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OPTIMIZING YIELD AND MITIGATING BIOTIC STRESS: THE INTERACTIVE EFFECTS OF NITROGEN FERTILIZATION, PLANT DENSITY AND VARIETY OF MAIZE

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Abstract. In this study, four maize varieties (SC10, SC122, TWC310, TWC352) were tested with nitrogen fertilizers at 90, 120 and 150 kg N/fad and plant densities of 24,000 and 30,000 plants/fad. Results showed that higher nitrogen levels significantly improved leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR) within 60-90 days, leading to increased grain per row, 100-grain weight and overall yield, as well as earlier tasseling and silking. Conversely, higher plant densities reduced LAI, CGR and NAR and increased competition, which decreased grain weight per row and yield. Among the varieties, SC10 and TWC310 outperformed SC122 and TWC352 in growth and yield, demonstrating varied responses to nitrogen and density.

Keywords: *Nitrogen rates, plant density, yield parameters, Varietal Performance, growth matrics, maize varieties.*

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1. Introduction

Maize (Zea mays L.) is one of the most important cereal food crops in Egypt. In 2023, the maize produced in Egypt was again around 7.1 million tons (FAO, 2024). Many factors affect maize's grain yield, such as genetic constitution, fertilization and plant population. Research results confirm the trend toward using higher nitrogen fertilizer rates for recently created varieties that do well in high plant densities. According to studies, optimizing plant densities and nitrogen application rates can have a major impact on the leaf area index (LAI) at silking. This can increase radiation usage efficiency during grain filling and the interception of photosynthetically active radiation. This optimization technique has the potential to enhance light consumption, canopy structure and eventually grain yields in maize (Tian *et al*., 2022). Furthermore, the relationship between plant densities and nitrogen rates can affect the physiological properties of leaves, including the distribution and efficiency of photosynthetic N use, underscoring the significance of customized nitrogen management strategies for optimizing crop productivity in a range of planting scenarios (Lian *et al*., 2023).

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As noted by (Raina & Mazahar, 2022; Magray *et al*., 2022), nitrogen (N) is required for plant growth and is a vital component of several critical molecules like enzymes and chlorophyll. Brady (1984) points out that it is crucial to moderate how other necessary elements, including potassium and phosphorus, are used by plants. Plants may absorb nitrogen in a variety of forms, including nitrate, ammonium and amino acids. To enable nitrogen to be taken up and assimilated into amino acids through intricate metabolic pathways, certain transporters are needed (Wani *et al*., 2022). Furthermore, chlorosis and other apparent signs related to nitrogen deprivation might affect plant development, carbon fixation and other physiological processes (Yang *et al*., 2022). Thus, it is essential to maintain sufficient nitrogen levels for the best possible plant development and productivity.

Many factors, including grain weight/ear and 100-grain weight, are all improved by raising nitrogen fertilizer levels to a certain point. Studies on genetic diversity have demonstrated the strong heritability and genetic advancement of variables like as ear height, cob weight and grain output per plant (Lavanya *et al*., 2022). The intricacy of determining maize yield is further highlighted by the existence of both additive and non-additive gene activities in the inheritance of these traits (Reddy *et al*., 2022). Moreover, artificial neural network-based prediction models have illustrated the multifactorial nature of maize productivity by stressing the significance of soil-water balance and climate circumstances (Miranda, 2023). Biotic stress refers to the damage caused to plants by living organisms such as viruses, bacteria, fungi, parasites, harmful insects and weeds. Plants have evolved complex mechanisms to detect and respond to such threats. Essential nutrients like nitrogen (N), phosphorus (P) and potassium (K) are crucial for plant growth and development. Adequate NPK fertilization can enhance plant resistance to biotic stress by improving overall plant health and vigor (Khan *et al*., 2015). Besides the proline is an osmoprotectant and helps plants cope with biotic stress by stabilizing proteins and membranes and scavenging free radicals (Kaur *et al*., 2022). Providing plants with NPK fertilizer ensures they receive essential nutrients-nitrogen (N), phosphorus (P) and potassium (K) which are vital for their growth and development. Adequate nutrition can help plants better manage stress. Noreldin (2005) and Sharifi and Taghizadeh (2009) showed that raising nitrogen fertilizer rates from 90 to 150 kg N/fad increased nitrogen and potassium content in grains but reduced the phosphorus percentage and maize cultivars showed varied responses to nitrogen levels as well as the highest grain yield and other growth parameters like kernel number/ear and grains ear/row were achieved with the highest nitrogen fertilizer levels.

To evaluate the effects of varying nitrogen fertilizer rates and plant population densities on the growth, development and yield of four maize varieties (SC10, SC122, TWC310, TWC352). The study aims to determine the optimal nitrogen levels and plant densities that maximize crop yield and quality, while also assessing the response of different maize cultivars to these agronomic practices.

2. Material and Methods

This investigation was conducted during the two 2021 and 2022 seasons at the Agricultural Research Station, Fac. Agric. and Cairo University, Egypt, to study the response of four maize varieties to nitrogen fertilizer rates and plant population densities. Soil samples were taken before land preparation for mechanical and chemical analysis in (Figure 1 and Table 1).

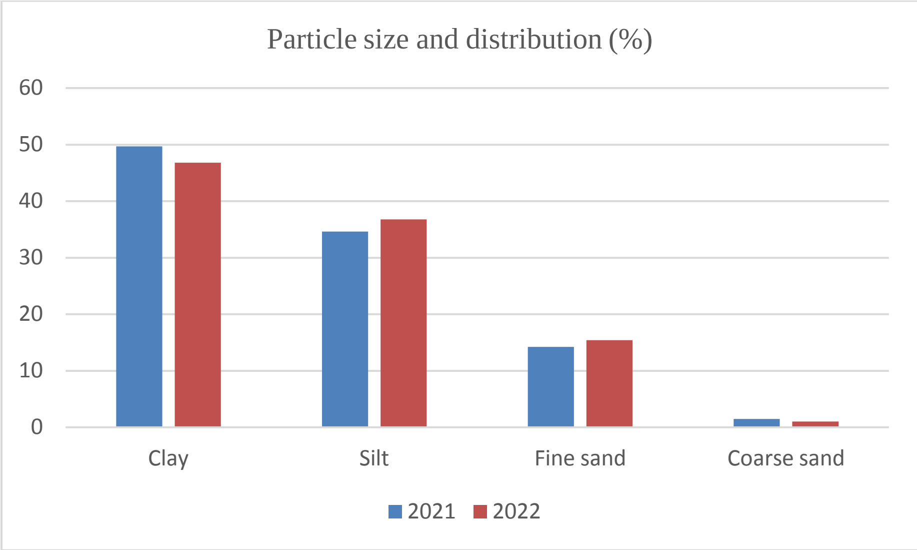

Figure 1. Physical analysis of soils at the experimental fields of Agricultural Research Station, Cairo University during the 2021 and 2022 growing seasons

Table 1. Chemical analysis of soils at the experimental fields of Agricultural Research Station, Cairo University during the 2021 and 2022 growing seasons

Chemical analysis	2021	2022
pH	8.02	7.82
EC dm/m	2.41	2.52
N ppm	14.00	14.6
P ppm	9.4	10.6
K ppm	33.9	35.4

The experimental design used was a split-split plot with three replications. The main plots were assigned for nitrogen fertilizer rates, plant population densities and varieties were randomly distributed in the sub and sub-sub plots, respectively. The first treatment was nitrogen fertilizer, which was applied as ammonium nitrate, 33.5% N, at three nitrogen rates, i.e., 90, 120 and 150 kg N/fad. Nitrogen was applied in two equal doses as a side dressing after thinning (3 weeks after sowing) and the second dose was applied 3 weeks later. The second treatment was plant population density, which ranged between 24000 and 30000 plants/fad. The third treatment was that four maize varieties were used in this study: two white single crosses, i.e., SC10 and SC122, as well as two three-way crosses, TWC310 (white) and TWC352 (yellow). Normal culture practice was used as recommended for growing maize each plot consisted of five ridges, 4 m long and 70 cm apart (plot size was 14 m^2). The outer ridge was taken to measure vegetative growth characters. Grain yield and yield components were determined from the remaining two ridges (plot size was 1/300 fad, one fad = 4200 m^2 or 0.42 ha), to assess growth attributes, five guarded plants were taken from each plot after nearly 60 and 90 days from planting. Plants were carefully cut out at the soil surface and carried immediately to the laboratory where they were separated into leaves. The fresh weight of these organs was determined the proline % at leaves. To estimate the dry weight of each organ, samples of 100 grams from each part were dried at 70° C until they reached a constant weight. The following characters were estimated:

I. Flowering characters:
1. Number of days to 50% tasseling
2. Number of days to 50% silking

II. Vegetative characters:
1. Leaf area index (LAI)
2. Crop growth rate, CGR (g/m^2/day), the crop growth rate of a unit leaf area of a canopy cover at any instant in time (t) is defined as the increase of plant materials / unit ground area per unit of time (g m^2/day) as follows:

$$CGR = (w_2 - w_1)/ (t_2 - t_1),$$

where W_1 and W_2 refer to total dry weight (g) at 60 (t_1) and 90 (t_2) days after planting, respectively.

3. Net assimilation rate, NAR (g/m^2/day) The net assimilation rate (NAR) of a plant at an instant in time (t) is defined as the increase of plant materials per unit leaf area per unit time (g m^2/day) as follow:

$$NAR = (w_2 - w_1) (LnA_2 - LnA_1)/ (A_2 - A_1) (t_2 - t_1),$$

where W_1, A_1 and W_2, A_2 refer to total dry weight (g) and blade leaf area (m^2) at 60 (t_1) and 90 (t_2) days after planting, respectively.

The two growth attributes were computed according to the formula of Watson (1952) and Radford (1967).

III. Yield and Yield components:
1. Number of grains/rows
2. 100-grain weight (g) adjusted to 15.5% moisture content
3. Grain yield was adjusted to 15.5% moisture in arddab / faddan (ard/fad).

IV. Chemical analysis:

At harvest, it was measured in grains:

– Grain nitrogen proportion (N%). The Kjeldahl technique, as explained by Pratt and Chapman (1961), was used to measure it.
– Grain proportion (P%) of phosphorus. It was ascertained by Jackson (1958).
– The proportion of potassium (K%) in grains according to Richards (1954).
– Proline's interaction with ninhydrin was used to determine the content of proline in leave (Marín Velázquez *et al*., 2010).

Statistical analysis:

The obtained data were statistically analyzed according to Steel and Torrie (1980). The treatment means were compared according to the LSD test. In the tables of the analysis of variance, * and ** indicate significant and highly significant differences at 0.05 and 0.01 levels of probability, respectively.

3. Results and discussion

3.1. Flowering characters:

3.1.1. Number of days to 50% tasseling:

The effects of the investigated factors on the number of days from planting to 50% tasseling and silking are shown in Tables 2 and 3, respectively. The results showed that the four maize varieties differed significantly in the number of days from planting until the ear was 50% formed in both growing seasons. SC10 had a later ear date than the other corn varieties tested, SC122, TWC310 and TWC352, during both growing seasons. Kandil et al. (2016) found that SC 155 is the oldest tassel date than his SC10. However, Attia et al. (2009) found that SC10 in Table 2 had the highest number of days with 50% tasseling. Results similar to those in Table 3 were reported by Chen et al. (2015) who found that nitrogen application reduced the number of days from sowing to silk formation by 50%. Chisanga et al. (2019), however, showed that silk maturation timing was not significantly affected by nitrogen fertilizer application. In general, increasing the amount of nitrogen fertilizer can significantly reduce the number of days from seeding to corn maturity. For example, during the 2021 and 2022 growing seasons, applying nitrogen at rates of 90, 120 and 150 kg N/fad accelerated silk formation by 1.5–1.9 days.

Table 2. Effect of nitrogen fertilizer rates, plant population densities and maize varieties as well as their interaction on number of days from planting to 50% tasseling in 2021 and 2022 growing seasons

Density 1000 plants/fad	Varieties	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	63.3	61.3	61.0	61.9	61.0	59.7	58.0	59.6
	SC122	62.3	62.0	60.7	61.7	60.3	56.3	58.3	58.3
	TWC310	62.3	62.0	60.0	61.4	59.3	58.7	56.3	58.1
	TWC352	61.3	60.3	60.0	60.6	58.7	58.7	57.0	58.1
Mean		62.3	61.4	60.4	61.4	59.8	58.3	57.4	58.5
30	SC10	62.7	61.3	60.3	61.4	60.3	58.3	59.0	59.2
	SC122	62.0	61.0	60.3	61.1	59.3	58.3	58.0	58.6
	TWC310	61.3	61.0	60.0	60.8	59.0	58.7	56.0	57.9
	TWC352	61.0	61.0	60.0	60.7	58.3	59.3	59.3	59.0
Mean		61.8	61.1	60.2	61.0	59.3	58.7	58.1	58.7
Means overall density	SC10	63.0	61.3	60.7	61.7	60.7	59.0	58.5	59.4
	SC122	62.2	61.5	60.5	61.4	59.8	57.3	58.2	58.4
	TWC310	61.8	61.5	60.0	61.1	59.2	58.7	56.2	58.0
	TWC352	61.2	60.7	60.0	60.6	58.5	59.0	58.2	58.6
	Mean	62.1	61.3	60.3	61.2	59.6	58.5	57.8	58.6
LSD at 0.05 for	N	0.54				0.66			
	D	0.39				NS			
	H	0.60				0.92			
	N x D	NS				1.49			
	N x H	NS				1.60			
	D x H	NS				NS			
	N x D x H	NS				2.26			

This is consistent with the findings of Rimski-Korsakov et al. (2012) and Mueller and Vyn (2016) suggest that plant population density does not significantly influence the timing of silk formation. This is probably due to the slower emergence of silk threads due to more active vegetative growth at a lower density.

Table 3. Effect of nitrogen fertilizer rates, plant population densities and maize varieties as well as their interaction on number of days from sowing to 50% silking in 2021 and 2022 growing seasons

Density 1000plants/ fad	Varieties	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	65.0	64.7	64.7	64.8	64.0	63.0	61.0	62.7
	SC122	67.0	65.7	64.3	65.7	63.7	62.7	61.3	62.6
	TWC310	66.0	64.0	63.0	64.3	62.3	62.3	61.0	61.9
	TWC352	69.3	67.3	66.3	67.7	63.7	62.3	60.0	62.0
Mean		66.8	65.4	64.6	65.6	63.4	62.6	60.8	62.3
30	SC10	64.7	64.0	64.3	64.3	63.3	62.0	60.7	62.0
	SC122	65.3	64.3	64.0	64.6	62.0	62.0	61.0	61.7
	TWC310	64.3	63.0	62.7	63.3	62.3	61.3	62.0	61.9
	TWC352	68.0	64.7	65.0	65.9	63.0	61.7	60.0	61.6
Mean		65.6	64.0	64.0	64.5	62.7	61.8	60.9	61.8
Means overall density	SC10	64.8	64.3	64.5	64.6	63.7	62.5	60.8	62.3
	SC122	66.2	65.0	64.2	65.1	62.8	62.3	61.2	62.1
	TWC310	65.2	63.5	62.8	63.8	62.3	61.8	61.5	61.9
	TWC352	68.7	66.0	65.7	66.8	63.3	62.0	60.0	61.8
	Mean	66.2	64.7	64.3	65.1	63.1	62.2	60.9	62.1
LSD at 0.05 for	N	1.4				1.1			
	D	NS				NS			
	H	1.1				NS			
	N x D	NS				NS			
	N x H	NS				NS			
	D x H	NS				NS			
	N x D x H	NS				NS			

3.2. Vegetative and growth characters:

3.2.1. Leaf area index (LAI):

The findings presented in Table 4 demonstrate how the treatments under investigation affected the leaf area index (LAI), which is the ratio of the total leaf area per plant to the land area that the plant occupies. A crop's photosynthetic capability or amount of dry matter buildup is indicated by its leaf area index (LAI) during a certain development stage (Fang *et al*., 2019). The findings demonstrated that the LAI steadily rose as the organism grew. This might be because nitrogen fertilizer promotes the development of vegetative plants, which in turn increases the amount of leaf area per plant (Ye *et al*., 2022). With an addition of 120 kg N/ha, Dixit (2023) obtained the highest LAI values. According to Table 4 findings, plant population densities had a highly significant impact on LAI 60 and 90 days after planting throughout both growth seasons. The number of plants/fad increased from 24000 to 30000, which resulted in a significant increase in LAI after 60 and 90 days from planting in the 2021 growing season (2.83 vs 2.95 and 3.37 vs 3.69) and after 60 and 90 days from planting in the 2022 growing season (2.87 vs 3.21 and 3.92 vs 4.21). According to Njuguna et al. (2016), leaf area index was not substantially impacted by increasing plant population densities from 24000 to 30000 plants/fad at different growth stages. Table 4 data demonstrated that the leaf area of the four examined kinds of maize varied greatly. The four tested maize varieties' leaf area indices during the two development stages in both growing seasons vary substantially, according to data in Table 4. In the 2021 and 2022 growing seasons, SC10 had the greatest LAI values (3.43, 3.99, 3.43, 4.77) at 60 and 90 days following planting, respectively. TWC310, on the other hand, placed second, third and fourth in LAI in the two development stages over the two growing seasons, behind SC122 and TWC352. According to Zeidan et al. (2006), there were notable differences in maize varieties' LAI throughout the pre-flowering development phases. The information in Table 4 demonstrates that, at 60 and 90 days after planting in both growing seasons, the first-order interaction effects of nitrogen rates x plant population densities (N x D), nitrogen rates x varieties (N x H) and plant population density x varieties (P x H) on (LAI) were highly significant, except N x D after 60 days after planting in the 2021 growing season. The findings in Table 4 (see at the end of the paper) show that there were substantial differences between the tested types of maize in terms of how they responded to either nitrogen fertilizer or plant population density for the LAI. In general, SC10 responded better to increased nitrogen rates than TWC310, SC122 and TWC352. However, the leaf area index values obtained by all kinds under study were the greatest.

On the other hand, when planted at a pace of 24000 plants/fad, all investigated varieties SC 10 is the first to produce the greatest values of leaf area index. However, Dixit (2023) noted that planting maize single crosses at a pace of 20,000 plants per fad and increasing nitrogen fertilizer rates to 120 kg N/fad resulted in the highest levels of LAI. By adding 140 kg N/fad, Orabi et al. (2003) were able to attain the greatest value of LAI.

3.2.2. Crop growth rate, CGR (g/m^2/day):

The effect of the studied treatments on CGR is given in Table 5. Increasing nitrogen fertilizer rates from 90 kg N/fad to 120 and 150 kg N/fad caused a significant increase in CGR in 2021 growing seasons from 4.0 g m^2/day to 6.3 and 7.9 g m^2/day, respectively, it is indicated that the effect of plant population densities on crop growth rate (CGR), in the 2021 and 2022 growing seasons was highly significant during 60-90 days after planting. The significant effect of plant population densities is probably due to the increasing solar radiation interception captured by the foliage canopy. Generally, increasing the number of plants from 24000 to 30000 plants/fad led to a significant decrease in CGR from 6.4 to 5.8 and from 12.0 to 10.2 g/m^2/day in 2021 and 2022 growing seasons respectively. These results are in agreement with those obtained by Williams et al. (1968) and Zhang et al. (2022) who reported that the amount of solar radiation intercepted by the foliage canopy was the major determinant of crop growth rate during the vegetative growth.

Prasad et al. (1990) reported that increasing plant population density caused the lower leaves to be upright and did not affect the upper leaves. However, Govil and Pandey (1998) reported that the crop growth rate measured during the flowering period increased as plant population density increased. On the other hand, Zhang et al. (2022) found that crop growth rate at any growth period significantly decreased as plant population density increased due to competition between adjacent plants for solar and light energy.

Table 5. Effect of nitrogen fertilizer rates, plant population densities and maize varieties as well as their interaction on crop growth rate (CGR) in g/m^2/day at 60-90 days intervals in 2021 and 2022 growing season

Density 1000 plants/fad	Varieties	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	6.1	8.6	10.0	8.2	8.6	12.1	18.5	13.0
	SC122	3.1	5.6	6.8	5.2	8.6	11.0	13.9	11.2
	TWC310	5.5	9.5	10.6	8.5	11.2	11.8	17.1	13.4
	TWC352	2.8	3.8	4.3	3.6	13.9	8.2	9.0	10.3
Mean		4.4	6.9	7.9	6.4	10.6	10.8	14.6	12.0
30	SC10	5.3	7.4	9.8	7.5	9.4	12.1	11.8	11.1
	SC122	2.8	5.1	6.8	4.9	8.5	9.1	11.2	9.6
	TWC310	4.6	7.7	11.0	7.8	9.0	14.2	14.1	12.4
	TWC352	2.2	2.9	3.9	3.0	7.4	7.8	7.8	7.7
Mean		3.7	5.8	7.9	5.8	8.6	10.8	11.2	10.2
Means over-all density	SC10	5.7	8.0	9.9	7.9	9.0	12.1	15.2	12.1
	SC122	3.0	5.4	6.8	5.0	8.6	10.1	12.6	10.4
	TWC310	5.1	8.6	10.8	8.1	10.1	13.0	15.6	12.9
	TWC352	2.5	3.4	4.1	3.3	10.6	8.0	8.4	9.0
Mean		4.0	6.3	7.9	6.1	9.6	10.8	12.9	11.1
LSD 0.05 for	N	0.503				0.668			
	D	0.123				0.366			
	H	0.326				0.464			
	N x D	NS				0.633			
	N x H	0.565				0.804			
	D x H	NS				0.657			
	N x D x H	NS				1.138			

Results in Table 4 indicated that maize varieties differed concerning CGR during 60-90 days after planting. The mean values of CGR of TWC310 and SC10 were significantly higher than those of SC122 and TWC352. This may be due to that maize varieties differed in their genetic makeup. These results were in good harmony with those obtained by (Álvarez-Iglesias *et al*., 2022). The effect of the first-order interaction of nitrogen fertilizer rates and plant population density and varieties, ***i.e.*** N x D and N x H on CGR at 60-90 days after planting was significant in both growing seasons. However, the interactions of plant population density and varieties (D x H) as well as nitrogen fertilizer rates, plant density and varieties, N x D x H at the same growth period were not significant in 2021 growing season and highly significant in 2022 growing season. In 2021 growing season, planting TWC 310 at the rate of 30000 plants/fad and adding 150 kg N/fad produced the highest mean values of CGR (11.0 g/m^2/day). On the other hand, SC10 produced the highest value of CGR (18.5 g/m^2/day) by adding 150 kg N/fad and planting at the rate of 24000 plants/fad.

3.2.3. Net assimilation rate, NAR (g/m^2/day):

Based on Table 6 it appears that the high photosynthetic efficiency of leaves at this growth interval contributed to the comparatively high mean values of net assimilation rate after 60–90 days from planting. Table 6 makes it abundantly evident that in both growth seasons, the rates of nitrogen fertilizer had a significantly substantial impact on NAR. Fertilization with nitrogen was beneficial to NAR. The 2021 and 2022 growing seasons saw considerable increases in NAR of 2.3 and 3.9 g/m^2/day and 1.2 and 2.1 g/m^2/day, respectively, from raising nitrogen fertilizer rates from 90 kg N/fad to 120 and 150 N/fad. Suphachai et al. (2006) found that increasing nitrogen fertilizer levels increased leaf area and leaf area index (LAI), which boosted light interception and canopy photosynthesis. These results are consistent with their findings. According to Thompson et al. (2017), the maximum crop growth rate and net assimilation rate were seen with an application of 175 kg N/ha. Barbieri et al. (2013), however, found that fluctuations in nitrogen supply impact maize growth and development and cause significant alterations to crop physiological parameters. Lack of nitrogen somewhat lowered radiation interception, leaf area duration and leaf growth rate. In the pre-flowering period (45–60 days after planting), Zhang et al. (2022) found that increasing N fertilizer rates from zero to 180 kg N/fad greatly improved NAR. Nonetheless, NAR responded up to 135 kg N/fad to nitrogen fertilizer. Table 6 results demonstrate that, while it was extremely significant in the 2022 growing season, the influence of plant population density on net assimilation rate (NAR) over the 60–90 days following planting was not significant in the 2021 growing season.

Table 6. Effect of nitrogen fertilizer rates, plant population densities and maize varieties as well as their interaction on net assimilation rate (NAR) in g/m^2/day at 60- 90 days intervals in 2021 and 2022 growing season

Density 1000 plants/fad	Varieties	2021 growing season				2022 growing season			
		N rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	11.6	14.3	14.2	13.4	15.8	17.3	22.7	18.6
	SC122	7.2	10.5	11.8	9.8	21.3	21.9	22.8	22.0
	TWC310	11.2	16.4	16.2	14.6	20.7	16.9	20.6	19.4
	TWC352	8.5	10.0	6.3	8.2	18.6	17.5	15.6	17.2
Mean		9.6	12.8	12.1	11.5	19.1	18.4	20.4	19.3
30	SC10	11.4	13.5	15.7	13.6	19.9	21.4	16.1	19.1
	SC122	7.7	11.4	12.6	10.6	22.5	20.4	20.5	21.1
	TWC310	10.8	15.1	20.0	15.3	18.9	24.0	19.8	20.9
	TWC352	7.5	8.4	9.0	8.3	21.4	18.1	16.0	18.5
Mean		9.4	12.1	14.3	11.9	20.7	21.0	18.1	19.9
Means over-all density	SC10	11.5	13.9	15.0	13.5	17.9	19.4	19.4	18.9
	SC122	7.5	10.9	12.2	10.2	21.9	21.2	21.7	21.6
	TWC310	11.0	15.8	18.1	15.0	19.8	20.5	20.2	20.2
	TWC352	8.0	9.2	7.6	8.3	20.0	17.8	15.8	17.9
Mean		9.5	12.5	13.2	11.7	19.9	19.7	19.3	19.7
LSD at 0.05 for									
	N	1.20				0.67			
	D	NS				0.78			
	H	0.71				0.86			
	N x D	0.86				1.35			

N x H	1.23	1.49
D x H	NS	1.21
N x D x H	NS	2.10

These findings concur with those of Zhang et al. (2022) and Lambers et al. (2019), who found that when plant population densities increased, the net assimilation rate dramatically decreased. Table 6 shows that the net assimilation rates of the examined types of maize (SC10, SC122, TWC310 and TWC352) varied significantly 60–90 days after planting in the 2021 and 2022 growth seasons.

During the 2021 growing season, TWC310 achieved the highest mean value of NAR (15.0 g/m^2/day), with SC10, SC122 and TWC352 following closely behind (13.5, 10.2 and 8.3 g/m^2/day), respectively. At 60–90 days after planting in the 2022 growing season, SC122 generated the highest amounts of NAR (21.6 g/m^2/day). TWC310, SC10, and TWC352 followed with 20.2, 18.9 and 17.9 g/m^2/day, respectively and there were no discernible differences between TWC310 and TWC352. Genetic variations in physiological processes like photosynthesis and respiration may account for the variations in net assimilation rates amongst the examined types of maize. This is consistent with Álvarez-Iglesias et al. (2022) findings. Table 6 displays the interaction effects on net assimilation rate between nitrogen fertilizer rate and types (N x H) and between nitrogen fertilizer rate and plant population density (N x D). Throughout all growth seasons, these impacts peaked 60–90 days after planting. During the growth seasons of 2021 and 2022, the net assimilation rate responded to nitrogen supplied at a rate of up to 150 kg N/fad. Conversely, when plant population densities increased, NAR dramatically dropped. It could be the case that when there are more plants per unit area, they require more nitrogen; but, at higher densities, plants are less able to intercept light due to competition and mutual shade.

In the meanwhile, the way different types of maize responded to nitrogen fertilizer varied greatly. When fertilized with 150 kg N/fad during the 2021 growing season, TWC310 generated the highest value of NAR (18.1 g/m^2/day); however, in the 2022 growing season, TWC310 was followed by SC122, which produced the greatest values at the same nitrogen fertilizer rate. The acquired data further demonstrate that, in contrast to the second growing season, the other interactions between the parameters under study namely, D x H and N x D x H in Table 6 had no discernible impact on NAR in 2021. In general, the tested maize varieties' net absorption rates varied significantly depending on the nitrogen fertilizer rates and plant population density at 60–90 days after planting. The maximum average values of NAR were obtained by planting SC122 at the rate of 24000 plants/fad and adding 150 and 120 kg N/fad, respectively.

3.3. Yield and yield components:

3.3.1. Number of grains/rows:

During both growth seasons, the number of grains/rows was significantly impacted by the rates of nitrogen fertilizer (Table 7). In both growth seasons, the number of grains per row responded to nitrogen fertilizer rates of up to 150 kg N/fad. In the 2021 and 2022 growing seasons, it grew by 2.7 and 4.9 grains and 1.4 and 3.3 grains, respectively, in comparison to 90 kg N/fad. These findings may be explained by nitrogen's beneficial effects on ear size and dry matter buildup in grains, which are reflected in the growing number of grains/rows. These findings concur with the findings of (Belete *et al*., 2018). In the meanwhile, Melkie et al. (2020) observed that the amount of grain in a row in response to nitrogen fertilizer was up to 150 kg N/fad. According to Table 7 results, there was no significant difference in the number of grains/rows between the two growing seasons depending on the plant population densities. There was often a little drop in the number of grains/rows when the number of plants/fad increased from 24000 to 30000. Ngoune Tandzi and Mutengwa (2019) demonstrated that increasing plant population densities from 24000 to 30000 plants/fad did not significantly alter the number of grains/ears. On the other hand, Zhang et al. (2022) found that the number of grains/rows was significantly impacted by plant population density. Table 7 findings indicated that there were substantial differences in the number of grains/rows across the tested kinds of maize in both growth seasons. The largest number of grains/rows in the 2021 growing season was shown by TWC310 and SC10, followed by SC122 and TWC352 (46.1, 45.7, 43.0 and 34.5 grains/row), respectively. The second growing season saw TWC310 have the most rows/ear, with 47.1, 46.6, 44.7 and 35.1 grains/row, respectively, followed by SC10, SC122 and TWC352. Numerous researchers discovered that the number of grains/rows varied greatly throughout maize genotypes (Kandil *et al*., 2016; El-Mekser & Seiam, 2008). Conversely, single crossings outperform three-way crosses in terms of the number of grains per row, according to studies by (Mohamed *et al*., 2002) and El-Mekser and Seiam (2008)). Except for (N x H), the data in Table 7 show that the interaction effects of nitrogen fertilizer rates, plant population densities and maize types on the number of grains/rows in the 2021 growing season were significant.

Table 7. Effect of nitrogen fertilizer rates, plant population densities and maize varieties as well as their interactions on number of grains/rows in 2021 and 2022 growing seasons

Density 1000 plants/fad	Varieties	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	41.9	45.3	47.5	44.9	46.1	47.1	48.1	47.1
	SC122	39.6	43.4	45.7	42.9	42.1	44.7	46.2	44.3
	TWC310	42.7	52.1	48.3	47.7	46.6	47.8	47.7	47.4
	TWC352	31.9	35.9	36.7	34.8	36.5	33.5	36.1	35.4
Mean		39.1	44.2	44.5	42.6	42.9	43.3	44.5	43.6
30	SC10	45.2	46.5	48.1	46.6	43.9	45.5	48.7	46.0
	SC122	41.0	41.8	46.6	43.1	43.2	45.5	46.5	45.1
	TWC310	44.3	41.4	47.7	44.5	44.2	46.7	49.4	46.7
	TWC352	31.5	33.5	37.4	34.1	31.3	35.1	38.2	34.8
Mean		40.5	40.8	44.9	42.1	40.6	43.2	45.7	43.2
Means overall density	SC10	43.6	45.9	47.8	45.7	45.0	46.3	48.4	46.6
	SC122	40.3	42.6	46.1	43.0	42.7	45.1	46.4	44.7
	TWC310	43.5	46.8	48.0	46.1	45.4	47.2	48.5	47.1
	TWC352	31.7	34.7	37.0	34.5	33.9	34.3	37.2	35.1
Mean		39.8	42.5	44.7	42.3	41.8	43.2	45.1	43.4
LSD at 0.05 for									
	N	1.06				0.80			
	D	NS				NS			
	H	1.08				0.68			
	N x D	1.91				NS			

N x H	NS	NS
D x H	1.53	NS
N x D x H	2.65	NS

3.3.2. 100-grain weight (g):

Nevertheless, in the growing season of 2022, none of the interactions between the components under study were significant. In general, planting all maize types at a pace of 24000 plants/fad and adding 120–150 kg/N produced the highest values of grains per row. Regarding this, Zhang et al. (2022) found that the relationship between plant population densities (N x D) and N-fertilizer rates did not affect the number of grains/rows.

As can be seen from Table 8 results, in the growing seasons of 2021 and 2022, there was a considerable impact of nitrogen fertilizer rates on 100-grain weight. Up to 150 kg N/fad of N fertilization was the reaction of 100-grain weight. The weight of 100 grains grew by 1.8, 2.1 and 2.2, 1.7 g in the growing seasons of 2021 and 2022, respectively, when nitrogen fertilizer rates were increased from 90 kg N/fad to 120 and 150 kg N/fad. Increases in N rate up to 180 kg N/ha led to a considerable increase in grain weight (Fedotkin & Kravtsov, 2001). Table 8 data showed that, in both growth seasons, there was a substantial impact of plant population densities on 100-grain weight. Notably, there are now between 24,000 and 30,000 more plants/fad.

Plant population densities had a substantial impact on 100-grain weight in both growing seasons, according to data in Table 8. It is noteworthy that in the 2021 and 2022 growing seasons, respectively, there was a considerable decrease in the 100-grain weight (29.4 vs 28.3 g) and (34.0 vs 32.8 g) as a result of increasing the number of plants/fads from 24000 to 30000 plants/fad. The rivalry between maize plants in dense planting, which results in reduced ear size and subsequently decreased grain weight, may be the primary cause of this fall in 100-grain weight caused by increased plant population densities. By raising plant population densities, some researchers were able to significantly reduce the 100-grain weight Meky (1997), Said and Gabr (1999).

However, Ngoune Tandzi and Mutengwa (2019) and Zhang et al. (2022) found no discernible impacts of increasing plant population densities on 100-grain weight.

Table 8 results revealed that there were substantial differences in the 100-grain weight of the examined kinds of maize in both growing seasons. The greatest 100-grain weights in the 2021 growing season were recorded by SC10 and TWC310, followed by SC122 and TWC352 (31.2, 30.3, 27.3 and 26.5 g), in that order. In the second growing season, a similar pattern was seen. SC10 had the greatest 100-grain weight (35.4, 35.4, 33.4 and 29.5 g), followed by TWC310, SC122 and TWC352. El-Mekser and Seiam (2008) discovered a considerable difference in 100-grain weight amongst genotypes of maize.

However, Mohamed et al. (2002) found that single crossings outperformed three-way crosses in 100-grain weight. According to Table 8 data, the 2021 growing season saw substantial interaction effects between nitrogen fertilizer rates, plant population density and maize types on 100-grain weight, except (N x D x H). Except for (N x H and N x D x H), all interactions between the components under study were likewise significant during the 2022 growing season. The maximum 100-grain weight values were often achieved by applying 120–150 kg/N and planting all kinds at a pace of

24000 plants/fad. Regarding this, Suliman (2003) and Zhang et al. (2022) found that there was little relationship between plant population densities (N) and nitrogen fertilizer rates.

Table 8. Effect of nitrogen fertilizer rates, plant population densities and maize varieties as well as their interactions on 100-grain weight (g) in 2021 and 2022 growing seasons

Density 1000 plants/fad	Varieties	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	29.7	31.6	34.7	32.0	34.3	35.8	37.7	35.9
	SC122	26.5	27.9	28.8	27.7	32.5	34.0	35.1	33.9
	TWC310	28.5	31.7	32.8	31.0	34.5	36.2	38.3	36.3
	TWC352	25.8	26.7	27.7	26.7	28.1	29.9	31.9	30.0
Mean		27.6	29.5	31.0	29.4	32.4	34.0	35.7	34.0
30	SC10	28.3	29.6	33.5	30.4	32.6	35.4	36.7	34.9
	SC122	25.4	26.3	29.0	26.9	30.1	33.8	34.8	32.9
	TWC310	27.0	29.5	32.0	29.5	31.7	35.1	36.5	34.4
	TWC352	23.9	26.6	28.1	26.2	27.3	28.7	31.3	29.1
Mean		26.1	28.0	30.6	28.3	30.4	33.3	34.8	32.8
Means overall density	SC10	29.0	30.6	34.1	31.2	33.5	35.6	37.2	35.4
	SC122	26.0	27.1	28.9	27.3	31.3	33.9	34.9	33.4
	TWC310	27.8	30.6	32.4	30.3	33.1	35.6	37.4	35.4
	TWC352	24.8	26.7	27.9	26.5	27.7	29.3	31.6	29.5
Mean		26.9	28.7	30.8	28.8	31.4	33.6	35.3	33.4
LSD at 0.05 for									
	N	0.42				0.60			
	D	0.39				0.48			
	H	0.40				0.47			
	N x D	0.67				0.84			
	N x H	0.69				NS			
	D x H	0.57				0.81			
	N x D x H	NS				NS			

3.3.3. Grain yield (ard/fad):

According to data in Table 9, nitrogen fertilizer rates had a significantly substantial impact on grain output throughout both growing seasons. As the rate of nitrogen fertilizer increased, the mean grain yield in ard/fad increased considerably (Table 9). In the two growth seasons, it reacted to 90 kg N/fad and any subsequent additions. In the growing seasons of 2021 and 2022, respectively, the increases in grain yields brought about by the application of nitrogen fertilizer rates of 90, 120 and 150 kg N/fad were 2.6, 4.6 and 1.6, 3.9 ard/fad. This indicates that in both growing seasons, the response of grain yield reached 150 kg N/fad. The rise in ear features, such as the quantity of grains or rows, might be the cause of these findings. Table 7 and Table 8 of

100-grain weight. Additionally, it illustrates how nitrogen fertilizer has a noticeable impact on growing traits like NAR and the leaf area index Table 4 and Table 6. These findings concur with those of Zeidan et al. (2006) and Noreldin (2005). According to the statistical research, in the growing seasons of 2021 and 2022, plant population densities had a significantly substantial impact on grain yield/fad. Table 9 shows the mean values of grain yield/fad for ardab for population densities of 24000 and 30000 plants/fad, respectively, in the growing seasons of 2021 and 2022.

In the two growing seasons, the average grain output in ardab/fad rose considerably with plant densities; that is, grain yield increased as plant spacing reduced from 25 to 20 cm.

The two plant population densities in the two growing seasons produced significantly different grain yields, as indicated by the results of the least significant difference test (LSD). It could be the result of variations in the weather, light intensity, soil fertility and other environmental variables. These findings concur with those of Zhang et al. (2022) and El-Deeb (1990) who discovered that plant population density significantly impacted grain yield/fad. According to Mahgoub and EL-Shenawy (2006), grain yield per unit area rose dramatically with rising plant population densities.

Table 9. Effect of nitrogen fertilizer rates, plant population densities and maize varieties as well as their interactions on grain yield (ard/fad) in 2021 and 2022 growing seasons

Density 1000 plants/fad	Varieties	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	22.5	25.0	27	24.8	25	27	30.4	27.4
	SC122	19.9	21.3	23.7	21.6	23.2	24.6	28	25.3
	TWC310	20.2	23.6	26.5	23.4	24.3	26.7	32.2	27.7
	TWC352	18.4	19.8	21.5	19.9	20.2	21.4	25.8	22.5
Mean		20.2	22.4	24.7	22.5	23.2	24.9	29.1	25.7
30	SC10	20.8	23.6	25.5	23.3	23.4	25.7	27.3	25.4
	SC122	19.1	22.1	23.2	21.5	21.3	25	26.5	24.3
	TWC310	20.0	23.9	25.9	23.3	26.5	22.7	27.3	25.5
	TWC352	16.6	18.7	20.9	18.7	18.1	21.4	23.3	20.9
Mean		19.1	22.1	23.9	21.7	22.3	23.7	26.1	24.0
Means overall density	SC10	21.7	24.3	26.3	24.1	24.2	26.3	28.8	26.4
	SC122	19.5	21.7	23.5	21.6	22.2	24.8	27.2	24.8
	TWC310	20.1	23.8	26.2	23.4	25.4	24.7	29.8	26.6
	TWC352	17.5	19.3	21.2	19.3	19.2	21.4	24.6	21.7
	Mean	19.7	22.3	24.3	22.1	22.7	24.3	27.6	24.9
LSD at 0.05 for N		0.69				0.80			
D		0.52				0.55			
H		0.48				0.68			
N x D		NS				0.95			
N x H		0.84				1.18			
D x H		0.68				0.97			
N x D x H		NS				1.67			

Shapiro and Wortmann, (2006) found that a reduction in row spacing from 0.76 to 0.51 m led to a 4% increase in grain production in this area. Nonetheless, it was demonstrated by Abdel-Aziz (1987) and Nedic et al. (1991) that grain yield per unit area dropped as plant population densities increased. However, it was shown by Singh and Tajbakhsh (1986), Nunez et al. (1996) that an increase in plant population density had no appreciable effect on grain output. Increasing stand density may boost grain output because it promotes higher soil fertility and more plants per stand or number of plants at harvest. Conversely, increased plant population density may have decreased grain output because of mutual shade and competition in dense planting, which resulted in ear characteristics and reeducation of the leaf area index Table 4.

Table 9 findings revealed that there were substantial differences in the grain yields of the examined varieties of maize in both growing seasons, concerning ard/fad. The greatest grain yields in the 2021 growing season were recorded by SC10 and TWC310, followed by SC122 and TWC352 (24.1, 23.4, 21.6 and 19.3 ard/fad), in that order. Conversely, TWC310 produced the highest grain yield (26.6, 26.4, 24.8 and 21.7 ard/fad), followed by SC10, SC122 and TWC352. Grain yield in maize varied greatly among genotypes, according to El-Mekser and Seiam, (2008). Conversely, Mohamed et al. (2002) found that single crossings outperformed three-way crosses in terms of grain yield per unit area.

Except (N x D) and (N x D x H), the data in Table 9 show that the interaction effects of nitrogen fertilizer rates, plant population densities and maize varieties on grain production in ard/fad were significant in the 2021 growing season. Nonetheless, throughout the 2022 growing season, every interaction between the components under study was noteworthy. In general, planting all cultivars at a pace of 30,000 plants/fad and providing 120–150 kg/N produced the highest grain yield figures. According to Zhang et al. (2022), there is little correlation between plant population densities (N x D) and nitrogen fertilizer rates.

3.4. Chemical analysis:

3.4.1. Nitrogen concentration in grains (%):

The effect of N fertilizer rates, plant population densities and maize hybrids on nitrogen percentage in grains at harvest are presented in Table 10. Data in Table 10 showed that the effect of nitrogen fertilizer rates on N% in grains at harvest was highly significant in the 2021 and 2022 growing seasons. Increasing nitrogen fertilizer rates from 90 to 120 and 150 kg N/fad significantly increased N% in gains at harvest by 14.1 and 18.1% and 11.1 and 22.2% in the 2021 and 2022 growing seasons, respectively. The highest mean value of N% in grains was obtained by adding 150 kg N/fad. Many investigators obtained the same results Zhang et al. (2022) and Noreldin (2005) reported that increasing nitrogen fertilizer rates led to a significant increase in nitrogen content in maize grains. Results in Table 10 revealed that the effect of plant population densities on nitrogen percentages in grains at harvest was highly significant in both growing seasons. Increasing plant population densities from 24000 to 30000 plants/fad significantly increased N% in grains from 1.954 to 2.086% in the 2021, growing season and from 2.806 to 2.949% in, the 2022 growing seasons. Zhang et al. (2022) reported that increasing plant population density up to 30000 plants/fad significantly decreased N% in grains at harvest. However, Shapiro and Wortmann (2006) showed that N% in grains was not significantly affected by increasing plant population densities from 24000 to 30000 plants/fad. Respecting N% in grains, data in Table 10 showed that the studied maize hybrids significantly differed in the N content in grains in both growing seasons. In the 2021 growing season, TWC310 and SC10 exhibited the highest values of N% in grains, followed by TWC352 and SC122 (2.370, 2.085, 2.177 and 1.988%). However, in the 2022 growing season, TWC310 and SC10 had the highest values of N% in grains followed by SC122 and TWC352 (3.078, 2.976, 2.687 and 2.768%). In this regard, Shafshak et al. (1994) show that N% in grains was significantly affected by the different genotypes. Data in Table 10 indicate that the interaction effects between nitrogen fertilizer rates, plant population densities and hybrids were not significant in, 2021 and 2022 growing seasons.

Table 10. Effect of nitrogen fertilizer rates, plant population densities and maize hybrids as well as their interactions on nitrogen concentration in grains at harvest (%) in 2021 and 2022 growing season

Density 1000 plants/fad	Hybrids	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	1.523	2.080	2.020	1.874	2.653	2.847	3.230	2.910
	SC122	1.767	1.897	1.940	1.868	2.467	2.740	2.927	2.711
	TWC310	1.857	2.117	2.327	2.100	2.690	2.920	3.337	2.982
	TWC352	1.773	2.000	2.153	1.976	2.267	2.673	2.917	2.619
Mean		1.730	2.023	2.110	1.954	2.519	2.795	3.103	2.806
30	SC10	1.913	2.147	2.150	2.070	2.783	3.000	3.340	3.041
	SC122	1.887	2.130	2.037	2.018	2.587	2.840	3.047	2.824
	TWC310	2.040	2.213	2.413	2.222	2.867	3.167	3.493	3.176
	TWC352	1.837	2.070	2.200	2.036	2.410	2.833	3.023	2.756
Mean		1.919	2.140	2.200	2.086	2.662	2.960	3.226	2.949
Means overall density	SC10	1.718	2.113	2.085	1.972	2.718	2.923	3.285	2.976
	SC122	1.827	2.013	1.988	1.943	2.527	2.790	2.987	2.768
	TWC310	1.948	2.165	2.370	2.161	2.778	3.043	3.415	3.079
	TWC352	1.805	2.035	2.177	2.006	2.338	2.753	2.970	2.687
Mean		1.825	2.082	2.155	2.020	2.590	2.878	3.164	2.877
LSD at 0.05 for	N	0.100				0.108			
	D	0.064				0.116			
	H	0.103				0.122			
	N x D	NS				NS			
	N x H	NS				NS			
	D x H	NS				NS			
	N x D x H	NS				NS			

3.4.2. Proline concentration in leaves (%):

The impact of N fertilizer rates, plant population densities, and maize cross breeds on proline% at leaves in Table 11. Information in Table 11 shows that the impact of nitrogen fertilizer rates on proline% was profoundly noteworthy within the 2021 and 2022 developing seasons. Expanding nitrogen fertilizer rates from 90 to 120 and 150 kg N/fad essentially expanded proline% at leaves from 1.62 to 2.00% and 1.719 to 2.01% for 24000 and 30000 plants/fad within the to begin with the season, respectively. Moreover, within the moment season 2.41 to 3.008 % and 2.52 to 3.22%, for 24000 and

30000 plants/fad, respectively. The most elevated cruel esteem of proline% at clears out was gotten by including 150 kg N/fad. Comes about in Table 11 uncovered that the impact of plant population densities on proline% was profoundly critical in both developing seasons. Expanding plant population densities from 24000 to 30000 plants/fad altogether expanded proline% by 1.87 and 1.92% within the begin-with season and 2.68 and 2.86% within, the moment season. In maize (Zea mays L.), proline accumulation is a common response to environmental stresses (Verslues *et al*., 2024).

Table 11. Effect of nitrogen fertilizer rates, plant population densities and maize hybrids on proline (%) in leaves in 2021 and 2022 growing season

Density 1000 plants/fad	2021			2022		
	24	30	Mean	24	30	Mean
SC10	1.674	2.01	1.842	2.81	2.041	2.426
SC122	1.8	2.018	1.909	2.61	2.845	2.728
TWC310	2.00	2.00	2.000	2.888	3.108	2.998
TWC352	1.70	2.001	1.851	2.55	2.79	2.670
Mean	1.79	2.01	1.90	2.71	2.70	2.71
90	1.62	1.719	1.667	2.41	2.52	2.465
120	2.00	2.03	2.015	2.614	2.85	2.732
150	2.00	2.01	2.005	3.008	3.22	3.114
Mean	1.87	1.92	1.897	2.68	2.86	2.770
LSD at 0.05 for						
N	0.02			0.06		
D	0.054			0.012		
H	0.21			0.14		

3.4.3. Phosphorus content in grains:

The effect of N fertilizer rates, plant population densities and hybrids as well as their interactions on phosphorous percentage in grains at harvest are presented in Table 12. The effect of nitrogen fertilizer rates on P% in grains at harvest was highly significant in 2021 and 2022 growing seasons. Increasing nitrogen fertilizer rates from 90 to 120 and 150 kg N/fad significantly increased P% in gains at harvest by 0.257 and 0.330% and 0.288 and 0.274% in 2021 and 2022 growing seasons, respectively. The highest mean value of N% in grains was obtained by adding 150 kg N/fad. Many investigators obtained the same results Shafshak et al. (1994) and Zhang et al. (2022) reported that increasing nitrogen fertilizer rates led to a significant increase in phosphorus content in maize grains at harvest. Results in Table 12 revealed that the effect of plant population densities on phosphorus percentage in grains at harvest was highly significant in both growing seasons. Increasing plant population densities from 24000 to 30000 plants/fad significantly decreased P% in grains from 0.692 to 0.617% in 2021 growing season and from 0.0.762 to 0.696% in 2022 growing season. The same result was obtained by Zhang et al. (2022) who reported that P% in grains was significantly affected by plant population densities. However, Suliman (2003) showed that P% in grains was not significantly affected by increasing plant population densities from 24000 to 30000 plants/fad. Respecting P% in grains, data in Table 12 showed that the studied maize hybrids significantly differed in phosphorus content in grains at harvest in both growing seasons.

In 2021 growing season, SC10 and TWC310 exhibited the highest values of P% in grains, followed by TWC352 and SC122 (0.704, 0.683, 0.617 and 0.613%), respectively. However, in 2022 growing season, SC 10 and SC 122 had the highest values of P% in grains followed by TWC310 and TWC352 (0.780, 0.727, 0.725 and 0.684%), respectively. In this regard, Shafshak et al. (1994) show that P% in grains was significantly affected by the different genotypes.

Data in Table 12 indicate that the interaction effects among nitrogen fertilizer rates, plant population densities and hybrids were significant in 2021 and 2022 growing seasons, except that of (N x D x H) in 2021 growing season and (N x D) and (N x D x H) in 2022 growing season. In both growing seasons, SC10 exhibited the highest values of P% in grains (0.853% and 0.835%), respectively when planted at the rate of 24000 plants/fad and fertilized with 150 kg N/fad. This was true since maize plants should grow in high soil fertility with a wide distance between plants to permit capturing lighter and absorb more mineral nutrients.

Table 12. Effect of nitrogen fertilizer rates, plant population densities and maize hybrids as well as their interactions on phosphorus concentration in grains at harvest (%) in 2021 and 2022 growing season

Density 1000 plants/fad	Hybrids	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	0.670	0.767	0.853	0.763	0.736	0.850	0.919	0.835
	SC122	0.553	0.623	0.730	0.636	0.711	0.773	0.806	0.763
	TWC310	0.653	0.763	0.767	0.728	0.672	0.771	0.792	0.745
	TWC352	0.517	0.650	0.757	0.641	0.636	0.699	0.779	0.705
Mean		0.598	0.701	0.777	0.692	0.689	0.773	0.824	0.762
30	SC10	0.617	0.660	0.659	0.645	0.693	0.746	0.735	0.724
	SC122	0.527	0.590	0.657	0.591	0.653	0.723	0.695	0.690
	TWC310	0.613	0.657	0.647	0.639	0.624	0.759	0.733	0.705
	TWC352	0.483	0.650	0.643	0.592	0.620	0.646	0.722	0.663
Mean		0.560	0.639	0.652	0.617	0.647	0.719	0.721	0.696
Means overall density	SC10	0.643	0.713	0.756	0.704	0.715	0.798	0.827	0.780
	SC122	0.540	0.607	0.693	0.613	0.682	0.748	0.751	0.727
	TWC310	0.633	0.710	0.707	0.683	0.648	0.765	0.762	0.725
	TWC352	0.500	0.650	0.700	0.617	0.628	0.672	0.751	0.684
Mean		0.579	0.670	0.714	0.654	0.668	0.746	0.773	0.729
LSD at 0.05 for	N	0.026				0.035			
	D	0.020				0.020			
	H	0.023				0.025			
	N x D	0.035				NS			
	N x H	0.040				0.043			
	D x H	0.033				0.035			
	N x D x H	NS				NS			

3.4.4. Potassium content in grains:

The effect of N fertilizer rates, plant population densities and maize hybrids as well as their interactions on potassium percentage in grains at harvest is presented in Table 13. Data in Table 13 showed that the effect of nitrogen fertilizer rates on K% in grains at harvest was highly significant in 2021 and 2022 growing seasons. Increasing nitrogen fertilizer rates from 90 to 120 and 150 kg N/fad significantly increased K% in gains at harvest by 0.073 and 0.131% and 0.085 and 0.152% in 2021 and 2022 growing seasons, respectively. The highest mean value of K% in grains was obtained by adding 150 kg N/fad. Many investigators obtained the same results Zhang et al. (2022) and Noreldin (2005) reported that increasing nitrogen fertilizer rates led to a significant increase in potassium content in maize grains.

Results in Table 13 revealed that the effect of plant population densities on potassium percentage in grains at harvest was highly significant in both growing seasons. Increasing plant population densities from 24000 to 30000 plants/fad significantly decreased K% in grains from 0.575 to 0.517% in 2021 growing season and from 0.509 to 0.483% in 2022 growing season. However, Zhang et al. (2022) showed that K% in grains was not significantly affected by increasing plant population densities from 20000 and or 24000 to 30000 plants/fad. Respecting K% in grains, data in Table 13 showed that the studied maize hybrids significantly differed in potassium content in grains at harvest in both growing seasons. In 2021 growing season, TWC310 and TWC352 exhibited the highest values of K% in grains, followed by SC10 and SC122 (0.594, 0.564, 0.533 and 0.494%), respectively. However, in 2022 growing season, TWC310 and S 10 had the highest values of K% in grains followed by SC122 and TWC 352 (0.578, 0.560, 0.458 and 0.387%), respectively. Data in Table 13 indicate that the interaction effects among nitrogen fertilizer rates, plant population densities and maize hybrids were significant in 2021 and 2022 growing seasons, except that of (N x D) and (N x D x H) in, 2021 growing season and (N x H) and (N x D x H) in 2022 growing season. In the 2021 and 2022 growing seasons, SC10 and TWC310 produced the highest values of K% in grains when planted at the rate of 24000 plants/fad and fertilized with 150 kg N/fad.

Table 13. Effect of nitrogen fertilizer rates, plant population densities and maize hybrids as well as their interactions on potassium concentration in grains at harvest (%) in 2021 and 2022 growing seasons

Density 1000 plants/fad	Hybrids	2021 growing season				2022 growing season			
		N-rate kg N/fad							
		90	120	150	Mean	90	120	150	Mean
24	SC10	0.498	0.582	0.664	0.581	0.591	0.610	0.668	0.623
	SC122	0.472	0.518	0.548	0.513	0.423	0.459	0.474	0.452
	TWC310	0.604	0.635	0.685	0.641	0.517	0.608	0.646	0.590
	TWC352	0.500	0.577	0.615	0.564	0.313	0.376	0.422	0.370
Mean		0.519	0.578	0.628	0.575	0.461	0.513	0.552	0.509
30	SC10	0.415	0.468	0.568	0.484	0.425	0.488	0.578	0.497
	SC122	0.412	0.492	0.522	0.475	0.354	0.445	0.593	0.464
	TWC310	0.498	0.552	0.588	0.546	0.443	0.574	0.681	0.566
	TWC352	0.425	0.582	0.685	0.564	0.267	0.455	0.490	0.404
Mean		0.438	0.523	0.591	0.517	0.372	0.491	0.586	0.483
Means overall density	SC10	0.457	0.525	0.616	0.533	0.508	0.549	0.623	0.560
	SC122	0.442	0.505	0.535	0.494	0.388	0.452	0.534	0.458
	TWC310	0.551	0.593	0.637	0.594	0.480	0.591	0.664	0.578
	TWC352	0.463	0.579	0.650	0.564	0.290	0.415	0.456	0.387
Mean		0.478	0.551	0.609	0.546	0.417	0.502	0.569	0.496
LSD at 0.05 for	N	0.027				0.014			
	D	0.015				0.021			
	H	0.024				0.020			

N x D	NS	0.036
N x H	0.042	NS
D x H	0.035	0.029
N x D x H	NS	NS

4. Conclusion

In conclusion, the study identified that for maximum grain yield, planting single-cross hybrid 10 (SC 10) at a density of 24,000 plants per feddan (fad) with nitrogen fertilizer application of 150 kg/fad resulted in the most favorable outcome.

In summary, the Proline percentage in maize leaves can fluctuate based on environmental conditions, genotype and stress levels.

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Table 4. Effect of nitrogen fertilizer rates, plant population densities, and maize varieties as well as their interactions on leaf area index (LAI) after 60 and 90 days from planting in 2021 and 2022 growing seasons.

Density 1000 plants/fad	Varieties	2021 growing season								2022 growing season							
		60 Days after sowing				90 Days after sowing				60 Days after sowing				90 Days after sowing			
		N-rate kg N/fad															
		90	120	150	Mean	90	120	150	Mean	90	120	150	Mean	90	120	150	Mean
24	SC10	2.79	3.16	3.75	3.23	3.19	3.69	4.35	3.75	2.63	3.43	3.97	3.34	3.61	4.61	5.43	4.55
	SC122	2.18	2.78	3.02	2.66	2.80	3.39	3.54	3.25	2.13	2.48	3.13	2.58	2.50	3.30	3.86	3.22
	TWC310	2.55	3.06	3.26	2.96	3.06	3.55	4.26	3.62	2.68	3.29	3.96	3.31	3.55	4.84	5.60	4.66
	TW 352	1.71	2.00	3.68	2.46	2.01	2.43	4.13	2.86	1.76	2.15	2.86	2.26	2.73	3.29	3.77	3.26
Mean		2.31	2.75	3.43	2.83	2.77	3.27	4.07	3.37	2.30	2.84	3.48	2.87	3.10	4.01	4.66	3.92
30	SC10	3.14	3.56	4.03	3.58	3.51	4.28	4.88	4.22	2.73	3.24	4.61	3.53	4.10	4.94	5.96	5.00
	SC122	2.43	2.97	3.51	2.97	2.79	3.46	4.18	3.48	2.44	2.93	3.72	3.03	2.98	3.48	4.11	3.53
	TWC310	2.96	3.20	2.89	3.01	3.14	4.10	5.24	4.16	3.00	3.78	4.57	3.78	3.88	4.71	5.64	4.75
	TWC352	1.91	2.18	2.65	2.25	2.26	2.82	3.63	2.90	2.01	2.64	2.91	2.52	2.98	3.60	4.17	3.58
Mean		2.61	2.98	3.27	2.95	2.93	3.67	4.48	3.69	2.54	3.15	3.95	3.21	3.49	4.18	4.97	4.21
Means overall density	SC10	2.96	3.36	3.89	3.40	3.35	3.99	4.62	3.99	2.68	3.34	4.29	3.43	3.86	4.77	5.69	4.77
	SC122	2.31	2.87	3.27	2.82	2.80	3.42	3.86	3.36	2.29	2.70	3.42	2.80	2.74	3.39	3.98	3.37
	TWC310	2.75	3.13	3.08	2.99	3.10	3.83	4.75	3.89	2.84	3.54	4.26	3.55	3.72	4.78	5.62	4.70
	TWC352	1.81	2.09	3.16	2.35	2.13	2.62	3.88	2.88	1.89	2.40	2.88	2.39	2.86	3.45	3.97	3.42
Mean		2.46	2.86	3.35	2.89	2.85	3.47	4.28	3.53	2.42	2.99	3.71	3.04	3.29	4.10	4.82	4.07
LSD at 0.05 for	N	0.07				0.09				0.12				0.05			
	D	0.08				0.07				0.10				0.06			
	H	1.04				0.09				0.11				0.11			
	N x D	NS				0.12				0.17				0.10			
	N x H	0.12				0.15				0.16				0.20			
	D x H	0.10				0.12				0.13				0.16			
	N x D x H	0.17				0.21				NS				NS			