rows; V10, rapid vegetative growth; VT, tasseling; R1, flowering and pollination; R2, blister; R3, milk; R4, dough; R5, dent; R6, physiological maturity.

Figure 1. Temperature, rainfall, and irrigation in different maize development stages, Piracicaba, São Paulo, Brazil, 2016–2017

China is 60 kg ha^{-1}, 150 kg ha^{-1}, and 130 kg ha^{-1}, respectively (Lopes *et al.*, 2017).Costa *et al.* (2017), used nitrogen fertilization as top-dressing in dry farming in the region of Cariri, Ceará, Brazil, and found that grain yield increased by 506 kg ha^{-1} using ammonium sulfate fractionation in two applications instead of one, and the maximum yield was 4,108 kg ha^{-1}. However, in an irrigated system implemented in the south of Brazil, the average yield of maize was 18,081 kg ha^{-1} (Vian *et al.*, 2016), evidencing the edaphoclimatic susceptibility and the large productive potential of maize. In addition to the importance of maize in grain production, maize forage is one of the best options to maintain milk production in winter keeping the same cattle herd and grazing area (Costa *et al.*, 2014; Noce *et al.*, 2014; Guedes *et al.*, 2017). Maize forage has been used not only in dairy cattle production but also in sheep production in the Northeast of Brazil (Cruz *et al.*, 2016). A previous study reported that the dry matter (DM) and crude protein of maize forage in São Cristovão, Sergipe, Brazil, were 26.0% and 6.71%, respectively (Cruz *et al.*, 2016).

Using swine manure with nitrogen concentrations of 0, 64, 128, 192, and 256 kg, fresh matter (FM) and DM of maize forage increased by 24,910 and 5,590 kg ha^{-1}, respectively, from the lowest to the highest dose of nitrogen, and the highest forage fresh matter yield (FFMY) and forage dry matter yield (FDMY) were 50,820 Kg ha^{-1} and 19,070 Kg ha^{-1}, respectively. (Moreira *et al.*, 2015). Guedes *et al.* (2017) found that FM increased by 3,915 kg from 0 to 80 kg ha-1 of nitrogen, and the maximum FFMY was 19,882 kg ha^{-1}. In three years of cultivation, the authors observed that the highest FDMY was 18,327 kg ha^{-1} using 100 m³ of vinasse, which was 8,304 kg higher than that obtained with the lowest nitrogen dose (Silva *et al.*, 2016a). The objective of this study is to evaluate the effect of fertilization with different nitrogen doses on variables in six maize hybrids, including growth, FFMY, FDMY, total grain yield (TGY), and grain dry matter content (GDMC) in the region of Piracicaba, São Paulo, Brazil.

MATERIALS AND METHODS

The experiment was conducted from November 2016 to March 2017 in Piracicaba, São Paulo, Brazil, in an experimental area located on the campus of ESALQ/USP (latitude, 22º 42' S, longitude, 47º 38' W; altitude, 546 m). The climate of the region is Cwa according to Köppen's classification: high-altitude subtropical, with hot summers, few frosts, and the predominance of rains in the summer (Alvares *et al.*, 2013). The amount of rainfall (mm) and irrigation (mm), maximum and minimum temperature (ºC), and relative air humidity in the study period are shown in Figure 1.The soil of the region is classified as Eutroferric Red Nitosol and Latosol (Weil & Brady, 2017). The chemical analysis of the soil at the 0–0.40 m depth indicated the following composition: pH 5.3 (H2O); 72 mg dm^{-3} of P; 9.4 mmolc dm^{-3} of K; 3.9 cmolc dm^{-3} of Ca; 1.8 cmolc dm^{-3} of Mg; 3.1 cmolc dm^{-3} of H+Al; 0.2 cmolc dm^{-3} of Al. The experimental design was of completely randomized blocks in a 6 x 4 factorial scheme [six maize hybrids x four nitrogen doses (0, 60, 120, and 180 kg ha^{-1})], with four replicates. The experiment consisted of 96 experimental plots (3.2 m x 3.85 m, 12.32 m²), totaling 1182.72 m². The hybrids DOW 2B587 (H1), DEKALB 175 Pro (H2), PIONEER 30F53VYHR (H3), DOW 2B587 PW (H4), DOW 2B633PW C4M CRUISER (H5), and Santa Helena SHS7930 PRO2 (H6) were used. Liming was performed in September 2016 with a dose of 500 kg ha^{-1}. After that, manual weeding was performed and 250 mL of herbicide (glyphosate) was applied using six 20-L sprayers, and the application was repeated one week before planting to eliminate the remaining weeds. The experiment was sown on November 5, 2016, with fertilizer formulation 0-14-14 (N, P_2O_5, K_2O) at a dose of 400 kg ha^{-1}. Fertilization as top-dressing was performed on December 10, 2016 with different nitrogen doses in each treatment. Cultural practices included only two manual weedings.

Table 1. Mean plant height (cm) of maize hybrids in the study period, Piracicaba, São Paulo, Brazil, 2016

	Height of maize hybrids (cm)						MG
	H1	H2	H3	H4	H5	H6	
8 DAE	9.33 A	8.77 A	10.69 A	9.13 A	8.75 A	9.73 A	9.4
16 DAE	22.88 A	20.38 A	25.19 A	21.19 A	19.69 A	21.59 A	21.8
24 DAE	40.44 A	36.19 A	44.66 A	41.68 A	36.81 A	41.19 A	40.1
32 DAE	78.25 B	75.19 B	108.6 A	82.63 B	72.63 B	84.25 B	83.5
40 DAE	110.4 D	144.7 AB	141.2 ABC	132.7 BC	127.4 CD	151.6 A	134.7
MG	52.23 C	57.04 BC	66.06 A	57.46 BC	53.06 C	61.67 AB	57.9

*The means followed by the same letters in each line were not significantly different from each other using Tukey's test at a level of significance of 5%. DAE, days after emergence.

Table 2. Forage yield and grain dry matter content of maize hybrids, Piracicaba, São Paulo, Brazil, 2016–2017

Variables	Maize hybrids						MEAN
	H1	H2	H3	H4	H5	H6	
FFMY	81955.4a	78785.7a	88562.5a	85249.9a	79232.1a	77937.5a	81953.9
FDMY	25225.1a	23806.1a	25908.9a	23837.1a	22540.7a	22640.6a	23993.1
GDMC (%)	29.26 b	36.52 ab	31.99 b	36.17 ab	43.82 a	43.16 a	36.82

*The averages followed by the same letter do not differ statistically amongst themselves considering a Tukey test at 5% significance. FFMY, forage fresh matter yield; FDMY, forage dry matter yield; GDMC, grain dry matter content.

Table 3. Average grain yield par hectare, from each hybrid, Piracicaba-SP, 2016/2017

Variable (kg ha^{-1})		Maize hybrids						Average
		H1	H2	H3	H4	H5	H6	
Doses of	0	5,559	5,661	5,379	6,222	8,137	7,140	6,350
	60	6,715	8,124	6,799	8,343	9,191	8,654	7,971
	120	8,122	9,905	9,303	9,000	10,643	10,218	9,532
	180	7,927	11,088	10,616	10,715	10,531	12,595	10,579
TGY		7,081 c	8,694 ab	8,024 bc	8,570 abc	9,625 a	9,651.8 a	8,608

*The averages followed by the same letter do not differ statistically amongst themselves considering a Tukey test at 5% significance.

The plots were irrigated using drip tapes with a spacing of 0.50 m per emitter, at an average flow rate of 1 L h^{-1}, with three rows per plot between the rows. Irrigation was controlled using six tensiometers installed at a depth of 0.20 m. An irrigation depth of 20 mm was used for germination. The mean soil moisture tension levels were measured every four days, and subsequent irrigation was performed when the levels exceeded 10 kPa (Benevute *et al.*, 2016). An irrigation depth of 20 mm was used for germination. The irrigation depth (ID) to be applied was determined by the difference between the volumetric moisture at field capacity (θ_{cc}) and the current volumetric moisture (θ_i) multiplied by the effective root depth (Z) (400 mm). The moisture at field capacity (θ_{cc}) was considered the moisture corresponding to the value of Ψ_m= 10 kPa, according to Benevute *et al.* (2016). The θ_i values were estimated using the soil water retention curve. The curve was obtained using Richards extractor in the Laboratory of Soils and Water Quality of ESALQ/USP and adjusted using the equation proposed by Van Genuchten (1980).

$$\theta i = 0.2938 + \left[\frac{(0.4934 - 0.2938)}{\left[1+(0.113\Psi_m)^{1.3211}\right]^{0.2431}}\right]; \text{ (R}^2\text{=1.00 and p<0.01)} \quad (1)$$

Where
θ_i is the current volumetric humidity (cm^3 cm^{-3})
Ψ_m is the current matrix potential of water in the soil (kPa).

The accumulated ID in the study period was 54.76 mm distributed in five irrigation events (Figure 1). Moreover, in this period, the accumulated rainfall was 871.5 mm, with 407.8 mm in the vegetative stage and 463.72 mm in the reproductive stage (until R6, corresponding to the harvest stage and the end of the experimental period).

Plant growth was evaluated every 8 days starting on day zero after emergence (November 10, five days after sowing). Subsequent measurements were made at 8 days after emergence (DAE) (11/18/2016), 16 DAE (11/26/2016), 24 DAE (12/4/2016), 32 DAE (12/12/2016), and 40 DAE (12/20/2016). Plant height (PH) was evaluated, and the growth curves of the evaluated treatments were generated. Maize forage was harvested at 95 days after sowing on February 8, 2017. The limit for measurement of PH was established at 0.2 m from the soil, with the harvest of one linear meter of plants spaced at 0.7 m, corresponding to an area of 0.7 m² in each plot. On average, seven plants were measured per linear meter, with an inter-plant spacing of 15 cm and a population density of 100,000 plants ha^{-1}. FFMY (in kg ha^{-1}), FDMY (in kg ha^{-1}), and GDMC (in percentage) were measured. On March 20, 2017, maize was harvested to determine the TGY in Kg ha^{-1}, production harvest, and the amount of forage in one linear meter of each plot (treatment). After harvesting, the plants were dried in a forced circulation air oven at 65 ºC until reaching a moisture content of 13–14%. After that, harvest yield was determined in 0.7 m² and represented as yield per hectare. The experimental data were subjected to analysis of variance using the factorial test at a level of significance of 5%. When significant differences were found, the Tukey's test for the hybrids and regression analysis for the nitrogen doses was used. The statistical analyses were performed using the Assist at software version 7.7 beta® (Francisco & Carlos, 2016).

RESULTS AND DISCUSSION

PH was significantly affected by the nitrogen doses, with a linear increase in growth as the nitrogen doses increased (PH =

55.67 + 0.0251 x nitrogen doses, p>0.05). Hybrid 6 presented the highest PH at 40 DAE followed by hybrids H3 and H2 (Table 1). Neumann *et al.* (2017) reported that there was a positive correlation between PH and biomass production in six maize hybrids, and the highest plants presented the highest yields. In our sample, the rapid initial growth of H6, H2, and H3 significantly contributed to crop yield at the end of the growth cycle (Tables 2 and 3).

Large variations in PH as a function of the nitrogen doses were not detected because at 40 DAE, nitrogen had been applied for only 15 days. However, there were small variations in PH between 32 and 40 DAE. Furthermore, Guedes *et al.* (2017) indicate that fertilization at planting strongly affects PH and spike height and increase both spike FM and total FM. Fertilization at planting was similar between the treatments.

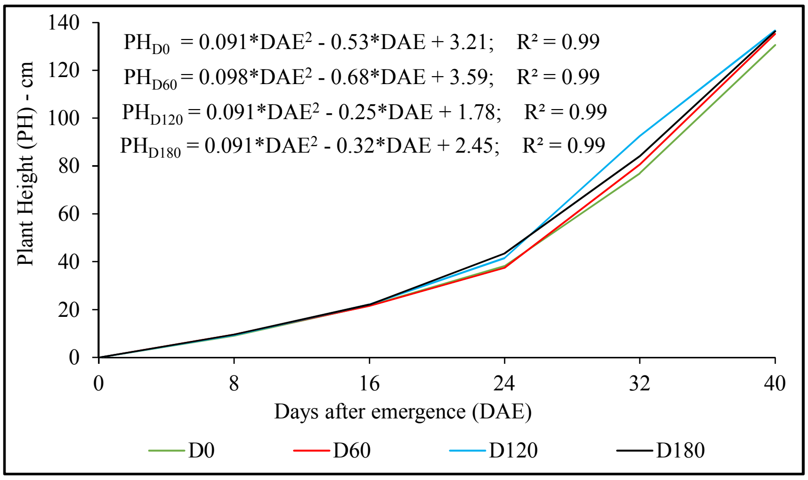


Figure 2. Mean growth curves as a function of nitrogen doses, Piracicaba, São Paulo, Brazil, 2016. Nitrogen concentrations: D0, 0 kg ha^{-1}; D60, 60 kg ha^{-1}; D120,120 kg ha^{-1}; D180, 180 kg ha^{-1}

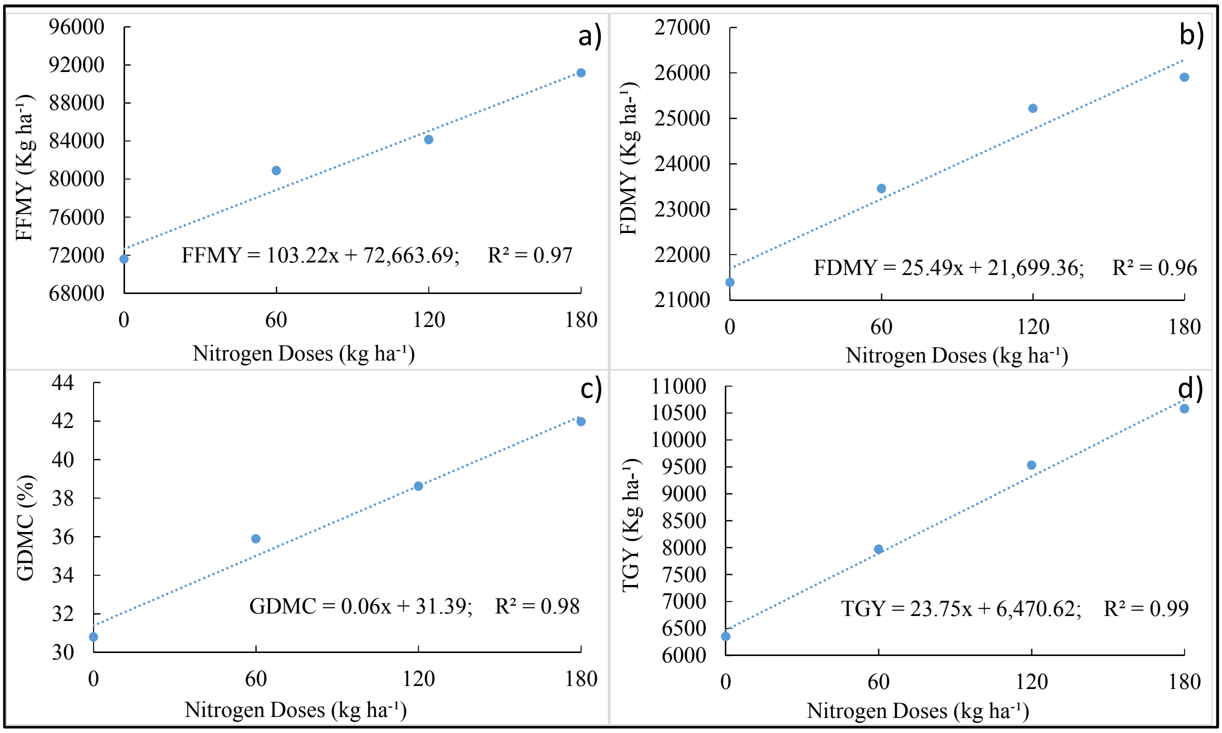


Figure 3. Regression analysis of forage fresh matter yield (FFMY), forage dry matter yield (FDMY), grain dry matter content (GDMC), and total grain yield (TGY). Piracicaba, São Paulo, Brazil, 2015–2016

Therefore, PH is a parameter that can be used early in the evaluation of maize hybrids. Figure 2 shows that the growth curves of the hybrids studied here were not significantly affected by the used nitrogen doses. Conversely another study showed that the hybrids DKB 390 YG and DKB 390 PRO had their heights affected by the N doses of 0, 30, 60, and 90 Kg ha^{-1}; however, plant height was measured at the end of the growth cycle, which might have been favored by the longer growth period in these two hybrids.

At 40 DAE, there were no significant differences in PH between the treatments. At later time points, significant differences were not detected because of the difficult access of farm workers to the crops. The mean FFMY, FDMY, and GDMC are shown in Table 2. FFMY and FDMY were not significantly different between the hybrids. The mean FFMY (23,993.1 kg ha^{-1}) was slightly higher than the values found by Silva *et al.* (2016a) (18,327 kg ha^{-1}), Moreira *et al.* (2015)

(19,070 kg ha^{-1}), and Guedes *et al*. (2017) (19,882 kg ha^{-1}).Hybrids H5 and H6 achieved the highest TGY followed by hybrids H2 and H4 (Table 3). TGY was lower in hybrid 1 compared to the other hybrids, approximately 35% and 36% lower than that in H5 and H6, respectively. In addition, the GDMC of hybrids 5 and 6 was higher than that of hybrid 1.All hybrids presented a linear increase in growth, evaluated by regression analysis with linear fits and high correlation coefficients (Figure 3). The highest FDMY was observed at the highest nitrogen dose (180 kg ha^{-1}), corroborating the results of Souza *et al*., (2016), who evaluated sweetcorn in Chapadão do Sul, Mato Grosso do Sul, Brazil, and found that the efficiency of water use was highest at 168.4 kg ha^{-1} of nitrogen (Figure 3b).As in the present study, Silva *et al*. (2016b) observed that TGY increased linearly, with a maximum value of 9,011.7 kg ha^{-1} at 90 kg ha^{-1} of nitrogen. In our sample, the highest TGY (10,745.6 kg ha^{-1}) was obtained at the highest nitrogen dose (180 kg ha^{-1}). This variable was slightly higher in our study because of different climatic and edaphic conditions and the use of different hybrids between the studies. Moreover, the relationship between fertilization and yield becomes more significant as plants reached their production peak. Freire *et al*. (2010) found that TGY was increased linearly as the nitrogen concentrations increased, with values of 15 and 16 Mg ha^{-1} at the highest dose (200 kg ha^{-1}). In contrast, a study that evaluated urea fertilization as top-dressing in maize and found that the highest yield of immature cobs was 14.8 Mg ha^{-1} using straw (Silva & Silva, 2003). TGY in both studies was higher than that in the present study because of the FM content, which would have decreased considerably if converted to DM, approaching the result of the present study. The increase in spike yield as the nitrogen concentration is increased may be because this nutrient has a stronger effect on plant growth and development, which affects yield in cases in which nitrogen is available to the crop (Wang *et al*., 2018). Therefore, the higher nitrogen doses may have prolonged the effect of this nutrient during maize growth and contributed to the higher yields. However, yield is decreased when maize hybrids are treated with high nitrogen doses, which may be because the supply exceeds crop requirements, resulting in the unnecessary uptake of this nutrient (Kitonyo *et al*., 2018). The nutritional requirements of maize need to be met because of the high rate of nutrient uptake from the soil. In this respect, high levels of nitrogen are required by this crop and this nutrient limits yield. For this reason, crop requirements can be met by adequate supplementation of nitrogen (Wang *et al*., 2018; Mesbah *et al*., 2017).The results indicated that the highest TGY was achieved at the highest nitrogen dose evaluated (180 Kg ha^{-1}). Nevertheless, whether higher doses produced higher TGY was not determined. Notwithstanding, this study demonstrates that maize is responsive to nitrogen fertilization, and higher doses cause higher yields.

Conclusions

The Dow 2B587 hybrid had a comparatively lower grain yield, with lower GDMC compared to hybrids Dow 2B633PW C4M Cruiser and Santa Helena SHS7930 PRO2.Nitrogen had a beneficial effect on the hybrids, and all studied variables increased linearly as nitrogen doses increased. Hybrids 2, 3, and 6 had the highest plant heights at 40 DAE. The evaluated hybrids had increasing responses to nitrogen, although full growth was not reached with the applied doses, evidencing the need to use larger doses in irrigated maize to identify the inflection point in the growth curve. The chosen hybrids strongly affected yield in response to fertigation.

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