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Research Article

Effect of Plant Density and Nitrogen Fertilization on the Productivity of Some Yellow Maize Hybrids

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Abstract:

The study investigated the effects of plant density, nitrogen fertilization rates, and maize hybrid selection on the growth, yield, and its components of two yellow maize hybrids (SC 168 and SC 180) over two growing seasons (2021 and 2022) at the experimental farm of Gemmeiza Agriculture Research Station in Egypt. A split-split plot design with three replications was used. Main plots were three plant densities, sub-plots were three nitrogen levels, and sub-sub-plots were the two hybrids. Growth attributes, yield components, and grain yield were evaluated. Results showed the SC 180 hybrid had higher 100-kernel weight (in first season) and grain yields than SC 168, indicating the importance of high-yielding hybrid selection. Increasing nitrogen from 40 to 80-120 kg/feddan increased 100-kernel weight (in first season) and grain yield in both seasons, emphasizing proper nitrogen fertilization. Higher planting densities of 25.000 and 30.000 plants/feddan increased grain yield versus 20.000 in both seasons, suggesting potential yield gains from optimized densities. Two and three-way interactions between factors significantly impacted yield variables, indicating nitrogen and density effects depending on the hybrid and vice versa. Combinations of SC 180, high nitrogen, and high density produced the numerically highest 100-kernel weight and grain yield overall in the second season.

1. Introduction

Maize (*Zea mays* L.) is a globally significant cereal crop that plays a pivotal role in food security and eco-nomic development. Nitrogen application and plant density are critical factors that profoundly influence maize characteristics and productivity (Fathy et al., 2019; Malaza et al., 2023; Omer et al., 2023). Numerous studies have investigated the effects of these factors on various maize cultivars, plant densities, and hybrid varieties, providing insights into optimizing maize production.

In Egypt, maize plays a vital role in bread making, livestock and poultry feed production, and various industrial processes, including starch and oil extraction. Despite its versatility and importance, Egypt faces challenges in meeting the increasing demand for maize due to population growth and limited arable land availability. In the 2021 growing season, Egypt cultivated approximately 2.8 million faddan (one faddan equals 4200 m^2): yielding an average of 23.6 ardab/fad (one ardab equals 140 kg) and producing 9.2 million tons of maize. However, local production only fulfills approximately 48-50% of the consumption demand.

Previous research has demonstrated that maize cultivars exhibit varying responses to nitrogen application and plant density. Fathy et al. (2019) reported that the SC 173 cultivar produced taller plants, longer ears, and a larger number of kernels per row than the TWC 352 cultivar under similar conditions. In contrast, TWC 352 exhibited larger ear diameters, more rows per ear, higher 100-kernel weights, higher kernel weights per ear, and higher ear, grain, and biological yields per unit area compared to SC 173. These findings highlight the importance of cultivar selection in maximizing maize productivity under different nitrogen regimes and plant densities.

Plant density has been extensively studied as a critical factor influencing maize growth and yield. Numerous studies have reported that increasing plant density within optimal ranges can enhance maize productivity. Malaza et al. (2023) found that higher plant densities, up to 57.143 plants per hectare, resulted in increased leaf area index (LAI): higher aboveground dry biomass (up to 21.53 t/ha): and higher grain yield (up to 7.17 t/ha). Similarly, Wang et al. (2020) observed that increasing plant density from 55.000 to 90.000 plants per hectare increased grain yield. Sibonginkosi et al. (2020) reported that increasing plant density from 44,444 to 57.143 plants per hectare increased plant height, cob height, thousand-kernel weight, and grain yield. Worku et al. (2020) and Agayo et al. (2021) also found that plant density significantly influenced plant height and grain yield, although the effects on other traits varied among studies. Furthermore, El-Rouby et al. (2021) and Piao et al. (2022) noted that increasing plant density within specific ranges (65.000 to 85.000 plants per hectare and 70.000 to 80.000 plants per hectare, re-sportively) resulted in higher grain yields. Zhang et al. (2022) observed a parabolic trend in grain yield as plant density increased from 60.000 to 90.000 plants per hectare. These findings collectively suggest that optimizing plant density is crucial for enhancing maize productivity by maximizing resource utilization and photosynthetic efficiency.

In addition to plant density, nitrogen fertilization plays a vital role in determining maize productivity. El-Rouby et al. (2021) reported that increasing nitrogen fertilization levels from 140 to 270 kg N per hectare resulted in higher grain yields. Paudel et al. (2021) found that nitrogen levels significantly affected plant height, ear length, ear diameter, number of kernels per row, and grain yield, although they did not influence days to 50% tasseling and days to 50% silking. Zhang *et al*. (2022) also observed that increasing nitrogen levels from 120 to 240 kg N per hectare increased grain yield. Conceptualization et al. (2023) investigated the interaction of nitrogen fertilization rates (0, 50, 100, and 150 kg N per hectare) and plant densities (55, 111, and 222 plants per square meter). They found that the highest grain yield (3.211 and 3.263 kg per hectare) and total biomass (11.464 and 11.760 kg per hectare) were obtained with a nitrogen rate of 150 kg per hectare and a density of 222 plants per square meter. Worku et al. (2020) reported that while maize yield contributing traits were not significantly affected by the interaction of nitrogen and density, stover and grain yields were influenced by this interaction. Absy and Abdel-Lattif (2020) and Paudel et al. (2021) also observed significant interactive effects of nitrogen fertilizer, plant density, and maize cultivars on various traits, although the specific effects varied among studies.

This study aims to integrate the findings from these previous studies to provide a comprehensive understanding of the effects of nitrogen fertilization and plant density on maize characteristics and productivity across different cultivars, hybrids, and environmental conditions. By synthesizing insights from multiple studies, we can develop strategies to optimize nitrogen use efficiency, enhance maize yields, and contribute to sustainable agricultural practices that support food security and economic growth under experimental conditions.

2. Materials and Methods

Two field experiments were carried out at the Experimental Farm of Gemmeiza Agriculture Research Station, Agricultural Research Center (ARC), Egypt during 2021and 2022 summer growing seasons. This investigation aimed to detect the response of two maize hybrids to different levels each of nitrogen fertilization and plant densities as well as their interactions

The research was conducted over two summer growing seasons (2021 and 2022) at the experimental farm of Gemmeiza Agriculture Research Station, Agricultural Research Center (ARC): Egypt.

The soil at the experimental site had a clay texture in both the 2021 and 2022 seasons, with near-neutral pH values ranging from 8.05 to 8.30, moderate electrical conductivity between 2.30 and 2.34 dS/m, and low organic matter content of 1.80 to 1.85%. Major nutrients were available at suitable levels, with available nitrogen ranging from 30.79 to 31.80 mg/kg, available phosphorus from 6.01 to 7.01 mg/kg, and available potassium from 119.00 to 121.02 mg/kg. Environmental conditions included highest solar radiation in June 2021 (260.97 MJ/m²) and lowest in October 2021 (75.08 MJ/m²): minimal rainfall with the highest amount of 2.1 mm in August 2021 and several months with 0 mm, wind speeds ranging from 0.4 to 0.8 m/sec in 2021 and 0.5 to 0.8 m/sec in 2022, maximum air temperatures peaking in July 2022 at 52.8°C and lowest in October 2021 at 27.1°C, and highest dew points in August at 22.4°C in 2021 and 22.9°C in 2022, indicating high humidity during these months.

A split-split plot design in a randomized complete block arrangement with three replications was employed. The main plots were assigned to three plant densities (D): the sub-plots were designated for three nitrogen levels (N): and the sub-sub-plots were allocated to two maize hybrids (V).

Each plot consisted of four rows, 6 meters long and 0.8 meters apart. Plant densities were achieved by varying the spacing between hills: 20 cm spacing for 20.000 plants per faddan, 25 cm spacing for 25.000 plants per faddan, and 30 cm spacing for 30.000 plants per fad-dan. Two plants were sown per hill and thinned to one plant per hill before the first irrigation to attain the desired plant densities. Three nitrogen levels were examined: 40 kg (N1): 80 kg (N2): and 120 kg (N3) of nitrogen per faddan. Nitrogen was applied as urea (46%) in two equal doses before the first and second irrigations. Additionally, calcium superphosphate was applied at 30 kg of P_2O_5 per faddan, and potassium sulfate at 24 kg of K_2O per faddan. Both fertilizers were incorporated into the soil during preparation and before sowing. The first irrigation was applied 21 days after sowing, with subsequent irrigations scheduled at intervals of 12-14 days.

Two yellow maize hybrids (V) were selected for the study:

1. Single Cross 168 (SC 168)
2. Single Cross 180 (SC 180)

Both hybrids were released by the Maize Research Department of the Agricultural Research Center in Egypt.

Yield and Yield Components Data Collection

Plants from the second and third rows were harvested, and grain yield was adjusted to 15.5% moisture. Data was collected for the following yield components:

1. Ear length (cm): Mean ear length measured from 5 ears per plot.
2. Ear diameter (cm): Average ear diameter obtained from 5 random ears per plot.
3. Number of rows per ear: Average number of rows per ear, calculated from 5 random ears per plot.
4. Number of kernels per row: Average number of kernels per row, calculated from 5 random ears per plot.

5. 100-Kernel weight (g): Randomly selected from shelled grains of each plot and adjusted to 15.5% grain moisture content.

6. Grain yield (ardab/feddan): Recorded at harvest by adjusting the grain yield per plot to 15.5% grain moisture content and converting to grain yield per faddan (1 ardab = 140 kg, 1 faddan = 4200 square meters).

3. Results

3.1. Planting density effect

In both seasons, the three tested planting densities did not significantly effect on the number of rows/ear and number of kernels/row in two seasons.

Sustained those recorded by El-Bana and Gomaa (2000) and Abdou et al. (2012). These results were also recorded by El-Shahed et al. (2013).

Shown in the Fig. (1 a & b) Data also revealed that the effect of plant density on 100kernels weight was significant in both seasons. Grain yield was significantly affected by plant density in both seasons and their combined, whereas the increase in plant density caused a significant increase in grain yield. The high grain yield was obtained at D3 30.000 plants/fed followed by D2 25.000 plants/fed and D1 20.000 plants/fed in both season and combined. The same trend was recorded by Fathy et al., (2019): Absy and Abd El lattif (2020): Wang et al., (2020): Asibi et al., (2022) who found, increase in grain yield due to increasing maize plant density.

3.2. Nitrogen level effect

The results showed that nitrogen fertilizer levels had no significant effect on the number of rows/ear and number of kernels/row in both season. The results concerning the number of rows/ear are in agreement with those recorded by Abd El-Maksoud and Sarhan (2008) as well as Mansour and Abd El-Maksoud (2009). However, El-Bana and Abdou et al. (2012) and El-Sobky et al. (2014) found that increasing N levels had no significant effect on number of rows/ear and number of kernels/row.

Data presented in Fig. (1 a & b): showed that the 100 kernels weight was significantly affected by nitrogen levels in both seasons. Regarding Fig. (1 a & b): exhibited that the grain yield/fed was significantly increased by increasing nitrogen levels in both seasons. Increasing nitrogen levels from 40 to 80 and 120 kg N/fed. increased grain yield from 24.08, 27.78 and 31.62, respectively in first season to 22.07, 26.15 and 32.32 ard/fed., respectively in second season.

3.2. Maize hybrids effect

Results in Fig. (1 a & b) cleared that differences between two maize hybrids in number of rows/ear and number of Kernels were highly significant in both seasons. These results were mainly due to the differences in the genetically made up of maize hybrid under study.

These results are in accordance with, Kamara et al., (2015): Fathy et al., (2019): Abd EL-Aty et al., (2019) Absy and Abd El-lattif (2020).

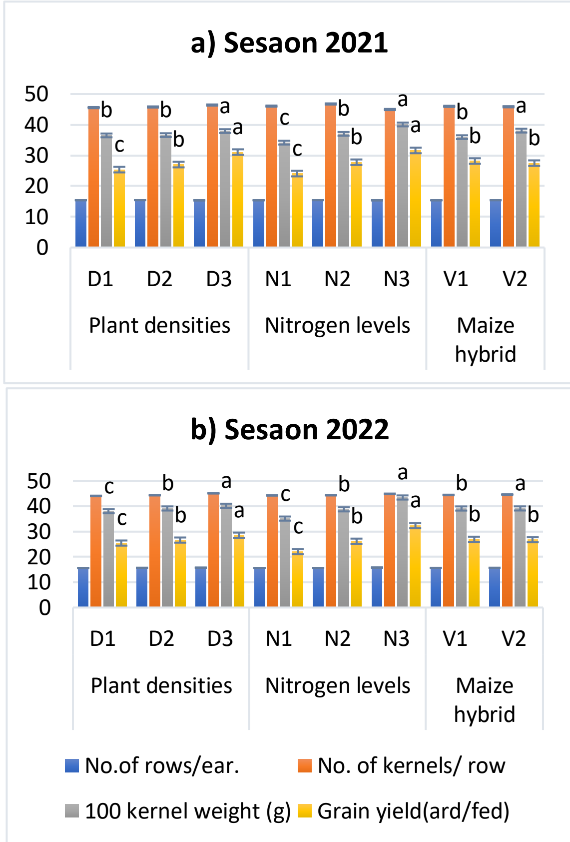

Figure 1 a & b. Effect of Maize Hybrids, Nitrogen Levels, and Planting Densities on No. of rows/ear, No. of kernels/ear, 100-Kernel weight and grain yield in seasons 2021 and 2022.

Data also showed that the differences between two maize hybrids were Significant in both seasons, the same results were obtained by Saied et al., (2008): Yosra et al., (2009): Fathy et al., (2019): Absy and Abd Ellattif, (2020).

3.4. Interaction effect

Figures 2 (a & b) and 3 illustrate the effect of interactions between nitrogen levels (N): plant densities (D): and maize hybrids (V) on several yield parameters, including the number of rows per ear, kernels per row, 100-kernel weight, and grain yield over the 2021 and 2022 growing seasons. These results highlighted significant trends and variations influenced by the interactions among nitrogen, plant density, and hybrid types, providing insights for optimizing maize yield under different agronomic conditions.

3.4.1. Number of Rows per Ear

The data reveals that the number of rows per ear generally increases with higher nitrogen levels across both seasons, indicating a statistically significant response to nitrogen application (Figure 3).

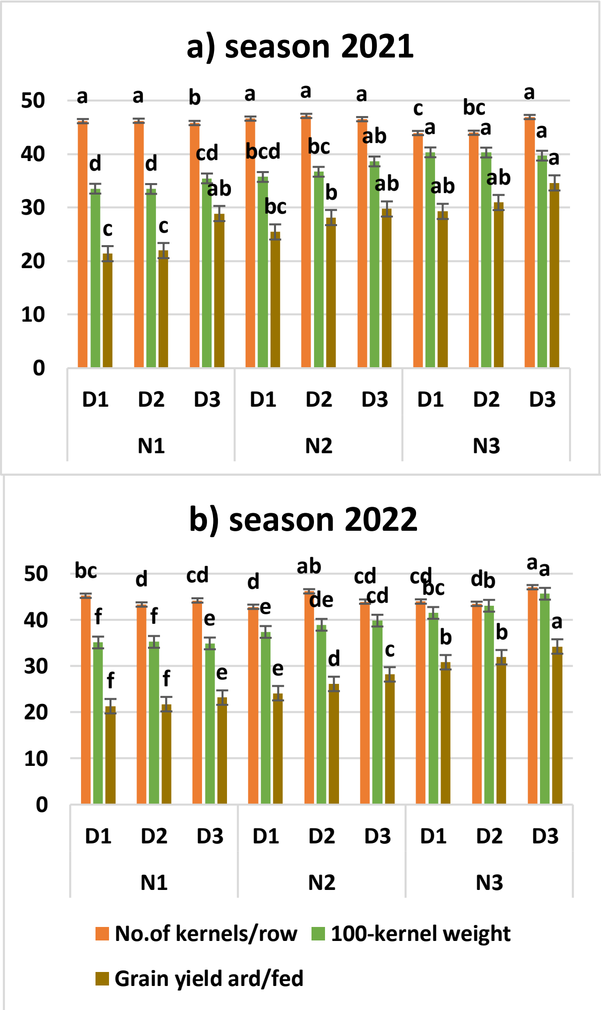

Figure 2 a & b. Effect of interactions between Nitrogen Levels (N) and plant densities (D) on No. of kernels/ear, 100-Kernel weight and grain yield in seasons 2021 and 2022.

For instance, under N3 conditions (120 kg N/fad): both hybrids (V1 and V2) exhibited higher row counts, with V1 showing the highest row count at N3 in 2021. This suggests a positive correlation between nitrogen availability and row development, likely due to enhanced nitrogen supporting growth. However, the impact of plant density on the number of rows per ear was less consistent and not statistically significant (Figure 2): as there were minimal differences observed between densities D1, D2, and D3 in both years.

In contrast, the combination of hybrid V1 with the lowest nitrogen level (N1) and the highest planting density (D3) in 2022 recorded the lowest number of rows per ear (15.20) (Figure 3): suggesting that low nitrogen levels combined with high planting densities may restrict ear development due to competition for limited nutrients. This finding underscores that while nitrogen significantly enhances the number of rows per ear, planting density alone has a limited effect on this parameter.

3.4.2. Number of Kernels per Row

The number of kernels per row demonstrates a clear trend of increasing with higher nitrogen levels across both seasons, with the highest kernel count observed at N3 (Figures 2 and 3). In 2022, hybrid V1 combined with the highest nitrogen level (N3) and highest planting density (D3) produced the maximum kernel count (47.00): while in 2021, the combination V1-N2-D3 produced 49.00 kernels per row. This suggests that the interaction of nitrogen and density positively impacts kernel formation, with higher nitrogen rates enhancing reproductive development.

Statistically, the number of kernels per row varied significantly with nitrogen and planting density interactions, particularly for V1 (Figure 3). This response indicates that nitrogen availability directly supports kernel formation, while higher planting densities might enhance this effect by promoting a denser canopy, influencing the micro-environment within the crop stand.

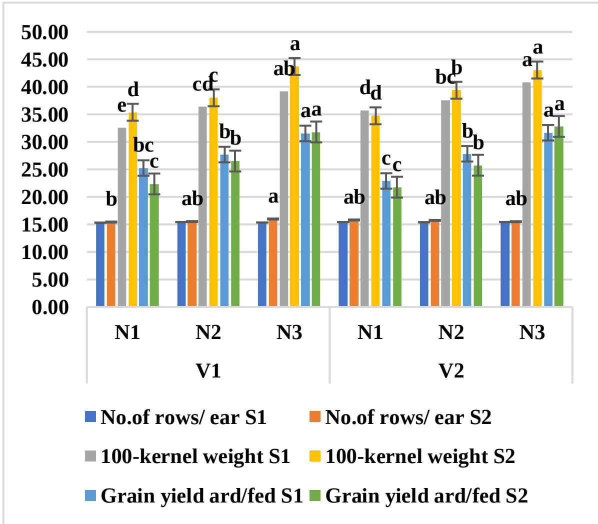

Figure 3. Effect of interactions between Maize Hybrids (V), Nitrogen Levels (N), on No. of rows/ear, No. of kernels/ear, 100-Kernel weight and grain yield in seasons 2021 and 2022.

3.4.3. 100-Kernel Weight

The data shows a progressive increase in 100-kernel weight with higher nitrogen levels (N1 < N2 < N3) across both seasons (Figure 4). In particular, hybrid V2, especially under the N3D3 treatment, achieved the highest kernel weights, with a significant increase in 2022 compared to 2021. The effect of plant density on kernel weight is also notable; higher densities (D3) appear to support greater kernel weights, likely due to enhanced competition that drives plants to allocate more resources toward seed development.

Across both hybrids, the interaction between nitrogen and density was statistically significant (Figure 5): as evidenced by the higher kernel weights in 2022, where environmental conditions may have been more favorable for kernel development. The V2-N3-D3 combination consistently recorded the highest kernel weights across both years, highlighting the optimal conditions for maximizing kernel weight. Conversely, the combination of V1 with N1 and D2 produced the lowest kernel weights, indicating that both higher nitrogen levels and higher planting densities are crucial for enhancing kernel weight in maize.

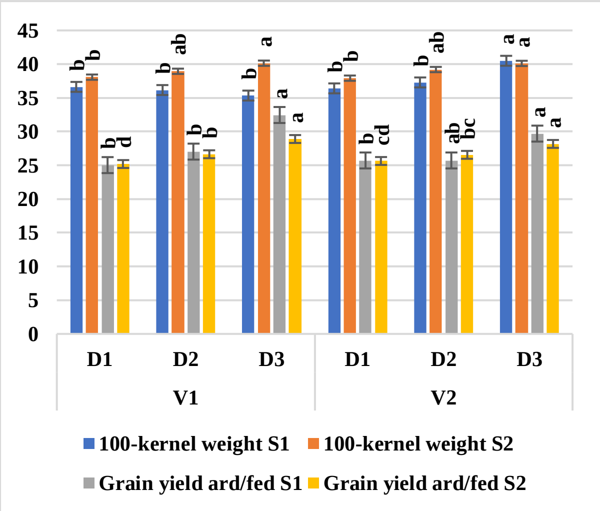

Figure 4. Effect of interactions plant densities (D) and maize Hybrids (V) on 100-Kernel weight and grain yield in seasons 2021 and 2022.

3.4.4. Grain Yield (ard/fad)

Grain yield per feddan showed a strong, statistically significant response to increased nitrogen levels, particularly at the N3 level, across both hybrids and seasons (Figures 2 and 4). Both V1 and V2 demonstrated increased yields with higher nitrogen levels, with the highest yields observed under the N3D3 treatment in 2022, reaching 34.61 ard/fed in 2021 and 34.23 ard/fed in 2022. This suggests that nitrogen plays a critical role in promoting biomass and grain production, especially when paired with optimal planting densities.

Hybrid V2 consistently produced higher grain yields than V1, particularly under high-density conditions (D2 and D3) (Figure 5). This observation indicated that V2 may be more efficient in utilizing nitrogen and converting it into yield under dense planting conditions, possibly due to genetic traits that enhance its response to nitrogen. The yield advantage of V2 over V1 was more pronounced in 2022, which may have benefitted from better growing conditions. This suggests a potential interaction effect where environmental factors, alongside nitrogen and density, influence hybrid performance.

3.4.5. Seasonal Variation and Environmental Influence

Across all measured parameters, the data from the 2022 season generally showed higher values compared to 2021, indicating that the environmental conditions in 2022 may have been more favorable for maize growth and development (Figures 2, 3, 4, and 5). Parameters such as 100-kernel weight and grain yield were consistently higher in 2022, particularly under the N3D3 treatment, which yielded optimal results for both hybrids. This suggests that the seasonality factor plays a crucial role, with variations in rainfall, temperature, or other climatic conditions possibly contributing to the enhanced productivity observed in 2022.

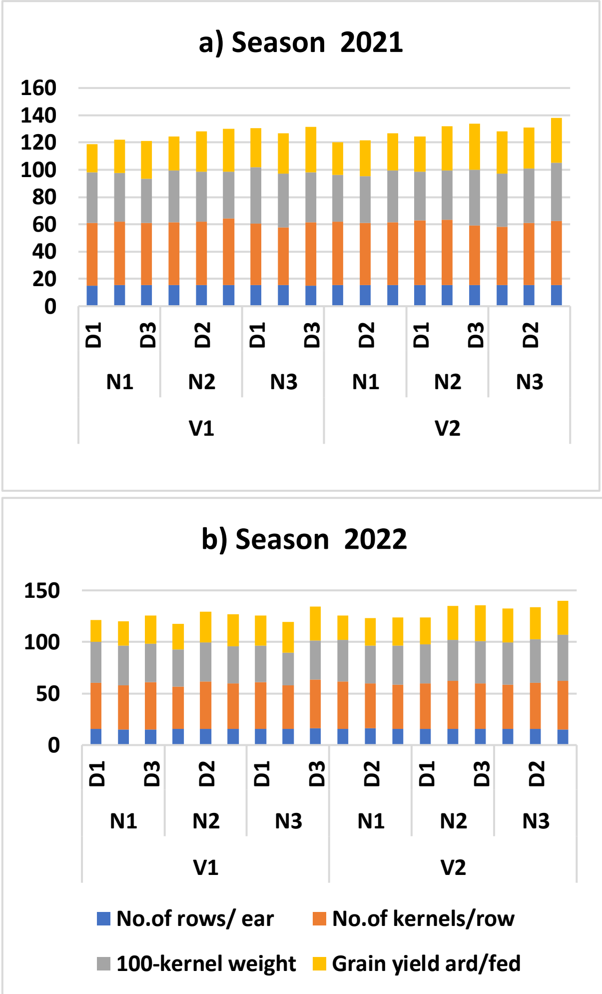

Figure 5 a & b. Main Effects and Interactions of Maize Hybrids, Nitrogen Levels, and Planting Densities on Yield Components and Grain Yield.

4. Discussion

The results indicated that planting density did not significantly affect the number of rows per ear or the number of kernels per row across both seasons, aligning with findings by El-Bana and Gomaa (2000): Abdou et al. (2012): and El-Shahed et al. (2013). However, planting density significantly influenced 100-kernel weight and grain yield in both seasons and when combined across years. This effect was observed in the increased grain yield as planting density rose, with the highest yield at D3 (30.000 plants/fed): followed by D2 (25.000 plants/fad): and the lowest at D1 (20.000 plants/fed). This trend is consistent with studies by Fathy et al. (2019): Absy and Abd El Lattif (2020): Wang et al. (2020): and Asibi et al. (2022): which similarly reported increased maize grain yield with higher planting densities. This response is likely to result from the increased plant population leading to enhanced canopy coverage, which may improve light interception, water use, and ultimately biomass production, thereby boosting grain yield.

Nitrogen fertilizer levels did not have a statistically significant effect on the number of rows per ear or the number of kernels per row, supporting previous studies by Abd El-Maksoud and Sarhan (2008) and Mansour and Abd El-Maksoud (2009). Similarly, El-Bana and Abdou et al. (2012) and El-Sobky et al. (2014) also reported no significant effect of nitrogen on these yield components. However, nitrogen levels significantly influenced 100-kernel weight and grain yield across both seasons, as seen in Figure 1 (a & b). Increasing nitrogen from 40 to 80 and then to 120 kg N/fed progressively increased grain yield, with the highest yields observed at the N3 level (120 kg N/fed) across both seasons. This increase suggests that nitrogen is crucial for biomass production and grain filling in maize, as it plays a fundamental role in plant metabolism, chlorophyll production, and the synthesis of proteins, which directly impact yield.

The study found significant differences between the two maize hybrids, S.C. 180 and S.C. 168, in terms of the number of rows per ear and number of kernels per row across both seasons, which are likely due to genetic differences between the hybrids. These findings are in line with results from Kamara et al. (2015): Fathy et al. (2019): and Abd EL-Aty et al. (2019): which highlighted the impact of genetic factors on maize yield components. Moreover, S.C. 180 consistently exhibited superior performance in grain yield and 100-kernel weight compared to S.C. 168, particularly under high nitrogen levels and dense planting conditions. This indicated that S.C. 180 may have a genetic advantage in utilizing nitrogen efficiently, resulting in enhanced reproductive development and yield potential.

Figures 2 (a & b) and 3 depict significant interaction effects between nitrogen levels, planting densities, and maize hybrids on key yield components, including the number of rows per ear, kernels per row, 100-kernel weight, and grain yield. For instance, the number of rows per ear increased with higher nitrogen levels but was minimally affected by planting density alone. The highest number of rows was observed in V1 at N3 in 2021, suggesting that nitrogen levels, rather than planting density, predominantly influence row formation in maize.

The number of kernels per row also increased with higher nitrogen levels, and the interaction between nitrogen and planting density was statistically significant, particularly for hybrid V1, indicating that higher nitrogen and planting density can enhance kernel formation. Similarly, 100-kernel weight increased progressively with nitrogen levels and higher densities, with the V2-N3-D3 combination producing the highest weights. Grain yield showed a significant response to both nitrogen levels and planting density across both hybrids and seasons, with the N3D3 treatment consistently yielding the highest output. This underscores the importance of combining high nitrogen levels and planting density to maximize grain yield.

Across all measured parameters, the 2022 season consistently recorded higher values than 2021, as shown in Figures 2, 3, 4, and 5. This suggests that environmental conditions in 2022, such as rainfall and temperature, were more conducive to maize growth and development. For instance, 100-kernel weight and grain yield were notably higher in 2022, particularly under the N3D3 treatment, indicating that favorable environmental conditions play a substantial role in enhancing yield. These findings highlight the importance of seasonality in crop management, as the effectiveness of nitrogen and density adjustments may vary depending on yearly environmental fluctuations.

5. Conclusion

This study underscores the critical importance of optimizing nitrogen levels, planting density, and hybrid selection to maximize maize yield components. The interactions between maize hybrids, nitrogen application rates, and planting densities significantly influenced both 100-kernel weight and grain yield across the two growing seasons. Higher nitrogen levels (120 kg N/fad) combined with the highest planting density (30.000 plants/fad) consistently produced the best outcomes, with hybrid S.C. 180 generally outperforming S.C. 168 in terms of kernel weight and grain yield, especially under the N3D3 treatment (Figure 5). These findings indicate that hybrid S.C. 180 is more responsive to higher nitrogen inputs and dense planting, which suggests a greater adaptability of this hybrid to intensified management practices.

While there were no significant differences observed in the number of rows per ear, the results highlight the importance of hybrid selection and nitrogen management in improving kernel weight and overall grain yield. The combination of the highest nitrogen level and planting density (N3D3) proved to be the most effective for maximizing maize production, demonstrating that intensified nitrogen fertilization and strategic planting density are essential for enhancing both kernel development and yield in maize.

These insights provide valuable guidance for maize producers aiming to optimize crop management for higher yields and improved grain quality. By focusing on appropriate nitrogen levels and planting density, especially with adaptable hybrids like S.C. 180, producers can potentially achieve better productivity and economic returns. In conclusion, the results from this study indicate that the interactions between maize hybrids, nitrogen levels, and planting densities have a significant impact on both 100-kernel weight and grain yield. Higher nitrogen levels (120 kg N/fad) and the highest planting density (30.000 plants/fad) consistently produced the best outcomes for both hybrids across the two growing seasons, with hybrid S.C. 180 generally performing slightly better than S.C. 168 in terms of 100-kernel weight and grain yield. The combination of the highest nitrogen level and highest planting density (N3D3) proved to be the most effective for maximizing maize production. This suggests that optimizing nitrogen fertilization and planting density is critical for enhancing both kernel development and yield in maize. Addition-ally, while there were no significant differences in the number of rows per ear, the results highlight the im-portance of hybrid selection and nitrogen management for improving kernel weight and grain yield, with hybrid S.C. 180 demonstrating a stronger response to higher inputs. These findings provide valuable insights for maize producers seeking to optimize their crop management practices for higher yields and better grain quality.

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