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IMPACT OF BIO-ORGANIC FERTILIZATION AND NITROGEN LEVELS ON MAIZE (*Zea mays* L.) RESILIENCE

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Abstract. A field study on maize growth in sandy soils found that applying 5 tons/fad of compost significantly enhanced plant growth and grain yield. Increasing the nitrogen (N) rate up to 135 kg N/fad also, led to a notable increase in plant and grain yield and resulted in early flowering. The application of phosphorus and potassium (PK) at a rate of 15.5 kg P_2O_5 + 48 kg K_2O/fad led to early flowering and significantly increased grain yield. Furthermore, the application of PK fertilizer led to an increase in the nitrogen and phosphorus content of grains in both growing seasons. The concentration of proline, which serves as an endogenous osmoprotectant against biotic stress, also increased. The suggested PK fertilizer level (15.5 kg P_2O_5 + 48 kg K_2O/fad) resulted in a notable rise in the CP% in grains. The research further revealed that the uptake of nitrogen in grains increased in response to higher nitrogen levels, with the maximum nitrogen utilization efficiency being 25.11 kg of grains/ kilogram of applied nitrogen.

Keywords: *Systemic resistance, proline and endogenous osmoprotectants, crude protein, nitrogen economy.*

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1. Introduction

Maize (*Zea mays* L.), a versatile crop within the Poaceae family, holds significant importance as a multipurpose grain. It serves various purposes including animal and poultry feed, human consumption, and industrial applications. Maize is utilized in the production of starch, dextrose, syrup, and flakes, highlighting its diverse utility across different sectors (Gul *et al.*, 2021).

Maize production faces challenges due to climate change and soil fertility deterioration, emphasizing the need for appropriate fertilizer use, soil management, and agronomic practices to sustain productivity and food security (Ocwa *et al.*, 2023). Nitrogen (N) is a crucial nutrient for plants, essential for various biological compounds vital for photosynthesis and agricultural efficiency. Maize grain yield and plant growth are directly impacted by nitrogen availability. Factors such as radiation interception, efficient utilization, and nitrogen partitioning to reproductive organs serve as indicators of the influence of nitrogen availability on maize grain output (Sandhu *et al.*, 2021).

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Studies have shown that nitrogen application significantly affects maize productivity, with climatic conditions playing a substantial role in maize yield. Additionally, research has highlighted the importance of optimizing genotype-environment-management interactions to help maize farmers adapt to climate change and enhance productivity (Zhang *et al*., 2022). The use of ethephon has been found to reduce maize nitrogen uptake while improving nitrogen utilization, showcasing the complex relationship between nitrogen application and maize growth (Gheith *et al*., 2022). Overall, nitrogen levels play a critical role in shaping maize growth, yield, and resilience against environmental stressors. Fertilization of phosphorus and potassium is important in balancing the fertility of inceptisol soil to support the growth and production of maize. Two of the twelve minerals that are necessary for plant growth are phosphorus (P) and potassium (K). Corn plants absorb large amounts of both P and K. In order to encourage strong seedling growth and stimulate root and shoot growth, phosphorus is essential. Because it increases resistance to disease and water stress, potassium is essential for corn growth. Corn plants can more effectively absorb other nutrients when they have enough K in their bodies (Gurmu, 2023).

Numerous studies have examined how zea mays *L*. responds to bio-organic fertilization in freshly reclaimed soils at varying doses of nitrogen fertilizer under biotic stress. It has been discovered that applying nitrogen fertilizer is crucial for increasing hybrid maize grain yield (Hussein *et al*., 2022). Furthermore, it has been demonstrated that applying nitrogen fertilizer to maize greatly increases grain output (Sharma *et al*., 2019). Moreover, it has been discovered that zinc levels and biofertilizers work together to enhance maize production and growth (Sasank & Dawson, 2022). According to research, there are some combinations of organic manure and mineral and nano nitrogen fertilizers that can boost maize plant height, grain production, and harvest index (Khalil *et al*., 2019). Numerous researches have focused on improving zea mays' resilience by bio-organic fertilization and examining how nitrogen fertilizer levels affect the bio stress response. According to one study, using a microbial consortium made up of Xanthobacter autotrophicus, Saccharomyces cerevisiae, Schizosaccharomyces pombe, and Pichia norvegensis with 70% NH_4NO_3 fertilizer improved the phenology, biomass, and germination of Zea mays (Velazquez-Medina *et al*., 2023). Research conducted on the impact of mycorrhiza (Rhizoglomus intraradices) and soil bacteria applications on maize production revealed that the concurrent usage of soil bacteria mitigated the adverse effects of mycorrhiza treatment (Thielicke *et al*., 2023). Furthermore, adding organic chicken manure fertilizer and inoculating maize plants with Funneliformis mosseae (FM) enhanced the nitrogen content and photosynthetic efficiency, indicating the possibility of utilizing FM and organic fertilizers to boost maize development (Yooyongwech *et al.*, 2022). Bio-Organic fertilization practices can result in producing quality plants with greater adaptation to the environment. Maize (*Zea mays* L.) is subjected to many biotic stresses, e.g., fungal, bacterial and viral diseases (Kapela *et al*., 2020). Many viral diseases found in maize as Cucumber mosaic virus, Maize chlorotic dwarf virus (MCDV), Maize mosaic virus (MMV) Maize chlorotic mottle virus (MCMV) and Maize streak virus (MSV). Viruses can reduce vegetative growth and corn quality. For example, CMV and Maize streak virus (MSV) which is transmitted by vectors severely reduces marketability. The economic losses caused by these diseases are complicated because both the cultivar and the environment in which the plants are growing can influence the severity of the symptoms. Proline is an important constituent that enhances biotic stress by affecting physiological and biochemical properties of plants (Hosseinifard *et al*., 2022; Sadeghipour, 2020; El-Beltagi *et al*., 2020). Application of bio-organic fertilization enhances proline synthesis which results in increased systemic resistance against maize pathogen (Qirat *et al*., 2018).

These studies collectively underscore the significance of bio-organic fertilization, nitrogen levels, and sustainable agricultural practices in improving maize resilience against biotic stress and enhancing crop productivity in the face of changing environmental conditions.

2. Materials and Methods

The study was carried out throughout the two succeeding growing seasons in 2022 and 2023. The purpose of this work was to investigate the effects of mineral fertilization (nitrogen and PK fertilizers) and bio-organic fertilization (compost) on the growth, yield, and yield components of maize (Z*ea maize L*.), as well as the concentration of NPK in the grains, crude protein, proline content, and nitrogen economy during both growing seasons, wheat was the previous winter crop.

Experimental design and treatments

The experimental design used a split-plot with four replications. Compost treatments were allocated to the main plots. The rates of nitrogen and PK fertilizers were dispersed at random in each Sup plot. There were twenty-four treatments in the field trial, which were combinations of:

1- Compost treatments:

Three treatments of compost were used in both seasons (zero, without compost, 5 tons/fad from each of maize compost and wheat compost.

Preparation of compost

There were two distinct piles of shredded maize straw and wheat, each heap measured a total of 3 x 2 x 1.5 m (9 m^3). It was made up of many layers of stover made of maize or wheat. A piece heap's approximate weight (100 kg apiece) was noted individually. Carefully, the shredded straw was distributed on a plastic sheet. The size of the heaps was adjusted by preparing compost inside a 1 × 1 m wood frame. To 100 kg of stover, 25 kg of pentonite, 50 kg of rock phosphates, and 20 kg of organic manure were added. Additionally, one liter of Trichoderma veridi was pressed into each layer of the piles. After adding Trichoderma veridi and Bacillus magatherium var phosphate, the compost needed to mature for 15 days. After that, it was necessary to add one liter of Azotobacter sp. and Azospirillum sp. and store the heaps until planting. Table 1 displays the chemical makeup of compost made from both wheat and maize at various stages of preparation needed to ensure that each kind of compost is fully mature.

2- Nitrogen fertilizer treatments

In the most current study, four treatments of nitrogen fertilizer rates were 0, 45, 90 and 135 kg of active nitrogen (as 33.5% ammonium nitrate)/faddan during both growth seasons in sub plot design, eight equal dosages of fertilizer were administered as a side dressing before to each irrigation.

3- Phosphorus and potassium fertilizer treatments

In the most current study, two treatments of the required rates of potassium and phosphorus fertilizer 200 kg/fad of calcium superphosphate, or 15.5 kg P_2O_5 and 48 kg K_2O of potassium sulphate, respectively in sub-sub plot design. Two applications of fertilizer were made, one before each of the growing seasons first irrigations and planting. Each plot was made up of five ridges spaced 70 cm apart and 6 m long. The first and fifth outer ridges were regarded as boundaries.

Table 1. Changes in chemical properties of organic wastes during composting process, 2022 and 2023 growing seasons

Samples	PH (1 :10 ex tract)	EC (ds/m at 25 ^{0}C)	Organic-C %	Organic matter %	Total N %	C/N ratio	Total P%
Maize straw		2022					
Zero time	8.3	1.8	51.6	88.7	0.8	64.9	0.6
First sample	8.1	1.6	49.2	84.6	0.8	55.8	1.1
Second sample	7.5	3.5	43.0	74.0	1.4	31.2	1.5
Third sample	7.3	3.9	36.9	58.8	1.5	22	1.7
Wheat straw		2022					
Zero time	8.1	1.3	45.2	77.7	0.7	62.8	0.7
First sample	7.6	1.4	43.7	75.2	0.8	57.5	1.0
Second sample	7.1	4.1	35.2	60.5	1.2	28.6	1.8
Third sample	7.2	4.4	29.1	50.1	1.6	18.9	1.8
Maize straw		2023					
Zero time	8.1	1.7	52.2	88.3	0.9	65.1	0.8
First sample	7.8	2.5	46.3	79.6	0.9	50.3	1.1
Second sample	7.4	3.4	35.8	61.6	1.1	33.2	1.4
Third sample	7.2	5.9	30.2	51.9	1.4	22.4	1.6
Wheat straw		2023					
Zero time	8.2	1.4	45.2	78.3	0.8	63.2	0.8
First sample	7.6	2.1	42.6	73.3	1.0	49.4	1.3
Second sample	7.3	3.8	32.8	56.4	1.2	26.5	1.5
Third sample	7.1	6.1	26.1	44.9	1.4	18.1	1.7

One ridge of the remaining three ridges was left to draw a sample of leaves for chemical analysis after one week from silking). Grain yield, yield components and other agronomic traits were determined from the remaining two ridges (plot size was 1/500 fad, one faddan = 4200 m^2 or 0.42 ha). Two maize grains were hand planted in hills spaced 25 cm and irrigation was applied using surface irrigation. Thinning to one plant per hill was done after 15 days from planting to give a population density of 24000 plant/fad. All plots were hand hoed twice for controlling weeds after 15 and 25 days from planting in each growing seasons. Recommended pest control was applied when necessary. Harvest took place after 110 days from planting which were quite enough for full maturation for all experimental treatments.

The following characters were noted:

1. Characteristics of vegetative growth. Tasseling and silking dates are calculated from the entire plot and expressed as the number of days from planting to 50% tasseling. Moreover, plant height (cm) at harvest, calculated as an average of 10 plants and measured from the ground rate to the base of the flag,

2. Yield and yield components. At harvest, the average number of grains per row was determined by weighing 100 grains (g), estimating the grain yield (ardab/fad) from the plots three center ridges, and measuring the average number of ears per row. The grains moisture content was adjusted to 15.5%.

3. Chemical composition. 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).
- To determine the crude protein percentage in grains, multiply the N% in grains by 6.25.
- Proline's interaction with ninhydrin was used to determine the content of proline in leave (Marín *et al*., 2009).

4. Nitrogen fertilizer economy

4.1. Nitrogen uptake (NUP) in grains.

4.2. Nitrogen Use efficiency (NUE) calculated as kg grain per kg nitrogen applied (kg grain kg^{-1}N applied).

4.3. Apparent nitrogen recovery (NRc), calculated as nitrogen in grains per kg nitrogen applied (kg N grain kg^{-1} N applied). All nitrogen fertilizer economy parameters (NUP, NUE and NRc) were calculated according to Godwin (1984) as follows:

NUP = Grain yield x N% in grains,

$$NUE = \frac{\text{Grain yield F - Grain yield C}}{\text{Fertilizer N applied}}$$

$NRc = \frac{\text{N uptake F - N uptake C}}{\text{Fertilizer N applied}}$, where: F= fertilized plots and, C=non-fertilized plot (control)

5. Statistical analysis

The obtained data were statistically analyzed according to Snedecor and Cochran (1967). The treatment means were compared according to the LSD test. Simple correlation was also calculated between grain yield and other studied traits. In the tables of the analysis of variance, * and ** indicates significant and highly significant differences at 0.05 and 0.01 rates of probability, respectively.

3. Results and Discussion

3.1. Effect of compost

3.1.1. Number of days to 50% tasseling and silking

The effect of different rates of compost on the number of days from planting to 50% tasseling in the 2022 and 2023 growing seasons was significant. In the first growing season in 2022, applying wheat or maize compost at a rate of 5000 kg/fad notably reduced the number of days to 50% tasseling by 1.29 and 0.56 days, respectively. Wheat compost exhibited more pronounced effects on tasseling compared to maize compost, although there was no significant difference between them (Obondo *et al*., 2021).

It is clear from Figure 1 that the effect of wheat and maize compost on number of days to 50%silking was significant in only 2022 growing season. In 2022 growing season, adding wheat compost significantly decreased number of days to 50% silking by 1.2 days (66.9 *vs* 65.7 days), whereas adding maize compost didn’t cause significant change in number of days to 50% silking (66.9 *vs* 66.1 days). These results are in a good agreement with those obtained by (Nofal & Silem, 2003). They revealed that adding FYM at the rate of 20-30 m^3/fad resulted in a significant reduce in number of days from planting to 50% silking (Amran et al., 2014).

3.1.2. Plant height (cm)

Results in Figure 1 showed that the effect of compost on plant height was not significant in both growing seasons. Generally, adding 5000 m^3 of wheat or maize compost led to a slight increase in plant height as compared to the control treatment (226, 225 *vs* 217 cm and 265, 266 *vs* 259 cm), in 2022 and 2023 growing seasons, respectively). These results are not in agreement with those obtained by EI-Aref et al. (2004) who reported that increasing organic manure rates significantly increased plant height. On the other hand, Ferdous et al. (2018) reported that plant height was significantly stimulated and enhanced by biogas manure treatment. Amran et al. (2014) showed that plant height was significantly increased with an application of 10 m^3 FYM/fad, Amran et al. (2014) found that plant height was significantly the highest when 16.82 ton/ha of fresh chicken manure was applied. However, El-Shafey and El-Hawary (2016) revealed that adding biogas at the rate of 3 (ton/fad) led to a significant increase in plant height in both growing seasons.

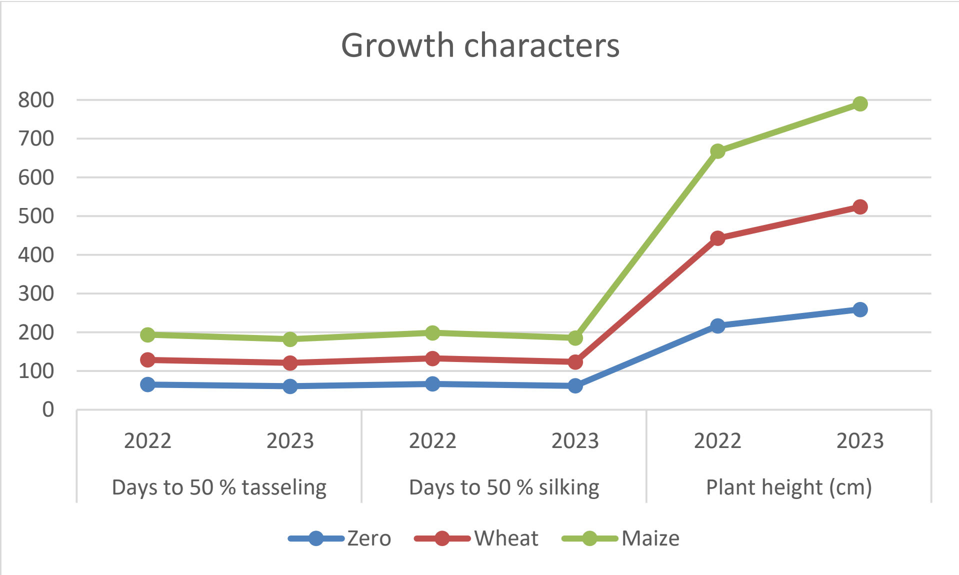

Figure 1. Effect of compost on number of days to 50% tasseling, silking and plant height (cm) in 2022 and 2023 growing seasons

3.1.3. Number of grains/row

The effect of compost on number of grains/row in 2022 and 2023 growing seasons is presented in Figure 2. The obtained results revealed mean values of number of grains/rows are greater in 2023 growing season than that in 2020 growing season (38.00 *vs* 34.28 grains/row). This may be due to that maize ears in the second growing season are health and bigger due to rich soil and suitable climatic factors in 2023 growing season. Data in Figure 2. sowed also that the effect of compost on number of grains/row was not significant in both growing seasons. Generally, there is little increase in number of grains/row due to adding 5000 m^3 compost/fad. There are no big differences in number of grains/rows between wheat compost and maize compost (34.53 *vs* 34.19 grains/row and 38.0 *vs* 38.3 grains/row in 2022 and 2023 growing season, respectively). The present results agree with those obtained by (Nofal & Silem, 2003) who found that FYM application did not significantly affected this trait. On the other hand, (Kandil *et al*., 2020; Zapałowska & Jarecki, 2024) obtained significant increase in number of grains/ear due to application of animal manures.

3.1.4. 100-grain weight

The effect of wheat and maize compost on 100-grain weight was significant in 2022 and 2023 growing seasons as presented in Figure 2. The obtained results revealed that adding 5000 (m^3/fad) of wheat and maize compost significantly increased 100-grain weight by 10.6 and 12.7%, in 2022 growing season, respectively. The corresponding increases in 2023 growing season were 6.78 and 5.6%, respectively. These results show clearly the important role of compost as source of nutrient minerals on maize plant growth in sandy soils due to its high contents of these nutrient elements as well as its role in improving soil structure as well as soil physical and chemical properties. Similar results were obtained Mosisa et al. (2022) who found that 100-grain weight increased with the application of organic-biofertilizers.

3.1.5. Grain yield (ard/fad)

Results in Figure 2 indicate that the grand mean value in the second growing season was greater than that of the first growing season (19.34 *vs* 10.96 ard/fad). This may be due to the high soil fertility (Table 1) in the experimental site and suitable climatic conditions in the second growing season as compared to the first one. The obtained results show clearly that the effect of compost on maize grain yield was significant in both growing seasons. Comparing to the check treatment (zero treatment), applying wheat compost or maize compost substantially increased grain yield by 4.34 and 12.92% in 2022 growing season, being 8.04 and 9.19% in 2023 growing seasons, respectively. It is worth noting that maize compost had enormous effect on grain yield than that of wheat compost, since it produces more grain yield/fad in both growing seasons (11.71 *vs* 10.82 ard/fad and 19.97 *vs* 19.76 ard/fad), in 2022 and 2023 growing seasons, respectively. The present results showed clearly the positive effect of compost on grain yield due to its high contents of nutritive elements and due to the role of micro-organisms in breaking down the organic matter and releasing complex compounds such as amino acids available for plant use and consequently increased the efficiency of organic matter for crop production. Similar results were obtained by Kandil et al., (2020) who found that grain yield was increased with the increase in application of FYM, biogass, EM-Bokashi and compost.

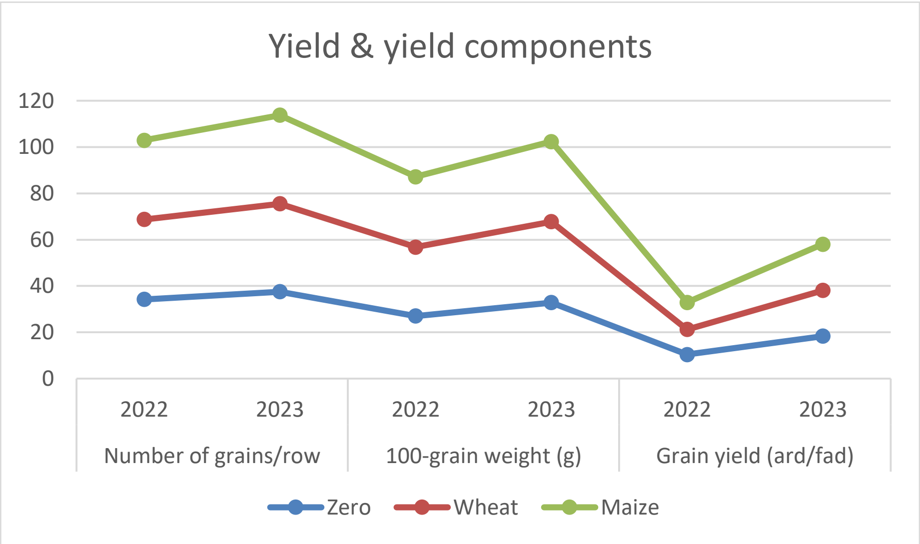

Figure 2. Effect of compost on number of grains/rows, 100-grain weight and grain yield (ard/fad), in 2022 and 2023 growing season

3.2. Effect of nitrogen fertilizer

3.2.1. Number of days to 50% tasseling and silking

The results presented in Figure 3 clearly demonstrate the significant impact of nitrogen fertilizer rates on the number of days from planting to 50% tasseling in both the 2022 and 2023 growing seasons. Increasing nitrogen fertilizer rates resulted in notable reductions in the time to reach 50% tasseling during both seasons. In the 2022 season, applications of nitrogen at 45, 90, and 135 kg/fad led to significant decreases in days to 50% tasseling by 1.3, 2.1, and 3.0 days compared to the control treatment without nitrogen. Similarly, in the 2021 season, these reductions were even more pronounced at 3.4, 4.6, and 4.7 days, respectively. This phenomenon can be attributed to the role of nitrogen in enhancing the accumulation of photosynthetic assimilates, thereby improving plant growth and hastening the tasseling process. These findings are consistent with previous research by El-Mekser (2004) supporting the positive influence of nitrogen on tasseling. Conversely, Shalaby et al. (1990) reported no significant impact of nitrogen fertilizer rates on tasseling duration. Regarding the number of days to 50% silking, Figure 3 reveals a highly significant effect of nitrogen fertilizer rates in both the 2022 and 2023 growing seasons. In 2022, applying nitrogen at rates of 45, 90, and 135 kg N/fad resulted in earlier silking by 1.5, 2.1, and 3.0 days compared to the control treatment without nitrogen. Similarly, in the following season of 2023, these values increased to 6.9, 8.0, and 8.4 days, respectively. This indicates that nitrogen application promotes early silking in maize by stimulating meristematic activity and enhancing vegetative growth, thereby advancing the silking process. These results are supported by Omar et al. (2022), who also observed a reduction in days to silking with nitrogen application. In contrast, Shalaby et al. (1990) found no significant influence of nitrogen fertilizer on silking dates.

3.2.2. Plant height (cm)

Results in Figure 3 showed that the effect of nitrogen fertilizer rates on maize plant height was highly significant in 2022 and 2023 growing seasons. The obtained data revealed that applying nitrogen at 45, 90 and 135 kg N/fad significantly increased plant height by 17.5, 19.1 and 23.2% in 2022 growing season, and by 33.5, 41.4 and 43.8% in 2023 growing season, respectively. These results indicated clearly that the role of nitrogen as a constituent of all proteins and nucleic acids which led to the increase in cells number and size which in turn encourage the elongation of the internodes of the stalk. Similar results were also reported by El-Hassanin et al. (2002) who found that increasing nitrogen rates significantly increased maize plant height.

3.2.3. Number of grains/row

Results in Figure 4 indicated significant effect of nitrogen application on number of grains/rows in both growing seasons. In 2022 growing season, applying nitrogen at 45, 90 and 135 kg/fad markedly increased number of grains/rows by 40.9, 59.5 and 66.5%, respectively. The corresponding increases in 2023 growing season were 50.4, 55.6 and 56.3% for the same nitrogen rates. The result obtained by El-Mekser (2004) are in agreement with our results. They found that increasing nitrogen levels significantly increased number of grains/rows.

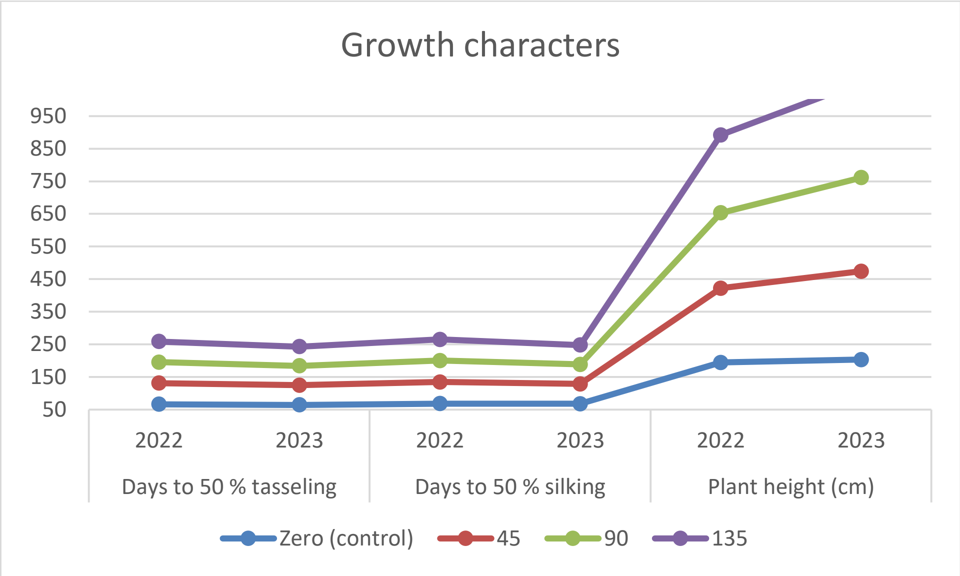

Figure 3. Effect of nitrogen fertilizer rates on number of days from planting to 50% tasseling, silking, and plant height (cm) in 2022 and 2023 growing season

3.2.4. 100-grain weight (g)

Data presented in Figure 4 revealed that nitrogen application significantly increased 100 grains weight in both growing seasons. In 2022 growing season, applying N at 45, 90 and 135 (kg/fad) increased 100 grains weight by 10.0, 15.1 and 23.2% over the check treatment, respectively. In 2023 growing season, the increase in 100 grains weight was 18.7, 34.2 and 38.5% over the control for the three respective nitrogen rates, respectively. These results were mainly due to the vital effect of nitrogen as a nutritive element and to the positive effect of N on plant growth, ear characters and grain formation. The present results were in agreement with those obtained by El-Mekser (2004) who found that 100-grains weight increased with the increase in nitrogen application rates.

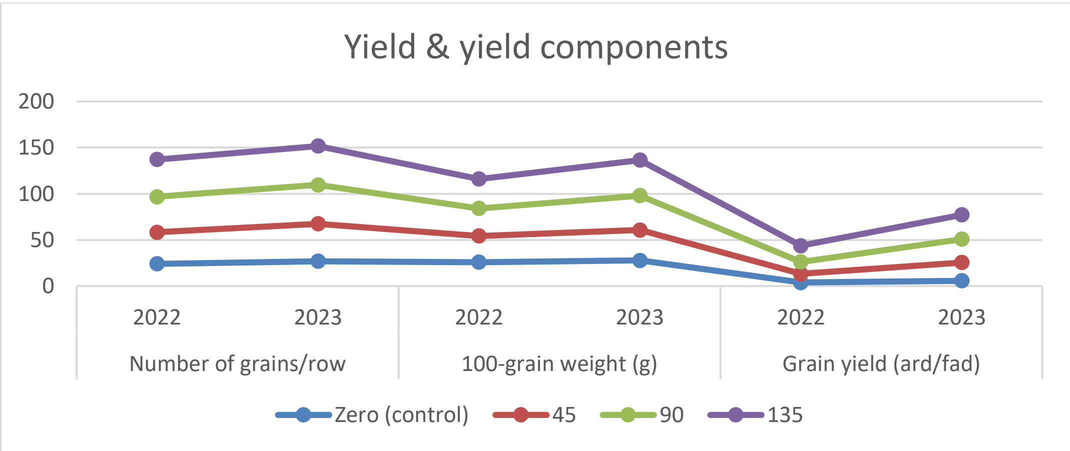

Figure 4. Effect of nitrogen fertilizer rates (kg N/fad) on number of grains/row, 100-grain weight and grain yield (ard/fad) in 2022 and 2023 growing seasons

3.2.5. Grain yield (ardab/fad)

Results in Figure 4 showed that the increase in nitrogen rates significantly increased grain yield in ard/fad in both growing seasons. In the first growing season, applying nitrogen at the rate of 45, 90 and 135 kg/fad significantly increased grain yield by 5.34, 9.16 and 13.54 (ard/fad) compared to the control, respectively. The corresponding increase in 2023 growing season for the same nitrogen rates were 13.94, 19.43 and 20.63 (ard/fad), respectively. These increases in grain yield per faddan might have resulted from the effect of nitrogen on increasing growth characters in terms of plant height and ear height as well as improving ear characters expressed as number of rows/ears, number of grains/row and 100 grain weight. Similar results were obtained by El-Mekser (2004) who found that the increase of nitrogen rates significantly increased grain yield.

3.3. Effect of phosphorus and potassium fertilizer

3.3.1. Number of days to 50% tasseling and silking

Data in Figure 5 revealed that number of days from planting to 50% tasseling and silking were significantly affected by applying phosphorus and potassium fertilizers in both growing seasons, except that of 50% silking in 2023 growing season. Adding PK fertilizers at the rate of 15.5 kg P_2O_5 + 48 K_2O led to a significant reduction of tasseling date by 0.5 and 0.7 day in both growing seasons as compared to zero PK. The corresponding reduction in silking date was 0.7 and 0.5 days with the rate of PK fertilization. These results are similar with those obtained by Barry and Miller (1992) who reported that time of 50% silking was reduced by increasing phosphorus fertilizer levels. Okalebo *et al* (1994) reported that tasseling stage showed large response to the applied P. On the other hand, Shafshak (1962) reported that phosphorus application at 32 kg P_2O_5/fad had no significant effect on tasseling date. Also, Khalifa (1970) added that increasing P_2O_5 and potassium (K) fertilizer rates did not cause significant effect on time of tasseling and silking.

3.3.2. Plant height (cm)

Results presented in Figure 5 showed that phosphorus and potassium fertilization had insignificant effect on plant height in 2022 and 2023 growing season. Generally, adding 15.5 kg P_2O_5 + 48 K_2O/fad produced slight and not significant increase in plant height as compared to the check treatment. These results are in a good harmony with those obtained by Khalifa (1970) who reported that increasing phosphorous and potassium fertilizer rate did not affect Plant height. On the other hand, Okalebo et al. (1994) reported that plant height showed large response to the applied phosphorous.

3.3.3. Number of grains/row

Results in Figure 6 revealed that phosphorus and potassium fertilization application had insignificant effect on the number of grains/rows in both growing seasons. Generally, adding PK fertilizers in a sandy soil at the rate of 15.5 kg P_2O_5 + 48 K_2O slightly increased number of grains/rows. However, Naomi et al. (2021) reported that phosphorous and potassium fertilization had no significant effects on number of grains/rows.

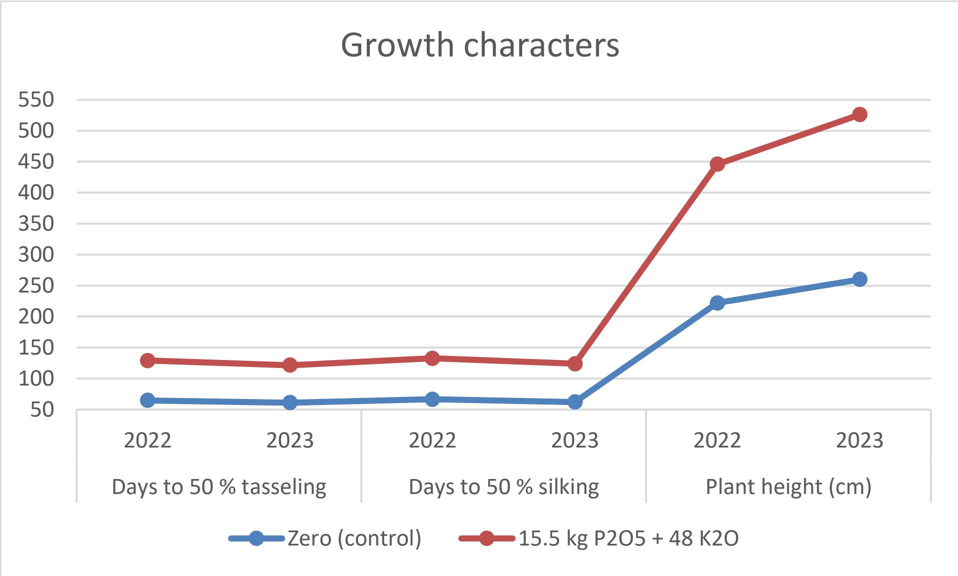

Figure 5. Effect of phosphorus and potassium fertilization on number of days to 50% tasseling, silking, and plant height (cm) in 2022 and 2023 growing season

3.3.4. 100-grain weight (g)

The effect of phosphorus and potassium fertilizer rate on 100-grain weight in 2022 and 2023 growing seasons is presented in Figure 6. The obtained results indicated that the effect of PK rate on 100-grain weight was highly significant in both growing seasons. Applying PK fertilizer at the rate of 15.5 kg P_2O_5 + 48 K_2O kg/fad markedly increased seed index by 3.1 and 4.5% as compared to the check treatment in 2022 and 2023 growing seasons, respectively. The obtained results showed the important role of phosphorus and potassium as major elements in the sandy soils which led to increase 100-grain weight. Similar results were obtained by Naomi et al. (2021). However, Khalifa (1970) reported that increasing P_2O_5 and K fertilizers did not significantly affect 100-grain weight.

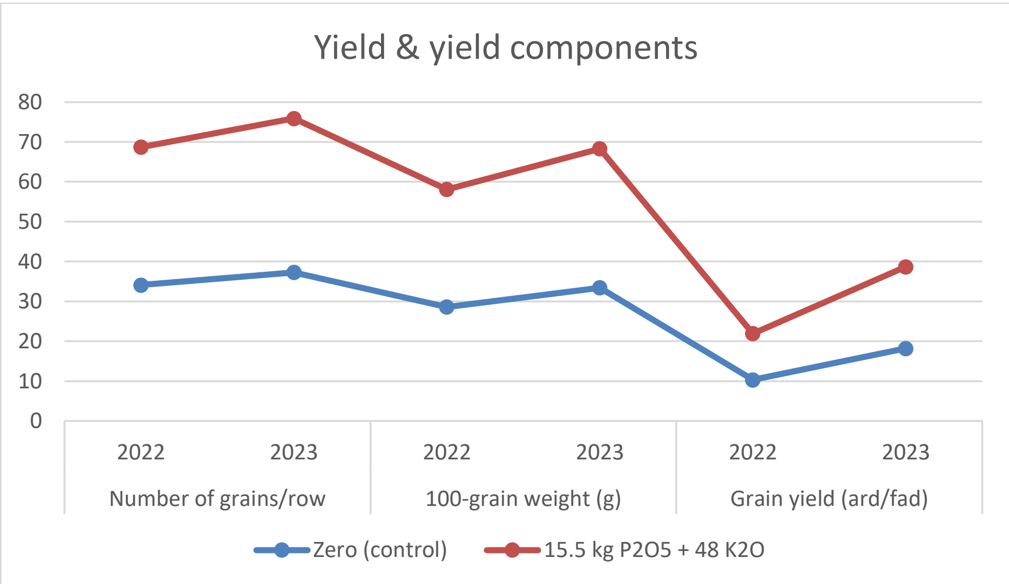

Figure 6. Effect of phosphorus and potassium fertilization on number of grains/rows, 100-grain weight and grain yield (ard/fad) in 2022 and 2023 growing season

3.3.5. Grain yield (ardab/fad)

Results in Figure 6 showed that phosphorus and potassium application had a significant effect on grain yield in ard/fad in 2022 and 2023 growing seasons. The increase in PK fertilizer rates significantly increased grain yield in ard/fad in both growing seasons by 12.5 and 12.8% compared to the control treatment in 2022 and 2023 growing seasons, respectively. This increase in grain yield per faddan might have resulted from the effect of PK fertilizer on increasing 100-grain weight. Similar results were obtained by Sharma et al. (2019). However, Bordoli and Mallavino (1998) reported that phosphorus fertilizer application with or without potassium fertilizer significantly increased grain yield despite the nonsignificant effect of P on the other plant and/or ear traits. On the other Hussein et al. (2022) reported that P fertilizer rates had no effect on the grain yield of maize.

3.4. Chemical analysis

3.4.1. Nitrogen percentage in grains

The impact of compost on nitrogen percentage in grains was found to be significant in both growing seasons as shown in Table 2. The highest nitrogen percentage in grains was achieved by applying wheat compost (0.85%) in the 2022 growing season, while maize compost led to the highest nitrogen percentage in grains (1.52%) in the 2023 growing season. Additionally, the influence of nitrogen fertilizer levels on nitrogen percentage in grains was highly significant across both growing seasons. Increasing nitrogen fertilizer levels from zero to 45, 90, and 135 kg N/fad resulted in significant increases in nitrogen percentage in grains by 0.06, 0.121, and 0.33% compared to the control treatment in the 2022 growing season. Similarly, in the 2023 growing season, these increases were 0.19, 0.399, and 0.55%, respectively. Furthermore, the results presented in Table 2 demonstrate that the effect of PK fertilizers on nitrogen percentage in grains was highly significant in both growing seasons. The application of 15.5 kg P_2O_5 + 48 kg K_2O/fad significantly increased nitrogen percentage in grains by 0.046% and 0.09% compared to the control treatment in both growing seasons, respectively.

3.4.2. Phosphorus percentage in grains

Results in Table 2 showed that the effect of compost on P% in grains was not significant in 2022 growing season, whereas it was highly significant in 2023 growing season. However, the highest mean value of P% in grains, in both growing seasons, was obtained by adding wheat compost at the rate of 5 t/fad (0.61 and 0.46%), respectively. The effect of nitrogen fertilizer levels on phosphorus percentage in grains was highly significant in both growing seasons. The increase in nitrogen fertilizer levels from zero to 45, 90 and 135 kg N/fad significantly decreased P% in grains by 0.002, 0.047 and 0.04% compared to the control treatment in 2022 growing season, respectively. In 2023 growing season, the decrease in P% in grains due to adding the same nitrogen fertilizer levels was 0.04, 0.07 and 0.25%, respectively.

Data in Table 2 show that adding PK-fertilizer at the rate of 15.5 kg P_2O_5 + 48 kg K_2O (recommended treatment) caused significant and insignificant decrease in P% in grains in both growing seasons as compared to zero treatment (0.65 *vs* 0.59% and 0.47 *vs* 0.46) in 2022 and 2023 growing seasons, respectively.

3.4.3. Potassium percentage in grains

Results in Table 2 show that the effect of compost on potassium percentage in grains was highly significant in both growing seasons. The highest mean values of K% in grains were obtained by adding maize compost at the rate of 5 t/fad as compared to wheat compost (0.395 *vs* 0.368 and 0.445 *vs* 0.424) in 2022 and 2023 growing seasons, respectively. The effect of nitrogen fertilizer levels on potassium percentage in grains was highly significant in both growing seasons Table 2. The increase in nitrogen fertilizer levels from zero to 45, 90 and 135 kg N/fad significantly increased K% in grains by 0.021, 0.046 and 0.07% compared to the control treatment in 2022 growing season, respectively. In 2023 growing season, the decrease in K% in leaves due to adding the same nitrogen fertilizer levels was 0.025, 0.055 and 0.08%, respectively. Data in Table 2 show that adding PK-fertilizer at the rate of 15.5 kg P_2O_5 + 48 kg K_2O (recommended treatment) caused significant increase in K% in grains in both growing seasons as compared to zero treatment (0.376 *vs* 0.366% and 0.429 *vs* 0.413) in 2022 and 2023 growing seasons, respectively.

Table 2. Effect of compost, nitrogen fertilizer rates and PK fertilizer rates on NPK, proline and crude protein percentages, 2022 and 2023 growing seasons

Treatments	Compost (t/fad)									
	N%	P%	K%	Proline	CP	N%	P%	K%	proline	CP
	2022 growing season					2023 growing season				
Zero	0.72	0.64	0.35	3.42	4.49	1.36	0.51	0.39	7.36	8.48
Wheat	0.85	0.61	0.37	4.21	5.31	1.43	0.46	0.42	7.84	8.96
Maize	0.83	0.61	0.40	4.22	5.21	1.52	0.42	0.45	8.41	9.51
LSD	0.11	---	0.01	0.54	0.65	0.05	---	0.01	0.18	0.30
Significance	**	NS	**	*	*	*	NS	**	*	**
N-fertilizer levels (kg N/fad)										
Zero	0.67	0.65	0.34	3.21	4.21	1.15	0.52	0.38	6.17	7.2
45 Kg/fad	0.73	0.65	0.36	3.42	4.56	1.34	0.48	0.41	7.37	8.39
90 Kg/fad	0.79	0.6	0.38	3.83	4.94	1.55	0.45	0.44	8.58	9.69
135 Kg/fad	1.01	0.58	0.41	5.31	6.31	1.7	0.42	0.46	9.7	10.65
LSD	0.045	0.026	0.018	0.17	0.28	0.084	0.073	0.018	0.416	0.527
Significance	**	**	**	*	**	**	**	**	*	**
PK fertilizer levels										
Zero	0.78	0.65	0.37	3.85	4.86	1.39	0.47	0.41	7.6	8.7
15.5 kg P_2O_5 +48 K_2O	0.84	0.59	0.38	4.12	5.14	1.48	0.46	0.43	8.15	9.26
LSD	0.032	0.018	---	0.1	0.2	0.059	---	0.013	0.26	0.373
Significance	**	**	NS	*	**	**	NS	*	*	**

3.4.4. Proline% in maize leaves

Results in Table 2 show that the effect of compost on proline percentage in maize leaves was significant in both growing seasons. The highest mean value of proline% in 2022 growing season was obtained by adding wheat compost at the rate of 5 t/fad compared to maize compost (4.21 *vs* 4.22%), whereas in 2023 growing season, the highest value was obtained by adding maize compost (7.84 *vs* 8.41%). The effect of nitrogen fertilizer levels on proline percentage was highly significant in both growing seasons Table 2. The increase in nitrogen fertilizer levels from zero to 45, 90 and 135 kg N/fad significantly increased proline% by 6.5, 19.3 and 65.4% compared to the control treatment in 2022 growing season, respectively. In 2023 growing season, the increase in proline% due to adding the same nitrogen fertilizer levels was 19.45, 39.01 and 57.21%, respectively. Data in Table 2 show that adding PK-fertilizer at the rate of 15.5 kg P_2O_5 + 48 kg K_2O (recommended treatment) caused significant increase in proline % in maize leaves in both growing seasons as compared to zero treatment (3.85 *vs* 4.12% and 7.6 *vs* 8.15) in 2022 and 2023 growing seasons, respectively.

3.4.5. Crude protein (CP) percentage in grains

Results in Table 2 show that the effect of compost on crude protein (CP) percentage in grains was significant in both growing seasons. The highest mean value of CP% in grains in 2022 growing season was obtained by adding wheat compost at the rate of 5 t/fad compared to maize compost (5.31 *vs* 5.21%), whereas in 2023 growing season, the highest value was obtained by adding maize compost (9.51 *vs* 8.96%). The effect of nitrogen fertilizer levels on CP percentage in grains was highly significant in both growing seasons Table 2. The increase in nitrogen fertilizer levels from zero to 45, 90 and 135 kg N/fad significantly increased CP% in grains by 0.35, 0.74 and 2.1% compared to the control treatment in 2022 growing season, respectively. In 2023 growing season, the increase in CP% in grains due to adding the same nitrogen fertilizer levels was 1.195, 2.492 and 3.46%, respectively. Data in Table 2 show that adding PK-fertilizer at the rate of 15.5 kg P_2O_5 + 48 kg K_2O (recommended treatment) caused significant increase in CP% in grains in both growing seasons as compared to zero treatment (3.85 *vs* 4.86% and 9.26 *vs* 8.7) in 2022 and 2023 growing seasons, respectively. This results agreements with (Dawoud & Noreldin, 2023; Dawoud *et al*., 2023).

3.5. Nitrogen economy

3.5.1. Nitrogen uptake in grains (NUP)

Results in Table 3 showed clearly that the increase in nitrogen levels increased N-uptake in grains in both growing seasons. In 2022 growing season, applying N at 45, 90 and 135 kg N/fad increased nitrogen uptake by 2.2, 4.5 and 8.4 times over the control treatment, respectively. The corresponding values in 2023 growing season were 4.0, 56 and 7.0 times over the control treatment, respectively. The average of the two seasons indicated a marked increase in nitrogen uptake due to increasing nitrogen fertilizer levels. These increases were relatively 2.5, 5.2 and 7.3 times over the control treatment for the nitrogen levels of 45, 90 and 135 kg N/fad, respectively (Mosisa *et al.*, 2022; Quan *et al*., 2020). This aligns with findings by El-Mekser (2004) and contrasts with results from Sisson et al. (1991). The combination of organic manure and chemical fertilizers notably enhances nitrogen use efficiency in crops like soybean and maize, leading to improved nutrient availability in soils and reduced nitrogen loss rates (Hua *et al*., 2020; Bar-Tal *et al*., 2004).

Table 3. Nitrogen uptake (kg/fad), nitrogen use efficiency (kg grains/kg N) and apparent nitrogen recovery (%) as affected by nitrogen fertilizer levels, 2022 and 2023 growing seasons

N-fertilizer levels (kg N/fad)	N-uptake (kg/fad)	N-use efficiency (kg grains/kg N)	Apparent N recovery (%)
2022 growing season			
Zero	2.48	----	---
45	5.71	9.46	7.16
90	11.19	12.74	9.67
135	20.97	13.53	13.69
Mean	10.09	11.91	10.17
2023 growing season			
Zero	7.64	----	----
45	30.74	40.76	51.76
90	42.53	25.67	38.76
135	53.31	19.29	33.83
Mean	33.31	28.57	41.31
Average over two growing seasons			
Zero	5.06	----	----
45	18.23	25.11	29.24
90	26.86	19.21	24.21
135	37.14	16.41	23.76
Mean	21.82	20.24	25.72

3.5.2. Nitrogen use efficiency (NUE)

The effect of nitrogen fertilizer levels on nitrogen use efficiency in 2022 and 2023 growing seasons is presented in Table 3. The obtained results showed that applying 45 kg N/fad produced the highest nitrogen use efficiency. The average of the two seasons was 25.11 kg grains per one kg of nitrogen. The obtained results revealed also that applying nitrogen fertilizer at the rate of 135 kg N/fad decreased the nitrogen use efficiency to 16.41 kg grains per one kg of nitrogen. It could be concluded from these results that to obtain the high grain yield in sandy soils, N level must be increased up to 90-135 kg N/fad. Different studies have reported varying effects of nitrogen levels on NUE; for instance, Sisson et al. (1991) noted a decrease in NUE with increasing nitrogen levels, while Compbell et al. (1993) and Shafshak et al. (1994) found that NUE increased with higher nitrogen fertilizer levels. Additionally, Moll et al. (1982) observed a range of 20-32 kg grain per one kg of soil nitrogen when 225 kg N/ha was applied (Gheith *et al.*, 2022).

3.5.3. Nitrogen recovery (NRc)

The data in Table 3 revealed that the highest nitrogen recovery percentage was achieved when applying 45 kg N/fad during the 2022 growing season, with a recorded value of 51.33%. The average recovery percentage across both growing seasons was 29.25%. It was observed that as nitrogen levels exceeded 45 kg N/fad, the percentage of nitrogen recovery tended to decrease. This trend is supported by findings from Mahgoub (1987), indicating a decrease in nitrogen recovery with higher fertilizer nitrogen levels. In contrast, Shafshak et al. (1994) reported an increase in nitrogen recovery with rising nitrogen levels, while Nofal (1999) noted a slight reduction in nitrogen recovery as nitrogen levels increased.

4. Conclusions

Field experiments conducted at the Ismailia Research Station and Agricultural Research Center in Egypt during 2022 and 2023 provided significant insights into maize's response to various fertilizers. The experiments, which used a split-plot design with four replicates, recorded growth characteristics, yield components, and chemical analysis. Key findings include the impact of compost, with 5 tons/fad of wheat or maize compost leading to early tasseling and silking. Both types of compost significantly increased the 100-grain weight and grain yield, with maize compost having a more pronounced effect. The compost also significantly affected the nitrogen and potassium percentages in grains, as well as the crude protein percentages. Nitrogen fertilizer significantly increased growth and yield-related traits, as well as nitrogen, phosphorus, and potassium percentages in grains. Higher levels of nitrogen fertilizer led to increased crude protein content in grains. Phosphorus and potassium fertilizers had a significant effect on the number of ears per 100 plants, 100-grain weight, and grain yield. They also significantly increased nitrogen and phosphorus percentages in grains, as well as crude protein percentages. The addition of PK fertilizer at a rate of 15.5 kg P_2O_5 + 48 kg K_2O/fad significantly increased the N, P, and K% content of grains and the percentage of crude protein in grains. However, in 2022, the influence on the P% content in grains was not significant. The results showed that grain's uptake of nitrogen increased with elevated nitrogen levels. Applying 45 kg N/fad resulted in the highest efficiency of nitrogen utilization, with an average of 25.11 kg grains per kilogram of nitrogen over the two seasons. The highest nitrogen recovery was achieved by applying 45 kg N/fad, but recovery decreased as nitrogen levels increased above this amount. These findings offer valuable insights into the effects of wheat and maize compost, nitrogen fertilizer, and phosphorus and potassium fertilizers on maize growth, yield, and nutrient content. They could inform agricultural practices aimed at optimizing maize production and nutrient management strategies.

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