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Research Article

Effects of nitrogen fertilization and plant densities on growth and yield traits for new commercial yellow maize hybrids

Abd El-Razek, U.A.[1], El-Gazzar I.A.I. [2] and Khedr S.E. [2,*]

[1] Agronomy Department, Faculty of Agriculture, Tanta University, Egypt.
[2] Maize Research Dept., Field Crops Research Institute, ARC, Giza, Egypt.
* Correspondence: Khedr S.E.

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Abstract:

New yellow maize hybrids require optimized agronomic practices to maximize their productivity. A field experiment was conducted at Sakha Agricultural Research Station, Egypt, during the 2023 and 2024 summer seasons to evaluate the response of four maize hybrids (SC181, SC182, SC183, and SC185) to three nitrogen fertilization levels (80, 120, and 160 kg N/fed) and three plant densities (20,000, 25,000, and 30,000 plants/fed). The study was laid out in a randomized complete block design with a split-split plot arrangement in three replications. Combined analysis across both seasons indicated significant effects of nitrogen, plant density, and hybrid on all studied traits. Grain yield, plant height, and ear height increased with higher nitrogen levels and plant densities. Conversely, higher plant densities decreased ear length, kernel number per row, and 100-kernel weight. Days to 50% silking decreased with higher nitrogen levels and increased with density. Grain yield significantly improved by 8.92% and 14.64% with 120 and 160 kg N/fed compared to 80 kg N/fed, respectively. Similarly, increasing plant density to 25,000 and 30,000 plants/fed enhanced yield by 8.45% and 9.98%, respectively. SC185 recorded the highest grain yield, followed by SC182, SC183, and SC181. Stability analysis revealed that SC182, SC183, and SC185 were relatively stable across environments, while SC181 was environment specific. It is recommended to grow these hybrids under 160 kg N/fed and sown it with density of 30,000 plants/fed for maximum productivity.

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop worldwide, after wheat and rice. It is cultivated under a wide range of environmental conditions due to its high adaptability. The genetic improvement and development of new maize hybrids rely heavily on the integration of appropriate agronomic practices to optimize productivity. Among these, nitrogen fertilization and plant density are key factors influencing maize growth and grain yield (Huseyin and Omer, 2010).

Nitrogen (N) is a vital macronutrient required in large amounts for plant development and yield formation. Determining the optimal N rate for new maize hybrids is critical to enhance productivity while minimizing negative environmental impacts (Shi et al., 2016). Numerous studies have reported that increasing N rates can significantly improve yield components, such as ear length, number of kernels per row, and grain weight, up to a certain threshold beyond which no further benefit is observed (El-Sheikh, 1998; Arfa, 2012; Davidson et al., 2015). Over-application of nitrogen, however, leads to fertilizer waste, economic losses, and environmental risks such as nitrate leaching.

Plant density is another crucial agronomic factor affecting light interception, water and nutrient use efficiency, and overall crop architecture. Optimal plant density varies depending on hybrid maturity, soil fertility, moisture availability, and row spacing (Argenta et al., 2001; Boomsma et al., 2009). High planting densities often enhance grain yield per unit area, although excessive densities may reduce per-plant productivity due to competition (Antonietta et al., 2014; El-Naggar, 2015). Therefore this study aims to: Determine the appropriate nitrogen level and plant density required to achieve maximum grain yield for four newly registered commercial yellow maize hybrids (SC181, SC182, SC183, and SC185). Assess the yield stability of these hybrids across different environments using multi-environment trials, thereby identifying the most stable and adaptable genotypes.

2. Materials and Methods

The field study was conducted during the two consecutive summer growing seasons of 2023 and 2024 at Sakha Agricultural Research Station, located in Kafr Elsheikh Governorate, Egypt (31.10° N latitude and 30.94° E longitude). The experimental site is characterized by a clayey soil with moderate fertility under typical Mediterranean climatic conditions.

Four newly released yellow maize (*Zea mays* L.) single-cross hybrids (SC181, SC182, SC183, and SC185) developed by the Maize Research Department, Field Crops Research Institute, Agricultural Research Center (ARC), Egypt, were evaluated in this study. The experiment was laid out in a split-split plot design within a randomized complete block arrangement (RCBD) with three replications. The main plots were assigned to three nitrogen fertilization levels: 80, 120, and 160 kg N/feddan (1 feddan = 4200 m²), applied as urea (46% N) in two equal doses—before the first and second irrigations. Sub-plots were allocated to three

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plant densities: 20,000, 25,000, and 30,000 plants/feddan, which were achieved by adjusting the spacing between hills (30, 25 and 20 cm) on rows that were 80 cm apart. Sub-subplots were allocated to the four maize hybrids. Each experimental unit consisted of four ridges, each 6 meters long and 0.8 meters wide.

Phosphorus and potassium fertilizers were applied at land preparation at rates of 30 kg P_2O_5 and 24 kg K_2O per feddan, respectively. All recommended agronomic practices for maize production were followed uniformly across treatments, including land preparation, irrigation, pest and weed control.

Meteorological data collected from the experimental site during the two growing seasons indicated typical seasonal variation in temperature, humidity, wind speed, and pan evaporation. Notably, the second season experienced higher average maximum temperatures and relative humidity, particularly during July and August. These climatic conditions are expected to have influenced plant growth and development during critical reproductive stages.

Soil samples collected before sowing from a 0–30 cm depth revealed that the soil texture was clayey in both seasons, with slight seasonal variation in chemical properties such as pH, electrical conductivity (EC), available nitrogen (as ammonium and nitrate), phosphorus, and potassium contents. Overall, the soil was moderately alkaline (pH > 8) with acceptable fertility status, which supports maize cultivation.

Data were recorded from the inner two rows of each plot on the following traits: days to 50% silking, plant height (cm), ear height (cm), ear length (cm), number of kernels per row, 100-kernel weight (g), and grain yield (ardab/feddan) at 15% grain moisture content (1 ardab = 140 kg). Standard methods were used to measure each trait according to maize research protocols.

Data were subjected to combined analysis of variance (ANOVA) across the two years according to the split-split plot design described by Gomez and Gomez (1984), using the SAS software package (SAS Institute, 2008). Significance of main effects and interactions was determined at the 0.05 probability level. To assess the yield stability of the four maize hybrids, six different stability analysis methods were employed across the 18 resulting environments (3 nitrogen levels × 3 plant densities × 2 years) according to Eberhart and Russell (1966) for regression coefficient (bi) and deviation from regression (S^2d_i),Francis and Kannenberg (1978) for coefficient of variation (CV%),Wricke (1962) for covalence (W^2_i),Lin and Binns (1988) for superiority index (Pi), Huehn (1990) for mean absolute rank difference ($Si^{(1)}$) and variance of ranks across environments ($Si^{(2)}$).

These analyses were conducted to determine both the adaptability and stability of grain yield performance of the tested hybrids under varying nitrogen levels and plant densities across different environmental conditions.

3. Results and Discussion

The combined analysis of variance across two growing seasons revealed that the year effect (Y) was significant or highly significant for all studied traits, indicating a considerable influence of seasonal climatic conditionsparticularly temperature and humidityon maize performance, as shown as in Table (1).

Both nitrogen fertilization (N) and plant density (D) had significant or highly significant effects on all measured traits, confirming their critical roles in determining plant growth, yield components, and final grain yield. Similarly, hybrid differences (H) were highly significant for all traits, reflecting genetic variability among the tested maize hybrids.

Several significant interactions were also observed. Notably, the D × Y interaction was highly significant for ear length and number of kernels per row, implying that plant density response varied between years. Additionally, the D × N interaction significantly affected days to 50% silking, ear length, and number of kernels per row, suggesting that the plant density effect was modified by nitrogen level.

Moreover, a significant D × N × Y interaction was observed for 100-kernel weight, indicating that the combined effect of plant density and nitrogen rate was influenced by seasonal conditions. Interactions involving hybrids were particularly important:

•The H × Y interaction significantly affected plant height, ear height, grain yield, and number of kernels per row.

•The H × N interaction was significant for grain yield.

•The H × D interaction showed significance for days to 50% silking, plant height, ear height, ear length, and number of kernels per row.

•The three-way H × N × D interaction significantly influenced plant height and grain yield, while the four-way H × N × D × Y interaction was significant for grain yield alone.These findings highlight the importance of evaluating genotype × environment × management interactions when assessing maize performance. The significant hybrid × environment interactions, particularly for grain yield, emphasize the need for selecting stable genotypes suitable for variable environmental conditions.

These results are consistent with previous studies which reported significant effects of nitrogen levels, planting density, and their interactions with genotypes on maize growth and yield components (Mosa, 2001; Shakarami and Rafiee, 2009; Arfa, 2012; Mashiqu et al., 2013; El-Naggar et al., 2016; El-Naggar et al., 2017; Shrestha et al., 2018; Abd El-Aty et al., 2019).

Table 1. Mean squares due to nitrogen levels (N),plant densities(D), hybrids (H) and their interactions for seven traits across two years (Y).

S.O.V.	df	Days to 50 % silking	Plant height (cm)	Ear height (cm)	Grain yield (ard/fed)	Ear length (cm)	Number of kernels / row	100 kernel weight (g)
Y	1	163.62*	10388.9**	2460.37**	421.34 *	64.46**	1692.32**	1030.79**
Rep/Y	4	10.75	1247.89	415.63	36.88	4.21	0.88	13.47
N	2	96.33**	11621.68**	7971.68**	234.02**	106.21**	261.74**	571.29**
NY	2	2.81	79.46	346.16	0.14	1.96	22.06	28.74
Ea	8	1.19	496.99	188.16	6.55	0.52	7.98	14.21
D	2	13.52**	2776.19*	1909.47**	128.20**	476.32**	1246.42**	533.42**
DY	2	1.86	101.53	5.180	2.75	20.10**	42.00**	6.38
DN	4	4.82**	297.65	212.25	5.38	9.43**	69.21**	60.52
DNY	4	1.17	71.94	36.34	0.65	0.43	17.40	22.84**
Eb	24	0.69	206.67	141.96	4.87	0.82	6.75	5.36
H	3	46.84**	22570.72**	7462.04**	141.15**	4.76**	120.20**	443.38**
HY	3	0.45	511.53**	335.62*	109.54**	2.2	111.39**	7.08
HN	6	0.42	152.16	62.62	12.14*	0.31	3.34	1.05
HD	6	1.76**	252.16*	171.01*	2.50	2.26**	7.42*	0.97
HNY	6	0.45	131.24	46.54	5.49	0.231	1.72	3.79
HDY	6	0.17	147.68	41.48	1.16	0.678	6.04	6.06
HND	12	0.37	255.25*	87.27	9.57*	0.533	2.42	5.42
HNDY	12	0.62	86.04	37.02	11.70*	0.750	3.67	4.91
Ec	108	0.56	111.27	66.23	5.78	0.50	3.51	3.92

Table 2 presents the combined effects of nitrogen levels, plant densities, and four new commercial hybrids on seven agronomic traits across two growing seasons. The table illustrates how these factors collectively influence traits such as days to 50% silking, plant height, ear height, ear length, number of kernels per row, 100-kernel weight, and grain yield. These results provide valuable insights for identifying the optimal management practices to achieve the highest productivity of the studied hybrids under varying environmental conditions.

Nitrogen fertilization had a significant effect on all studied traits across plant densities, hybrids, and seasons. Increasing nitrogen levels from 80 kg N/fed (N_1) to 120 kg N/fed (N_2) and 160 kg N/fed (N_3) led to a significant reduction in days to 50% silking by 2.93% and 3.30%, respectively, indicating that higher nitrogen rates promote earlier flowering. This finding is consistent with previous studies by Mosa (2001), Abd El-Aty and Darwish (2006), Arfa (2012), and El-Mouslhy (2019).

Grain yield (ardab/feddan) significantly increased with rising nitrogen levels, with N_2 and N_3 improving yield by 8.92% and 14.64% over N_1, respectively. This improvement was accompanied by noticeable increases in plant height (3.92% and 11.54%), ear height (2.03% and 11.95%), ear length (0.61% and 12.06%), number of kernels per row (2.01% and 9.82%), and 100-kernel weight (2.67% and 16.15%) with N_2 and N_3, respectively.

In conclusion, the application of 160 kg N/fed (N_3) resulted in the highest mean values for all traits, followed by 120 kg N/fed (N_2), confirming the positive response of maize hybrids to increased nitrogen availability. These findings align with those reported by Khalil (2007), Arfa (2008), Mosa et al. (2010), and Abd El-Aty et al. (2019), who noted that increasing nitrogen fertilization improves yield and yield components by enhancing vegetative and reproductive growth parameters.

Plant density had a significant effect on all measured traits across nitrogen levels, hybrids, and seasons. Increasing plant density from 20,000 plants/fed (D_1) to 25,000 (D_2) and 30,000 plants/fed (D_3) led to noticeable increases in days to 50% silking (by 0.95% and 1.36%), plant height (0.92% and 5.93%), ear height (0.71% and 8.33%), and grain yield (8.45% and 9.98%), respectively. These findings highlight the positive effect of higher plant density on overall biomass and yield accumulation, as supported by Chen et al. (2010) and Al-Naggar et al. (2017). However, elevated plant densities were associated with significant reductions in ear length, number of kernels per row, and 100-kernel weight. For example, the lowest density (D_1) recorded the highest values for these traits, suggesting that reduced intra-plant competition enhances grain filling and kernel development. These results are consistent with those of Mosa (2001), Mashiqa et al. (2013), El-Mouslhy (2019) and Mahmoud (2021), and who reported that increasing plant density may negatively affect reproductive traits due to competition for light, nutrients, and water.

Table 2. Combined effect of nitrogen levels, plant densities, and hybrids on seven traits across years.

Nitrogen level (N)	Days to 50 % silking	Plant height (cm)	Ear height(cm)	Grain yield (ard/fed)	Ear length (cm)	Number of kernels /row	100 kernel weigh(g)
N 1	63.87	278.11	157.29	24.44	17.91	36.75	32.49
N 2	62.00	280.72	160.48	26.62	18.02	37.49	33.36
N 3	61.76	301.30	176.09	28.02	20.07	40.36	37.74
L.S.D 0.05	0.39	8.54	5.25	0.98	0.27	1.07	1.43
Plant density							
D1	62.06	278.11	161.20	24.83	21.34	42.51	37.44
D2	62.65	280.11	162.69	26.93	18.45	37.88	34.11
D3	62.91	301.30	170.77	27.31	16.21	34.21	32.04
L.S.D 0.05	0.28	4.08	4.08	0.75	0.29	0.87	0.77
Hybrid							
SC181	62.57	303.53	174.68	26.62	18.97	39.29	33.78
SC182	61.94	291.18	175.12	24.91	18.50	36.50	38.75
SC183	63.84	257.03	152.29	25.38	18.34	32.40	33.05
SC185	61.81	295.08	157.40	28.53	18.86	39.60	32.53
L.S.D 0.05	8.20	4.01	3.09	0.91	0.19	0.68	0.74

Higher densities improved grain yield, but they compromised some yield components. Therefore, optimal plant population must balance between maximizing yield and preserving yield quality traits.The mean performance of the four new commercial maize hybrids across nitrogen levels, plant densities, and seasons revealed clear genotypic differences for all studied traits. Regarding earliness, hybrid SC185 recorded the shortest time to 50% silking (61.81 days), followed by SC182 (61.94 days), while SC183 was the latest (63.84 days).

For plant height, SC181 was the tallest hybrid (303.53 cm), followed by SC185 (295.08 cm), whereas SC183 was the shortest (257.03 cm). In terms of ear height, SC182 had the highest value (175.12 cm), while SC183 had the lowest (152.29 cm).The highest yield was obtained by SC185 (28.53 ardab/fed), followed by SC181 (26.62 ardab/fed), whereas SC182 and SC183 had the lowest yields (24.91 and 25.38 ardab/fed, respectively).As for ear length, SC181 had the longest ears (18.97 cm), slightly exceeding SC185 (18.86 cm), while SC183 and SC182 had shorter ears (18.34 and 18.50 cm, respectively).The number of kernels per row was greatest in SC185 (39.60), followed closely by SC181 (39.29), while SC183 recorded the lowest number (32.40). Interestingly, SC182 had the heaviest 100-kernel weight (38.75 g), followed by SC181 (33.78 g), while SC185 had the lightest kernels (32.53 g).

These results demonstrate that SC185 was the most productive and earliest hybrid, excelling in yield, earliness, ear length, and kernel number per row. SC181 combined high yield with superior plant height and yield components, while SC182 excelled in kernel weight and SC183 was distinctive for its short stature and early maturity. These findings agree with previous research highlighting significant genetic variability among maize hybrids (El-Naggar et al., 2020; Mosa et al., 2022).

The interaction between nitrogen levels and hybrids revealed that increasing nitrogen fertilization from 80 to 160 kg N/fed led to a progressive increase in grain yield across all hybrids, except SC183, where yield peaked at 120 kg N/fed. SC185 showed the best response to high nitrogen applications presented in Figure 1.

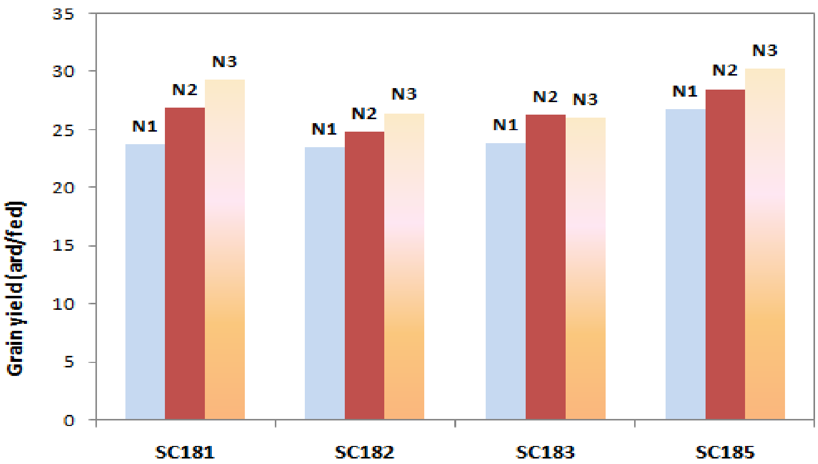

Figure 1. Effect of the interaction between hybrids× nitrogen levels on grain yield.

Moreover, the three-way interaction among hybrids, nitrogen levels, and plant densities highlighted that the highest yield (31.43 ardab/fed) was achieved by SC185 under the combination of 160 kg N/fed and 30,000 plants/fed. Conversely, the lowest yield (20.49 ardab/fed) was recorded for SC182 under the lowest input combination. These results support the recommendation of using 160 kg N/fed and 30,000 plants/fed to maximize productivity of the tested hybrids, as shown as in Figure 2.

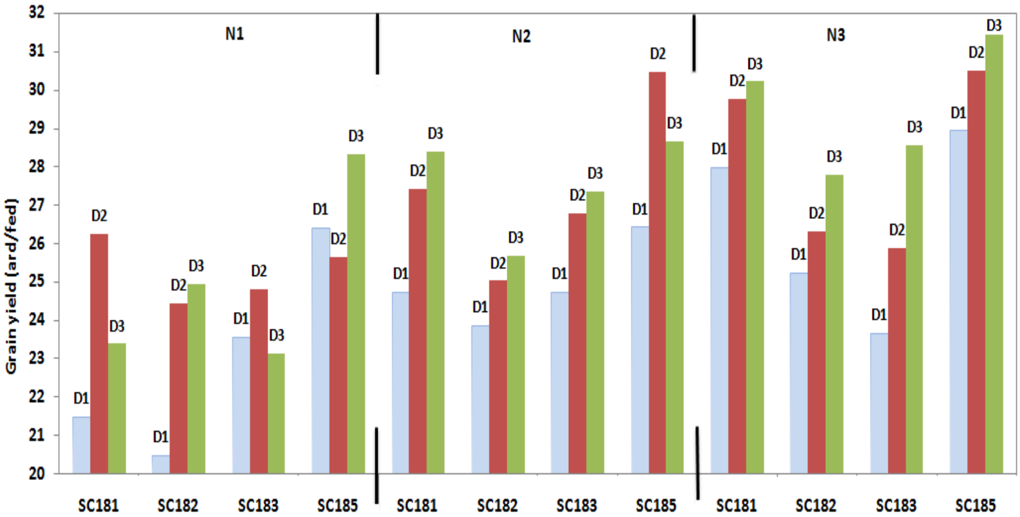

Figure 2. Effect of the interaction between hybrids × nitrogen levels × plant densities for grain yield (ard/fed) across two years.

Stability analysis across 18 environments (3 nitrogen levels × 3 plant densities × 2 years) revealed that SC182, SC183, and SC185 were the most stable hybrids according to multiple parametric (e.g., regression coefficient b_i, deviation from regression S^2di) and nonparametric indicators (e.g., CV%, Wi^2, Pi, $Si^{(1)}$, and $Si^{(2)}$). In contrast, SC181 showed instability in most measures and should be recommended only for specific, well-characterized environments, as shown as in Table 3.

Table 3. Estimates of parametric and Wi 2 nonparametric stability measure of four new commercial hybrids for grain yield.

Hybrid	CV%	b_i	S^2d_i	W_i^2	P_i	$S_i^{(1)}$	$S_i^{(2)}$
SC181	16.03	1.67*	0.42	81.04	8.65	0.09	1.29
SC182	12.18	1.11	0.33	37.25	13.52	0.08	0.59
SC183	8.18	0.65*	0.04	43.25	9.79	0.09	0.88
SC185	8.05	0.57*	1.68*	75.69	0.93	0.05	0.88
Mean	11.11	1.00	0.61	59.30	8.22	0.07	0.91

These results align with findings by Mosa et al. (2021, 2024), Shojaei et al. (2021), and Matongera et al. (2023), who emphasized that high yield and wide adaptability are essential goals in hybrid maize breeding programs.

4. Conclusion

The study demonstrated that both nitrogen fertilization and plant density have significant effects on the growth and yield of new yellow maize hybrids. Grain yield, plant height, and ear height improved with increased nitrogen levels up to 160 kg N/fed and plant density up to 30,000 plants/fed. However, higher plant densities negatively impacted certain yield components, such as ear length and kernel weight. Among the tested hybrids, SC185 produced the highest yield, while SC182, SC183, and SC185 exhibited greater yield stability across different environments compared to SC181. Based on these results, it is recommended to cultivate these high-performing hybrids using 160 kg N/fed and a planting density of 30,000 plants/fed for optimal maize production.

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