



# Evaluating Compost, Nitrogen and PK Fertilizer Effects on Maize Crop Productivity: Toward Economically Efficient Nitrogen Management

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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## ABSTRACT

The effects of nitrogen (N) fertilizer (0, 45, 90, and 135 kg N/fad), phosphorus-potassium (PK) application (0 vs. recommended rate: 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O/fad), and wheat and maize composts on maize growth, yield, nutrient dynamics, and nitrogen economy were examined in a two-year field study. With increases of 4.3–12.9% and 8.0–9.2% over seasons, respectively, maize compost

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considerably increased grain yield (15.8 ard/fad) above wheat compost (15.2 ard/fad) and control, according to results from a split-plot design with four replicates. While the effects of phosphorus (P) differed by season, both composts increased the percentages of nitrogen (N) and potassium (K) in leaves and grains. While ear characteristics, yield components, and nutrient content in leaves and grains were increased by increasing N rates up to 135 kg/fad, nitrogen utilization efficiency (NUE: 25.11 to 16.41 kg grains/kg N) and recovery (29.24% to 23.76%) were decreased. While effects on ear morphology and P content were mixed, PK fertilization greatly increased yield, crude protein, and N and K in grains. At 45 kg N/fad, recovery and N efficiency were at their best. Combining compost with moderate N and PK inputs increased sustainability and productivity, indicating that balanced fertilization (45 kg N/fad + PK) and maize compost are good ways to maximize maize production and control nutrients.

**Keywords:** *Wheat straw; maize compost; fertilizer optimization; agronomic traits; nitrogen recovery; nutrient dynamics.*

## 1. INTRODUCTION

Global agricultural systems face intensifying pressure to reconcile food security with environmental and economic sustainability. By 2050, food production must increase by 60–70% to meet the demands of a growing population, yet conventional practices reliant on synthetic fertilizers exacerbate greenhouse gas emissions, soil degradation, and water pollution (FAO, 2017; Tilman et al., 2011). Maize (*Zea mays* L.) is a critical staple crop for global food security, supporting livelihoods and economies across diverse agroecological zones (FAO, 2021). However, achieving optimal maize productivity remains a challenge, particularly in regions where soil fertility depletion and inefficient nutrient management practices constrain yields (Vanlauwe et al., 2015).

Nitrogen (N) fertilizers, while critical for crop productivity, contribute disproportionately to these challenges: approximately 50% of applied N is lost to the environment through leaching, volatilization, or denitrification, driving economic losses and ecological harm (Fowler et al., 2013; Zhang et al., 2015). Concurrently, rising fertilizer prices fueled by geopolitical and supply-chain disruptions threaten farm profitability, particularly in resource-limited regions (FAO, 2022). These dual crises underscore the urgent need for integrated nutrient management strategies that optimize crop yields while enhancing nitrogen use efficiency (NUE) and economic returns. Organic amendments such as compost are increasingly advocated as sustainable alternatives to synthetic fertilizers. Compost application improves soil organic carbon, microbial diversity, and nutrient retention, potentially reducing reliance on mineral N while enhancing crop resilience (Diacono &

Montemurro, 2010; Lal, 2020). For instance, Möller and Müller (2012) demonstrated that compost integration could replace 20–30% of synthetic N without compromising maize yields. However, the synergistic effects of compost with phosphorus (P) and potassium (K) fertilizers remain poorly quantified, particularly in systems where PK imbalances limit NUE (Dobermann & Cassman, 2004). While graded N rates have been widely studied, their interaction with compost and PK fertilization, the key to tailoring site-specific recommendations, is yet to be systematically evaluated (Ladha et al., 2016). Our investigations emphasize the significance of nitrogen fertilization and the possible advantages of using bio-organic fertilizers to enhance maize development and production in freshly recovered soils under biotic stress.

Nitrogen (N), phosphorus (P), and potassium (K) are essential macronutrients for maize growth, but their application in unbalanced ratios or excessive quantities often leads to economic losses and environmental degradation, such as greenhouse gas emissions and water pollution (Ju et al., 2009). While synthetic fertilizers are widely used to address nutrient deficiencies, rising input costs and sustainability concerns have intensified the search for integrated nutrient management strategies that combine organic amendments like compost with reduced inorganic fertilizer doses (Agegnehu et al., 2016). Compost, a nutrient-rich organic fertilizer, enhances soil structure, water retention, and microbial activity, potentially reducing dependency on synthetic nitrogen (Chivenge et al., 2011). Conversely, inorganic PK fertilizers provide readily available P and K, which are vital for root development and stress tolerance in maize (Grant et al., 2012). However, the synergistic effects of compost, nitrogen, and PK

fertilizers on maize productivity and their economic implications remain underexplored. Optimizing these interactions could unlock pathways to economically efficient nitrogen management, balancing crop yield goals with cost-effectiveness and ecological sustainability (Marenya et al., 2020). This study evaluates the agronomic and economic impacts of compost, nitrogen, and PK fertilizer combinations on maize productivity. The findings will contribute to evidence-based recommendations for smallholder farmers and policymakers seeking to adopt sustainable intensification practices in maize-based systems.

## 2. MATERIALS AND METHODS

### 2.1 Study Site and Soil Characteristics

Under a sprinkler irrigation system, field two experiments on maize were conducted over two consecutive growing seasons, 2023 and 2024, at a private farmer in sandy soils in Egypt, Table 1. Pre-planting soil analysis confirmed consistent physicochemical properties across both seasons, with pH ranged from 7.9 to 8.1 and low total soluble salts (0.20–0.21%). The preceding crop in both seasons was wheat (*Triticum aestivum* L.).

In both growing seasons, wheat was the preceding winter crop. Soil samples were taken before planting for chemical analysis (Table 2).

### 2.2 Treatments and Design Experiments

#### 2.2.1 Compost

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

#### 2.2.2 Nitrogen fertilizer

Four rates (0, 45, 90, and 135 kg N/fad (as ammonium nitrate, 33.5% N)). Fertilizer was applied in eight equal doses as a side dressing before each irrigation in both growing seasons.

#### 2.2.3 PK fertilizer

Two levels (No PK and recommended rate 200 kg/fad calcium superphosphate (15.5%  $P_2O_5$ ) + 50 kg/fad potassium sulfate (48%  $K_2O$ )). Fertilizer was applied twice, before planting and the first irrigations in both growing seasons.

### 2.3 Experimental Design

A split-plot design with four replications was employed. Main plots were assigned to compost treatments, while subplots were allocated to nitrogen (N) and phosphorus-potassium (PK) fertilizer combinations. The experiment comprised 24 treatments, including:

### 2.4 Agronomic Practices

Maize (*Zea mays* L.) was manually sown on 70 cm-wide ridges at an interhill spacing of 25 cm, with two seeds planted per hill. Seedlings were thinned to one plant per hill 15 days after planting (DAP), establishing a final stand density of 24,000 plants per fad (1 fad = 0.42 ha). Nitrogen (N) was applied in eight split doses synchronized with irrigation events, whereas phosphorus-potassium (PK) fertilizers were administered in two stages: pre-planting (basal application) and during the first irrigation. Manual weed management was conducted twice, at 15 and 25 DAP, to minimize competition. The crop was harvested at physiological maturity, 110 days after planting.

### 2.5 Data Collection

#### 2.5.1 Yield and yield components

All ear characteristics were measured at harvest as an average of 10 ears, these characteristics were: Ear length (cm) and Ear diameter (cm), and Ear height (cm) at harvest, measured from the ground to the uppermost bearing node as an average of 10 plants.

Number of rows/ ears, number of ears/100 plants at harvest/fad, and Grain yield Ardab/fad, all characteristics estimated from the three middle ridges of the plots. The moisture content of the grains was adjusted to 15.5 %.

### 2.6 Chemical Analysis

#### 2.6.1 Leaves and grain nutrients

Total N (Kjeldahl method; Pratt and Chapman, 1961), P (spectrophotometry; Jackson, 1958), and K (flame photometry; Richards, 1954).

#### 2.6.2 Crude grain protein %

Calculated as  $N\% \times 6.25$ .

**Table 1. Physical properties of the soil site used in the growing season.**

Physical properties				
Clay %	Silt, %	Fine sand, %	Coarse sand, %	Texture
14.0	20.1	52.5	12.8	Sandy loam

**Table 2. Chemical properties of the soil site used in the growing season**

Chemical properties					
pH (1:2.5)	Total soluble salt, %	Total N, %	Available N, ppm	Available K, ppm	Available P, ppm
8.0	0.2	0.1	27.7	163.0	9.6

### 2.6.3 Nitrogen fertilizer economy

Nitrogen uptake (NUP) in grains, Nitrogen Use efficiency (NUE) calculated as kg grain/kg nitrogen applied (kg grain kg<sup>-1</sup>N applied), and apparent nitrogen recovery (NRC), calculated as nitrogen in grains per kg nitrogen applied (kg N grain kg<sup>-1</sup> N applied). All nitrogen fertilizer economy parameters (NUP, NUE, and NRC) were calculated according to Godwin, (1984) as follows:

$$NUP = \text{Grain yield} \times \text{N\% in grains},$$

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

$$NRC = \frac{\text{N uptake F} - \text{N uptake C}}{\text{Fertilizer N applied}},$$

Where: F= fertilized plots and, C=non-fertilized plot (control)

## 2.7 Statistical Analysis

Data were analyzed using ANOVA and were calculated according to (Snedecor & Cochran, 1980). Treatment means were compared via LSD test at  $P \leq 0.05$  and  $P \leq 0.01$ . Pearson's correlation coefficients between grain yield and other traits were calculated.

## 3. RESULTS AND DISCUSSION

### 3.1 Effect of Compost

#### 3.1.1 Effect of compost on ear characteristics

Results in Fig. 1 indicated the effects of three compost treatments (Zero, Wheat residue compost, and Maize residue compost, applied in tons/fad) on maize growth in two growing seasons. Compost had an insignificant effect on ear height in both growing seasons. Generally, there was a slight increase in ear height due to

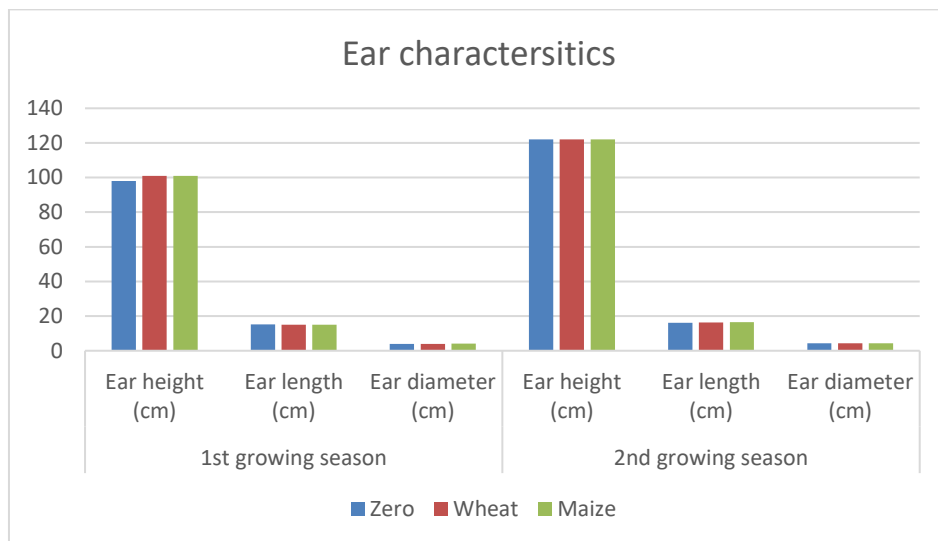
the applied compost. On the other hand, there were little differences between the two kinds of compost (wheat or maize) concerning ear height. These results are due mainly to the fact that ear height is under the control of genetic makeup and it's little affected by the applied compost. These results do not agree with those obtained by Zhang et al., (2021), who reported that increasing organic manure rates significantly increased ear height. The table evaluates the impact of compost type (Zero, Wheat residue, and Maize residue, applied in tons/fad) on maize ear morphology across two growing seasons. In the first season, ear height ranged from 98 cm (Zero compost) to 101 cm (Wheat and Maize composts), while ear length and diameter showed minimal variation (15.0–15.25 cm and 3.94–4.09 cm, respectively). No statistically significant differences (ns) were detected among treatments. During the second season, all treatments exhibited increased ear dimensions: ear height stabilized at 122 cm across all compost types, while ear length (16.2–16.5 cm) and diameter (4.3–4.4 cm) showed slight improvements. Despite these numerical gains, statistical significance remained absent (ns). Despite steady but slight gains in measures, the data indicate that compost type had no discernible impact on ear shape in either season. This pattern suggests that either longer-term applications or larger compost quantities may be required to elicit quantifiable agronomic results, or that seasonal factors like weather or soil conditions may have eclipsed the effects of compost. The obtained results are in agreement with those obtained by Ali et al., (2020), who reported that application of manures up to 4 m<sup>3</sup>/fad insignificantly affected ear length in one out of the two growing seasons.

#### 3.1.2 Effect of compost on yield and yield components

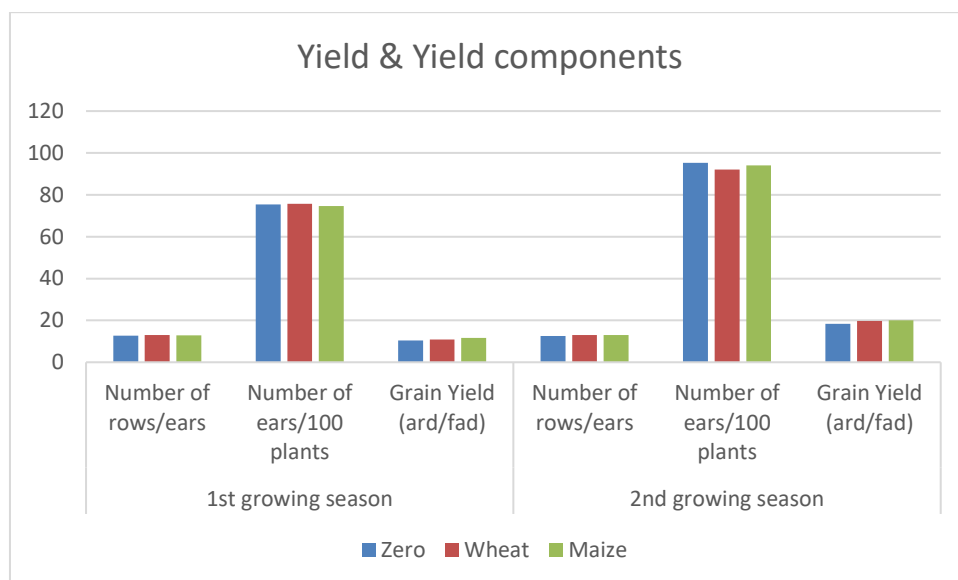
The effect of compost on the number of rows/ears is presented in Fig. 2. Results in Fig. 2

showed clearly that no big differences in mean values of number of rows /ears between the two growing seasons. This was true since this trait is under genetic control and less affected by environmental conditions. However, applying 5 tons/fad of compost had no significant effect on the number of rows/ears in both growing seasons. The present results agree with those obtained by Kihara et al., (2020), who found that FYM application did not significantly affect this trait. On the other hand, El-Mekser (2004) reported significant increases in the number of rows/ear due to the application of farmyard manure and/or BM-Bokashi.

Results in Fig. 2 show that the number of ears/100 plants was not significantly affected by applying either wheat or maize compost in two growing seasons. Generally, the obtained results indicate that adding maize compost decreased the number of ears/100 plants as compared with the check treatments without compost (74.6 vs 75.4 and 94.1 vs 95.3 ears/100 plants, in first and second growing seasons, respectively). The obtained results were in good agreement with those obtained by Mucheru-Muna et al., (2017), who reported that application of FYM up to 30 m<sup>3</sup>/fad had no significant effect in both growing seasons.



**Fig. 1. Effect of compost on ear height (cm), ear length, and ear diameter (cm) in two growing seasons**



**Fig. 2. Effect of compost on yield and yield components in two growing seasons**

Results in Fig. 2 indicate that the grand mean grain yield 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 clearly show that the effect of compost on maize grain yield was significant in both growing seasons. Compared to the check treatment (zero treatment), applying wheat compost or maize compost substantially increased grain yield by 4.34 and 12.92% in the first growing season and by 8.04 and 9.19% in the second growing season, respectively. It is worth noting that maize compost had an enormous effect on grain yield compared to that of wheat compost, since it produced more grain yield per fad in both growing seasons (11.71 vs 10.82 ard/fad and 19.97 vs 19.76 ard/fad, in first and second 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 El-Mekser (2004) who found that grain yield was increased with the increase in application of FYM, biogas manure, EM-Bokashi and compost.

### 3.2 Effect of N-fertilizer

#### 3.2.1 Effect of N-fertilizer on ear characteristics

Results in Fig. 3 showed that the increase in nitrogen fertilizer rates significantly increased ear height in both growing seasons. The obtained data revealed that applying nitrogen at 45, 90 and 135 kg N/fad significantly increased ear height by 20.9, 32.1 and 39.5% in the first season, and by 58.0, 71.6, and 74.7% in the second season, respectively. These results indicated the role of nitrogen as an essential nutritive element for plant growth. It also helps in increasing the meristematic activity and enhances internode elongation below the developing ear. Similar results were also reported by Dobermann, (2020), who found that increasing nitrogen rates significantly increased maize ear height at harvest.

Results in Fig. 3 showed that nitrogen fertilizer rates significantly affected ear length in the first and second seasons. Applying nitrogen at 45, 90 and 135 kg N/fad increased ear length by 22.1, 38.3 and 40.5% over the check treatment in the first season, respectively. The corresponding increase for the same nitrogen rates in the second season was 56.3, 65.5 and 67.6%, respectively. This result is a good manifestation of the role of nitrogen as an essential element in building maize ears and due to the positive effect of nitrogen in increasing vegetative growth and photosynthetic accumulation. Similar results were also obtained by Chen et al., (2017), who showed that increasing nitrogen fertilizer levels markedly increased ear length.

Results in Fig. 3 indicated that the effect of nitrogen fertilizer rates on ear diameter was highly significant in the first and second seasons. Increasing nitrogen fertilizer rates significantly increased ear diameter by 11.4, 22.9 and 22.9% in the first season over the check treatment, respectively. The corresponding increases in the second season were 31.4, 34.3 and 34.3 % over the check treatment, respectively. The contribution of nitrogen in increasing ear size, which is the fundamental component of grain yield, is clearly illustrated. These results are mainly due to the encouraging effect of N on the vegetative growth of the maize plant as mentioned before. A similar result was also reported by Dobermann, (2020), who reported a marked increase in ear diameter as a result of the increase in nitrogen fertilizer rate.

#### 3.2.2 Effect of N-fertilizer on yield and yield components

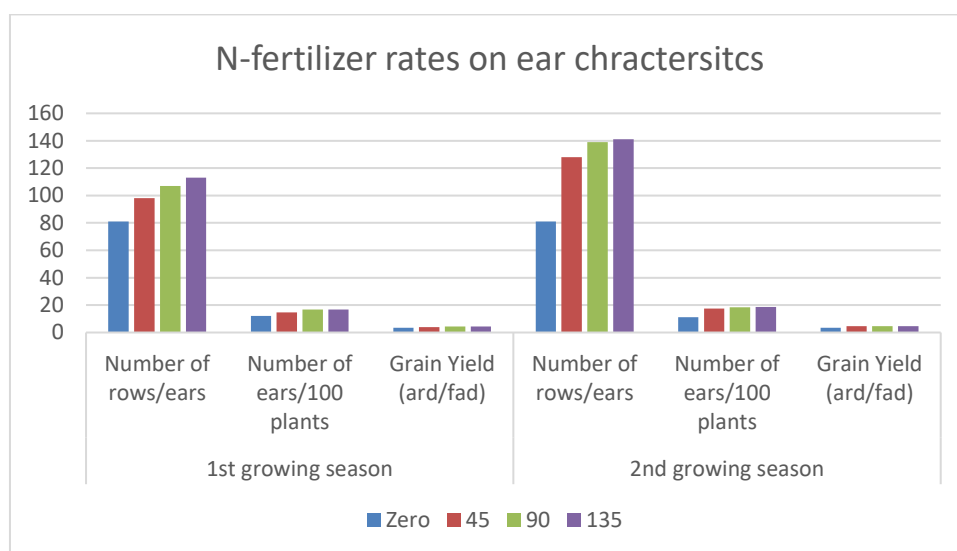
Results in Fig. 4 show the effect of nitrogen fertilizer rates on the number of rows/ears, which was highly significant in both growing seasons. Increasing nitrogen rate from zero up to 45, 90, and 135 kg N/fad significantly increased the number of rows/ears over the check treatment by 6.7, 11.7 and 11.1%, respectively in the first and 15.8, 17.5 and 18.4% in the second growing season. It could be concluded that N fertilizer application favorably affected the number of rows/ears due to the role of nitrogen in seed formation and plant growth.

The effect of nitrogen fertilizer rates on the number of ears/100 plants in the first and second growing seasons is presented in Fig. 4. The obtained results indicated that the effect of N-fertilizer rates on the number of ears/100 plants

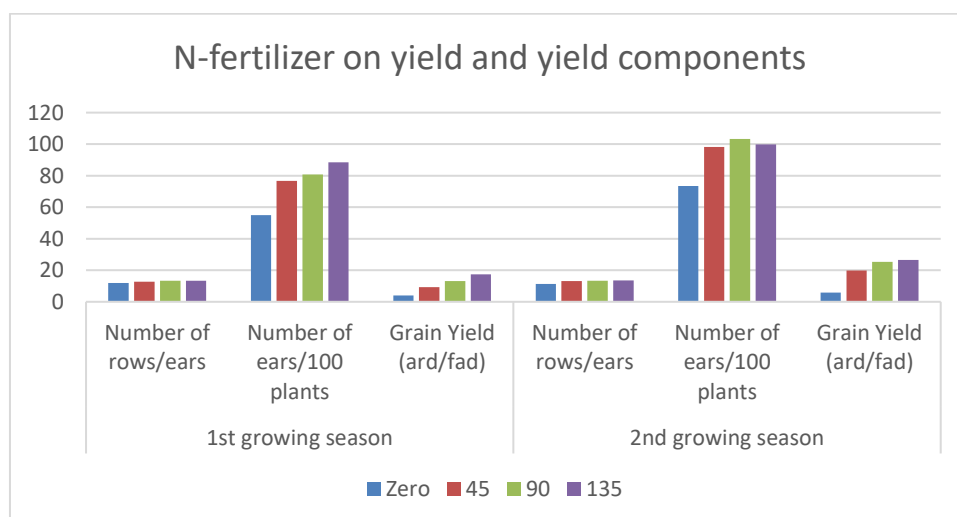
was highly significant in both growing seasons. In the first growing season, applying nitrogen at 45, 90 and 135 kg/fad markedly increased the number of ears/100 plants by 39.8, 47.0 and 61.0%, respectively. The corresponding increases in the second growing season were 33.8, 40.9 and 36.1% for the same nitrogen rates. The obtained results showed the vital role of N which seems to increase number of ears/plants in maize. A good supply of N will certainly increase the prolificacy of maize plants.

Results in Fig. 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 the second growing season for the same nitrogen rates was 13.94, 19.43 and 20.63 ard/fad, respectively. These increases in grain yield per fad might have resulted from the effect of nitrogen on increasing growth characters in terms of ear height as well as improving ear characters expressed as ear length, ear diameter, number of rows/ears, number of grains/row and 100-grain weight. A similar result was obtained by Chen et al., (2017), who found that increasing nitrogen rates significantly increased grain yield.



**Fig. 3. Effect of nitrogen fertilizer on ear height (cm), ear length (cm), and ear diameter (cm) in two growing seasons**



**Fig. 4. Effect of nitrogen fertilizer on the number of rows/ears, number of ears/100 plants, and grain yield (ard/fad) in two growing seasons**

### 3.3 Effect of Phosphorus and Potassium Fertilizer

#### 3.3.1 Effect of phosphorus and potassium fertilizer on ear characteristics

Phosphorus and potassium (PK) fertilization showed inconsistent effects on maize ear traits across two growing seasons Fig. 5. While PK application (31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O/fad) had no significant impact on ear height, length, or diameter in the first season, it significantly increased these parameters in the second season by 6.8%, 3.1%, and 2.3%, respectively, compared to the control (without PK). Due to PK availability, this seasonal disparity may reflect improved soil fertility or enhanced internode elongation and plant growth. Our findings align partially with Gao et al., (2017), who observed no effect on ear length.

#### 3.3.2 Effect of phosphorus and potassium fertilizer on yield and yield components

Phosphorus and potassium (PK) fertilization at 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O/fad in sandy soils showed variable effects on maize yield components Fig. 6. While PK application had no significant impact on the number of rows/ears in either growing season, it slightly improved this trait through enhanced plant growth. Conversely, PK rates significantly increased the number of ears/100 plants by 8.4% and 5.3% in the first and second seasons, respectively, compared to the control. Grain yield also increased significantly,

by 12.5% and 12.8% in the two seasons, likely due to PK-driven increases in ear number and grain yield. These results highlight PK's critical role in boosting ear formation and overall productivity in maize, despite its limited influence on row number per ear. The obtained results showed the important role of phosphorus and potassium as major elements in the sandy soils, which led to an increase in the number of ears/plants in maize. A similar result was obtained by Gao et al., (2017).

### 3.4 Chemical Analysis

#### 3.4.1 Nitrogen percentage in leaves

Results in Table 3 showed that the effect of compost on N% in leaves was significant in the first and second growing seasons. Adding maize compost at a rate of 5 t/fad possessed the highest values of N% in leaves (1.837 and 2.220%) in two growing seasons, respectively. The effect of nitrogen fertilizer levels on nitrogen percentage in leaves was highly significant in both growing seasons. The increase in nitrogen fertilizer levels from zero to 45, 90 and 135 kg N/fad significantly increased N% in leaves by 0.225, 0.417 and 0.690% compared to the control treatment in the first growing season, respectively. In the second growing season, the increase in N% in leaves due to adding the same nitrogen fertilizer levels was 11.7, 23.6 and 0.655%, respectively. Data in Table 9 show that adding PK-fertilizer at the rate of 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O (recommended treatment) caused a

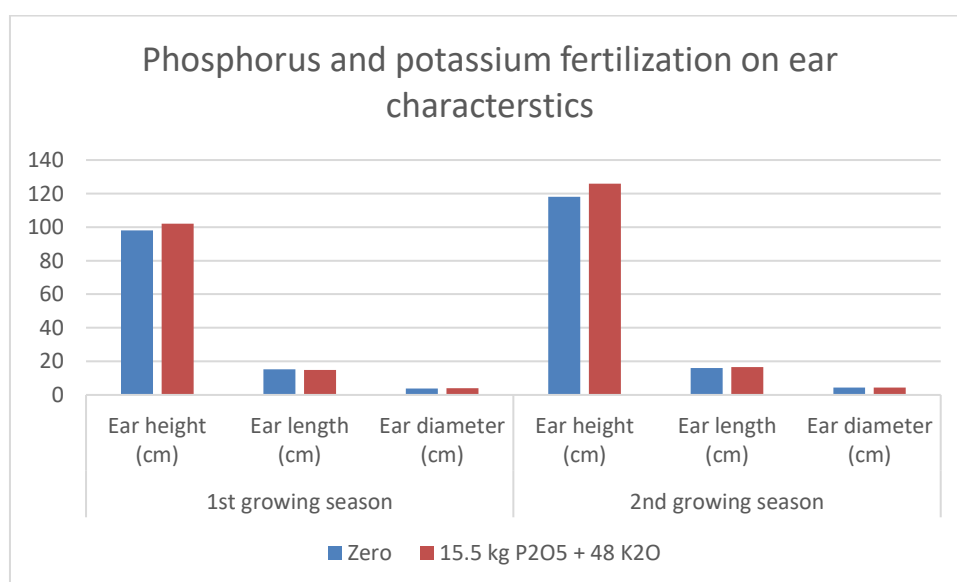


Fig. 5. Effect of phosphorus and potassium fertilization on ear height (cm), ear length, and ear diameter (cm) in two growing seasons

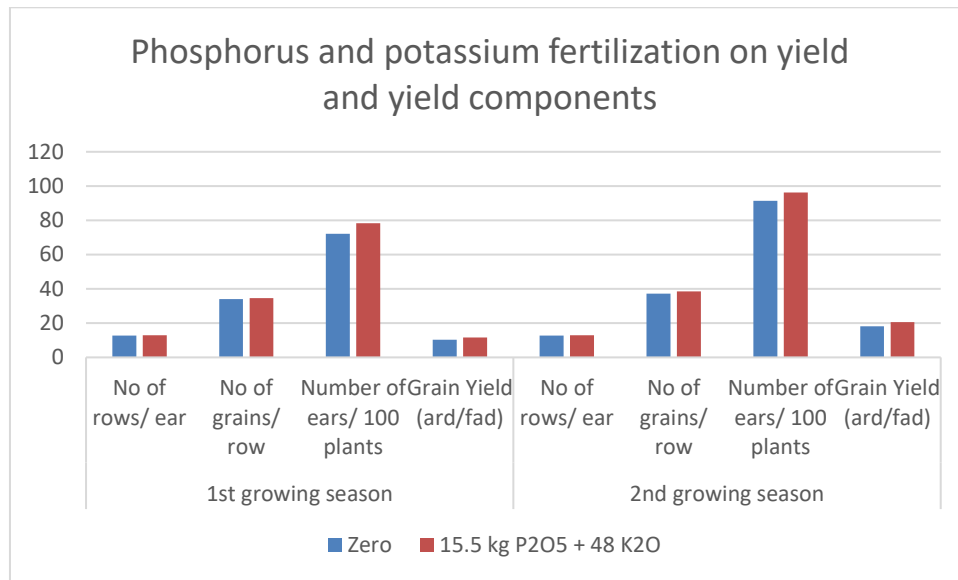


Fig. 6. Effect of phosphorus and potassium fertilization on yield & yield components in two growing seasons

Table 3. Effect of compost, nitrogen fertilizer rates and PK fertilizer rates on NPK percentages in leaves, in two growing seasons

Treatments	1 <sup>st</sup> growing season			2 <sup>nd</sup> growing season		
	N%	P%	K%	N%	P%	K%
<b>Compost treatment (t/fad)</b>						
Zero	1.472	0.515	0.676	1.658	0.540	0.871
Wheat	1.628	0.501	0.719	1.900	0.516	1.074
Maize	1.837	0.472	0.744	2.220	0.498	1.214
LSD	0.136		0.019	0.140	---	0.070
Significance	**	NS	**	**	NS	**
<b>Nitrogen fertilizer levels (kg N/fad)</b>						
Zero	1.312	0.613	0.657	1.620	0.621	0.997
45	1.537	0.524	0.708	1.810	0.542	1.048
90	1.729	0.437	0.730	2.002	0.467	1.070
135	2.002	0.410	0.757	2.275	0.442	1.097
LSD	0.140	0.037	0.037	0.143	0.041	0.037
Significance	**	**	**	**	**	**
<b>PK fertilizer levels</b>						
Zero	1.581	0.479	0.706	1.871	0.48	1.046
31 kg P <sub>2</sub> O <sub>5</sub> + 24 K <sub>2</sub> O	1.709	0.514	0.720	1.982	0.556	1.060
LSD	0.099	0.026	0.030	0.102	0.026	0.026
Significance	**	**	NS	**	**	NS
CV %	14.8	12.3	9.1	12.8	12.2	6.2

LSD: Least Significant Difference, Coefficient of Variation (CV%), NS: not significant

significant increase in N% in leaves in both growing seasons as compared to zero treatment (1.581 vs 1.709% and 1.871 vs 1.982 in the first and second growing seasons, respectively).

### 3.4.2 Phosphorus percentage in leaves

Results in Table 3 showed that the effect of compost on P% in leaves was not significant in

the first and second growing seasons. However, the highest mean value of P% in leaves, in both growing seasons, was obtained by adding wheat compost at the rate of 5 t/fad (0.501 and 0.516%), respectively. The effect of nitrogen fertilizer levels on phosphorus percentage in leaves 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 leaves by 0.089, 0.176 and 0.203% compared to the control treatment in the first growing season, respectively. In the second growing season, the decrease in P% in leaves due to adding the same nitrogen fertilizer levels was 0.079, 0.154 and 0.174%, respectively. Data in Table 3 show that adding PK-fertilizer at the rate of 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O (recommended treatment) caused a significant increase in P% in leaves in both growing seasons as compared to zero treatment (0.479 vs 0.514% and 0.480 vs 0.556 in the first and second growing seasons, respectively).

### 3.4.3 Potassium percentage in leaves

Results in Table 3 show that the effect of compost on potassium percentage in leaves was highly significant in both growing seasons. The highest mean values of K% in leaves were obtained by adding maize compost at the rate of 5 t/fad compared to wheat compost (0.744 vs 0.719 and 1.214 vs 1.074) in the first and second growing seasons, respectively. The effect of nitrogen fertilizer levels on potassium percentage in leaves was highly significant in both growing seasons. The increase in nitrogen fertilizer levels from zero to 45, 90 and 135 kg N/fad significantly increased K% in leaves by 0.051, 0.073 and 0.1% compared to the control treatment in the first growing season, respectively. In the second

growing season, the increase in K% in leaves due to adding the same nitrogen fertilizer levels was the same 0.051, 0.073 and 0.1%, respectively. Data in Table 3 show that adding PK-fertilizer at the rate of 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O (recommended treatment) caused the insignificant increase in K% in leaves in both growing seasons as compared to zero treatment (0.720 vs 0.706% and 1.060 vs 1.046 in the first and second growing seasons, respectively).

### 3.4.4 Nitrogen percentage in grains

The effect of compost on nitrogen percentage in grains was significant in both growing seasons Table 4. The highest value of N% in grains was obtained by adding wheat compost (0.851%) in the first growing season, whereas in the second growing season, the highest values of N% in grains (1.522%) were obtained by adding maize compost. The effect of nitrogen fertilizer levels on nitrogen 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 increased N% in grains by 0.056, 0.121 and 0.336% compared to the control treatment in the first growing season, respectively. In the second growing season, the increase in N% in grains due to adding the same nitrogen fertilizer levels was 0.191, 0.399 and 0.553%, respectively.

**Table 4. Effect of compost, nitrogen fertilizer rates, and PK fertilizer rates on NPK and crude protein percentages in grains, for two growing seasons**

Treatments	1 <sup>st</sup> growing season				2 <sup>nd</sup> growing season			
	N%	P%	K%	CP%	N%	P%	K%	CP%
<b>Compost treatments (t/fad)</b>								
Zero	0.719	0.640	0.351	4.493	1.356	0.506	0.394	8.479
Wheat	0.851	0.607	0.368	5.306	1.433	0.464	0.424	8.958
Maize	0.833	0.607	0.395	5.210	1.522	0.423	0.445	9.514
LSD	0.106	---	0.013	0.654	0.047	---	0.013	0.299
Significance	**	NS	**	*	*	NS	**	**
<b>N-fertilizer levels (kg N/fad)</b>								
Zero	0.673	0.648	0.337	4.206	1.151	0.517	0.381	7.198
45	0.729	0.646	0.358	4.556	1.342	0.477	0.406	8.393
90	0.794	0.601	0.383	4.942	1.550	0.446	0.436	9.690
135	1.009	0.578	0.407	6.309	1.704	0.418	0.461	10.654
LSD	0.045	0.026	0.018	0.283	0.084	0.073	0.018	0.527
Significance	**	**	**	**	**	**	**	**
<b>PK fertilizer levels</b>								
Zero	0.778	0.651	0.366	4.864	1.392	0.472	0.413	8.704
31 kg P <sub>2</sub> O <sub>5</sub> + 24 K <sub>2</sub> O	0.824	0.585	0.376	5.142	1.482	0.457	0.429	9.264
LSD	0.032	0.018	---	0.200	0.059	---	0.013	0.373
Significance	**	**	NS	**	**	NS	*	**
CV %	9.8	7.42	7.6	9.8	10.2	27.53	8.79	10.2

CP: crude protein% in the grain, LSD: Least Significant Difference, Coefficient of Variation (CV%), NS: not significant

Results in Table 4 show that the effect of PK fertilizers on nitrogen percentage in grains was highly significant in both growing seasons. Adding 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O/fad significantly increased N% in grains by 0.046 and 0.090% as compared to the control treatment in both growing seasons, respectively.

#### 3.4.5 Phosphorus percentage in grains

Results in Table 4 showed that the effect of compost on P% in grains was not significant in the first growing season, whereas it was highly significant in the second 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 (0.607 and 0.464%), 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 0.040% compared to the control treatment in the first growing season, respectively. In the second growing season, the decrease in P% in grains due to adding the same nitrogen fertilizer levels was 0.040, 0.071 and 0.248%, respectively.

Data in Table 4 show that adding PK-fertilizer at the rate of 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O (recommended treatment) caused significant and insignificant decrease in P% in grains in both growing seasons as compared to zero treatment (0.651 vs 0.585% and 0.472 vs 0.457 in the first and second growing seasons, respectively).

#### 3.4.6 Potassium percentage in grains

Results in Table 4 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 the first and second growing seasons, respectively.

The effect of nitrogen fertilizer levels on potassium percentage in grains was highly significant in both growing seasons Table 4. 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 the first

growing season, respectively. In the second growing season, the decrease in K% in leaves due to adding the same nitrogen fertilizer levels was 0.025, 0.055 and 0.080%, respectively.

Data in Table 4 show that adding PK-fertilizer at the rate of 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O (recommended treatment) caused a 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 the first and second growing seasons, respectively).

#### 3.4.7 Crude protein (CP) percentage in grains

Results in Table 4 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 the first growing season was obtained by adding wheat compost at the rate of 5 t/fad compared to maize compost (5.306 vs 5.210%), whereas in the second growing season, the highest value was obtained by adding maize compost (9.514 vs 8.958%).

The effect of nitrogen fertilizer levels on CP percentage in grains was highly significant in both growing seasons Table 4. The increase in nitrogen fertilizer levels from zero to 45, 90 and 135 kg N/fad significantly increased CP% in grains by 0.350, 0.736 and 2.103% compared to the control treatment in the first growing season, respectively. In the second growing season, the increase in CP% in grains due to adding the same nitrogen fertilizer levels was 1.195, 2.492 and 3.456%, respectively.

Data in Table 4 show that adding PK-fertilizer at the rate of 31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O (recommended treatment) caused a significant increase in CP% in grains in both growing seasons as compared to zero treatment (5.142 vs 4.864% and 9.264 vs 8.703 in the first and second growing seasons, respectively).

### 3.5 Nitrogen Economy

#### 3.5.1 Nitrogen uptake in grains (NUP)

Results in Table 5 showed clearly that the increase in nitrogen levels increased N-uptake in grains in both growing seasons. In the first 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 the second 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. The present results show clearly the important role of N application for maize plants when grown in sandy soils.

A similar result was also obtained by Zhao et al., (2022), who found that N uptake increased markedly with the increase in N levels.

### 3.5.2 Nitrogen use efficiency (NUE)

The effect of nitrogen fertilizer levels on nitrogen use efficiency in the first and second growing seasons is presented in Table 5. 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 of grains per kg of nitrogen.

The obtained results also revealed that applying nitrogen fertilizer at the rate of 135 kg N/fad decreased the nitrogen use efficiency to 16.41 kg grains per kg of nitrogen. It could be concluded

from these results that to obtain a high grain yield in sandy soils, N level must be increased up to 90-135 kg N/fad.

Results obtained by Zhang et al., (2015) confirmed that excessive nitrogen fertilization reduces NUE, with modern maize hybrids showing peak efficiency at 150–200 kg N/ha, beyond which marginal yield gains diminish. Dobermann et al., (2022) emphasized that precision nitrogen management (e.g., sensor-based fertilization) can improve NUE by 15–30% compared to uniform high-rate applications.

### 3.5.3 Nitrogen recovery (NRc)

Data presented in Table 5 indicated that the highest recovery percentage was recorded by applying 45 kg N/fad in the second growing season. Its value was 51.33%. The average of the two growing seasons was 29.25%. This result indicates that the percentage of nitrogen recovery decreased with the increase in N level to more than 45 kg N/fad. The result reported by Sarker et al., (2018), showed that N recovery tended to decrease as fertilizer nitrogen was increased. However, Zhang et al., (2020), found that N recovery was slightly reduced as N levels were increased.

**Table 5. Nitrogen uptake (kg/fad), nitrogen use efficiency (kg grains/kg N) and apparent nitrogen recovery (%) as affected by nitrogen fertilizer levels, in both growing seasons**

N-fertilizer levels (kg N/fad)	N-uptake (NUP) (kg/fad)	N-use efficiency (NUE) (kg grains/kg N)	Apparent N recovery (NRc) (%)
<b>1<sup>st</sup> growing season</b>			
Zero	2.483	----	---
45	5.706	9.46	7.16
90	11.19	12.74	9.67
135	20.97	13.53	13.69
Mean	10.087	11.91	10.17
<b>2<sup>nd</sup> growing season</b>			
Zero	7.644	----	----
45	30.744	40.76	51.76
90	42.532	25.67	38.76
135	53.312	19.29	33.83
Mean	33.312	28.57	41.31
<b>Average over two growing seasons</b>			
Zero	5.064	----	----
45	18.225	25.11	29.24
90	26.861	19.21	24.21
135	37.141	16.41	23.76
Mean	21.823	20.24	25.72

NUP: nitrogen uptake, NUE: nitrogen use efficiency, NRc: nitrogen recovery

#### 4. CONCLUSIONS

The field tests showed that adding organic compost to balanced inorganic fertilization greatly improves nutrient dynamics and maize productivity. Composts made from maize stover and wheat straw both increased grain output, but maize compost was more effective. Throughout two growing seasons, the amount of potassium (K) and nitrogen (N) in grains and leaves was continuously increased. Grain P content responded favorably to compost in the second season, although phosphorus (P) percentages in leaves were unaffected. The application of compost also resulted in a considerable increase in the amount of crude protein (CP) in grains, highlighting its significance in improving nutritional quality.

There was a dose-dependent response to nitrogen fertilization (0–135 kg N/fad): greater N rates increased nutrient uptake and yield components (ear length, diameter, and grain yield), but decreased recovery and nitrogen usage efficiency (NUE). The highest NUE (25.11 kg grains/kg N) and recovery (29.24%) were obtained with the ideal N rate of 45 kg/fad, indicating declining returns at higher levels. Although its effects on ear morphology and P in grains were not consistent, phosphorus-potassium (PK) fertilization (31 kg P<sub>2</sub>O<sub>5</sub> + 24 kg K<sub>2</sub>O/fad) increased grain yield, N, and K content in grains.

To maximize yield, nutrient efficiency, and grain quality, our results support a synergistic strategy that combines organic amendments (especially maize compost) with targeted PK fertilizer and moderate N (45 kg/fad). Maintaining soil health and resource efficiency while encouraging sustainable maize production might be achieved by balancing these inputs to reduce excessive dependence on high nitrogen dosages.

#### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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