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Growth and yield response of maize (*Zea mays* var. *saccharata*) to different nitrogen fertilization sources and rates

Реакция на растежа и добива на царевица (*Zea mays* var. *saccharata*) към различни източници и норми на азот

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ABSTRACT

Nitrogen is an essential plant nutrient and a major yield-determining factor, required for normal vegetative growth and grain development of maize. Applying nitrogen requires appropriate fertilization management to achieve efficient nutrient utilization. A field experiment was carried out on Fluvisol to evaluate the yield and growth parameters response of maize (*Zea mays* var. *saccharate*) to incremental rates of N fertilizer (100, 150, 200 kg N/ha) from two different fertilization sources – ammonium nitrate (NH_4NO_3) and urea (CH_4N_2O). Highest yield was measured in plants subjected to N_{200} (9.76 t/ha) fertilization rate with NH_4NO_3. A high linear correlation was observed between yield and nitrogen fertilization rate regardless of the nitrogen source. The effect of different nitrogen rates was significant on leaf number and mass, ears mass, internodes number and mass per plant. The results revealed that the nitrogen source significantly affected the number of leaves per plant and the leaves mass. The individual effects of fertilization rate and source on yield were not statistically significant in isolation. However, when considered together, they exhibited a significant effect at the 95% confidence level.

Keywords: *Zea mays*, urea, ammonium nitrate, yield

АБСТРАКТ

Азотът е основен хранителен елемент, определящ добива и необходим за нормалния вегетативен растеж и развитие на царевицата. Внасянето на азотни препарати изисква подходящо управление на торенето, за постигане на ефективно използване на хранителните вещества от растенията. Изведен е полски експеримент върху алувиално-ливадна почва за да се оцени реакцията на добива и параметрите на растежа на сладка царевица (*Zea mays* var. *saccharata*) към нарастващи нива (100, 150, 200 kg N/ha) на различни азотни източници – амониева селитра (NH_4NO_3) и карбамид (CH_4N_2O). Най-висок добив е отчетен от растенията, торени с NH_4NO_3 при норма от N_{200} (9.76 t/ha). Получена е висока корелационна зависимост между добива от и торенето – добивът се увеличава линейно с увеличаване на торовите норми, както при внасяне на NH_4NO_3, така и при - CH_4N_2O. Ефектът от различните азотни норми е значителен върху броя и масата на листата, масата на царевичните кочани, броя на междувъзлията и масата на растенията. Резултатите показват, че азотният източник оказва значим ефект върху броя и масата на листата. Установено е, че азотната норма и източник не оказват значим ефект върху отчетените добиви като отделни фактори, но взаимодействието между тях влияе значително при 95.0% ниво на достоверност.

Ключови думи: *Zea mays*, карбамид, амониева селитра, добив

INTRODUCTION

Maize (*Zea mays* var. *saccharate*) ranks as the second most extensively cultivated cereal crop globally. Its cultivation spans over 160 million hectares of agricultural land, constituting approximately 11% of global agricultural production (Poehlman, 1987; Linquist, 2012). Maize is renowned for its profitability among farmers, owing to its increased market demand, substantial yield per unit area, and relatively high market price.

Nitrogen (N) is a vital nutrient, essential for optimal plant growth and development, believed to increase crop yields by 30-50%. (Erisman et al., 2008; Godfray et al., 2010; Pangaribuan et al., 2018). Due to its rapid growth, maize requires high quantities of nitrogen at different growth stages. Choosing the proper nitrogen fertilization source, rate and timing of application are key management decisions to minimize nutrient loss and maximize yield in crop production systems (Gheysari et al., 2009; Khaliq et al., 2009).

The increased production of maize has led to a surge in nitrogen fertilizer usage. However, excessive nitrogen application not only results in a significant decline in grain yield and quality but also causes substantial nitrogen loss, leading to increased production costs and environmental pollution, affecting soil fertility and water quality (Andraski et al., 2000; Hong et al., 2007). Fertilizer manufacturers continually strive to enhance the efficiency of synthetic fertilizers to prevent excessive nitrogen additions (Gagnon et al., 2012). Nevertheless, nitrogen management in maize production remains challenging from economic, agronomic, and environmental perspectives (Ma and Biswas, 2016).

Urea and ammonium nitrate are the most commonly used nitrogen fertilizers in maize production (Sutton et al., 2011). The use of urea is increasing as it has certain advantages over other forms of N fertilizer in manufacturing, transporting, and marketing. However, significant N loss through ammonia volatilization can occur if urea is not properly incorporated into the soil through tillage, rainfall, or irrigation (Ma et al. 2010). Ammonium nitrate contains both ammonium and nitrate forms of nitrogen. The nitrate form, unlike ammonium, is less prone to volatilization and offers the advantage of immediate availability to plants. However, the use of ammonium nitrate has declined due to safety concerns related to its potential use in explosive devices.

With the dynamics of modern agriculture and the growing global population, there is a pressing need to prioritize efficient nutrient utilization in crop production through optimized fertilizer management strategies. The precise application of optimal rates and appropriate types of fertilizers plays a pivotal role in achieving this goal. The objective of this research was to evaluate the extent to which the type and rate of nitrogen fertilizer effects the growth parameters and yield of maize.

MATERIALS AND METHODS

A field experiment was carried out with maize (*Zea mays* var. *saccharate*) – Kneja-sladka 1, grown after forage peas in a crop rotation cycle, on Fluvisol (FAO, ISRIC World Soils). The soil at the experimental field had low pH (pH_{H_2O}-7.1; pH_{KCl}-6.3) and humus content was poor – 1.44% at 0-30cm soil sample. Mineral nitrogen content was low – 22.4 mg/kg, P_2O_5 was 17.65 mg P/100g, and K_2O was 19.72 mg K/100g.

The experiment was conducted in a randomized complete block design with a split-plot arrangement using four replications. Three incremental N fertilization rates (100, 150, and 200 kg N/ha) and two N-fertilizer sources – ammonium nitrate (NH_4NO_3) and urea (CH_4N_2O) were tested:

00A	$N_0P_0K_0$ control (no N fertilization)	
0A	$N_0P_{50}K_{50}$	
1A	$N_{100}P_{50}K_{50}$	NH_4NO_3
2A	$N_{150}P_{50}K_{50}$	
3A	$N_{200}P_{50}K_{50}$	
1B	$N_{100}P_{50}K_{50}$	CH_4N_2O
2B	$N_{150}P_{50}K_{50}$	
3B	$N_{200}P_{50}K_{50}$	

A control plot with no N fertilization applied was used in each replication for comparison. Nitrogen was applied at two equal splits, 50% at sowing and 50% when plants reached 30-40 cm height.

A uniform application of 50 kg/ha $Ca(H_2PO_4)_2 \cdot H_2O$ and KCl fertilizers was administered across all replications of the experiment. Weed management practices and irrigation were diligently performed based on the specific requirements and growth stage of the experimental crop. A subset of 10 randomly chosen plants from each replication was selected, and precise morphological measurements were obtained to determine growth parameters. The plants were harvested at the stage of full maturity when the maize kernels' humidity reached 15%.

The statistical analysis of data was performed using analysis of variance (ANOVA) using STATGRAPHICS Centurion software. The main effect of N rate, N fertilizer source, and crop growth stage and their interactions were analyzed using the multi-factor ANOVA on the measured variables. The comparison of means was performed with the least significance difference (LSD) when the F-test showed significance at $P \leq 0.05$ and 95% confidence level.

RESULTS AND DISCUSSION

Growth parameters

Plant height is a crucial growth parameter in maize due to its direct correlation with overall plant development, biomass accumulation, and grain yield potential. It serves as an essential indicator for crop monitoring, resource allocation assessment, and management decisions.

The NH_4NO_3-fertilized plants exhibited the greatest plant height (1.26 m) with N_{150} nitrogen rate applied. However, the observed differences between these fertilization treatments and the other variants were insignificant at the 95% confidence level. Among plants subjected to CH_4N_2O as the nitrogen source, the N_{100} fertilization resulted in the highest plants (1.27 m), with significant differences ($P \leq 0.05$) to plant heights from N_{200} rates (Table 1).

According to some researchers, different nitrogen sources have a significant effect on maize plant growth, increasing the number and length of the internodes, which results in a progressive increase in plant height (Gasim, 2001; Amin, 2011). However, our results revealed no statistically significant variations in plant heights concerning the applied nitrogen source and its rate. (Table 2). Factors such as environmental conditions, and genetic characteristics of the maize variety can also influence plant height and may mitigate the effect of nitrogen sources on plant growth. Similar findings were reported by Asghar et al. (2010) and Mukhtar et al. (2011), who concluded that plant height was not significantly affected by applied different nitrogen sources.

The first ear heights measured in the current study were within the expected range for the crop's developmental stage (Table 1). Among plants fertilized with NH_4NO_3, the greatest first ear height was observed at the N rate of 200 kg N/ha (0.23 m), but these differences did not reach statistical significance ($P \leq 0.05$). Conversely, plants fertilized with CH_4N_2O exhibited a distinct pattern, with the greatest first ear height (0.22 m) recorded at the lowest nitrogen rate of 100 kg N/ha, showing significant differences ($P \leq 0.05$) (Table 1). The nitrogen source itself was not found to have a significant impact on first ear height ($P = 0.0925$ at the 95% confidence level), consistent with findings reported by Turgut (1998) and Karasu (2012). However, the interaction between nitrogen levels and nitrogen sources demonstrated a significant effect on this parameter ($P = 0.0286$ at the 95% confidence level).

The leaf count per plant ranged between 7.30 and 8.90, and statistically significant differences were observed across the tested nitrogen sources, NH_4NO_3 and CH_4N_2O. The plants receiving N_{100} and N_{200} showed the highest leaf counts, with significant differences of 0.928 and 0.844, respectively, at $P < 0.05$ (Table 1). These results are consistent with earlier investigations conducted by Woldesenbet and Haileyesus (2016). The statistical analysis highlights the significant influence of both the nitrogen source and its rate on the leaf count.

Table 1. Effect of different nitrogen fertilization on plant growth parameters of maize

Nitrogen levels	Nitrogen sources	Plant height (m)	First ear height (m)	Leaf number per plant	Internodes number per plant	Ear number per plant	Mass per plant (kg)
$N_0P_0K_0$		1.20[a]	0.18[ab]	7.8[a]	8.2[a]	1.0[a]	0.24[a]
$N_0P_{50}K_{50}$		1.18[a]	0.14[a]	7.7[a]	7.8[a]	1.0[a]	0.25[a]
$N_{100}P_{50}K_{50}$		1.24[a]	0.20[bc]	8.8[b]	8.5[a]	1.1[a]	0.28[a]
$N_{150}P_{50}K_{50}$	NH_4NO_3	1.26[a]	0.21[bc]	7.8[a]	8.2[a]	1.3[a]	0.28[a]
$N_{200}P_{50}K_{50}$		1.22[a]	0.23[c]	8.9[b]	8.4[a]	1.2[a]	0.38[b]
LSD		0.107	0.051	0.928	0.756	0.345	0.054
$N_0P_0K_0$		1.20[ab]	0.18[ab]	7.8[ab]	8.2[b]	1.0[a]	0.24[a]
$N_0P_{50}K_{50}$		1.18[ab]	0.14[a]	7.7[ab]	7.8[ab]	1.0[a]	0.25[a]
$N_{100}P_{50}K_{50}$		1.27[b]	0.22[b]	8.3[b]	8.5[b]	1.3[ab]	0.29[b]
$N_{150}P_{50}K_{50}$	CH_4N_2O	1.19[ab]	0.18[a]	7.3[a]	7.3[a]	1.3[ab]	0.30[b]
$N_{200}P_{50}K_{50}$		1.15[a]	0.17[a]	8.2[b]	8.1[ab]	1.5[b]	0.30[b]
LSD		0.104	0.042	0.844	0.857	0.396	0.019

* Means within each column followed by the same letter are not significantly different at the 95% confidence level

Table 2. Effect of different nitrogen sources (NS) and levels (NL) on plant growth parameters of maize

		Plant height (m)	First ear height (m)	Leaf number per plant	Internodes number per plant	Ear number per plant	Mass per plant (kg)
NS	NH_4NO_3	1.24[a]	0.21[a]	7.93[a]	8.37[a]	1.20[a]	0.31[a]
	CH_4N_2O	1.20[a]	0.19[a]	8.5[b]	7.97[a]	1.37[a]	0.30[a]
LSD		0.047	0.026	0.527	0.434	0.237	0.029
	N_{100}	1.25[b]	0.21[a]	8.55[b]	8.50[b]	0.10[a]	0.28[a]
NL	N_{150}	1.22[ab]	0.19[a]	7.55[a]	7.75[a]	0.10[a]	0.29[a]
	N_{200}	1.18[a]	0.2[a]	8.55[b]	8.25[ab]	0.10[a]	0.34[b]
LSD		0.058	0.032	0.645	0.532	0.290	0.035
NL		0.0622[NS]	0.5848[NS]	0.0031*	0.0212*	0.5759[NS]	0.0021*
NS		0.1417[NS]	0.0925[NS]	0.0355*	0.0703[NS]	0.1640[NS]	0.2122[NS]
NL/NS		0.1189[NS]	0.0286*	0.9377[NS]	0.2340[NS]	0.5759[NS]	0.023*

* Means within each column followed by the same letter are not significantly different at the 95% confidence level;
** NS, * - Non significant or significant at P < 0.05%, using F-test

Under our experimental conditions, NH_4NO_3-fertilized plants exhibited a greater number of leaves, which can be explained by the efficiency of nitrogen source which composed of two forms (ammonium and nitrate). Similar findings have been reported by Amin (2011). The observed increase in leaf count per plant may be attributed to the well-known effect of nitrogen on promoting plant growth and height. This, in turn, leads to the development of more nodes and internodes, ultimately resulting in an increased production of leaves (Jhones et al., 1995).

The number of internodes ranged from 7.30 to 8.50, with the highest count recorded in plants fertilized with $N_{100}P_{50}K_{50}$ (8.50), irrespective of the nitrogen forms examined in the study (Table 1). Statistical analysis revealed a significant effect of nitrogen rate (*P* = 0.0212 at the 95% confidence level) on this parameter, while the nitrogen form did not exhibit a significant effect (*P* = 0.0703 at the 95% confidence level) (Table 2). These findings highlight the influence of nitrogen rate on the development of internodes and leaves in maize plants, suggesting that optimizing nitrogen application can contribute to enhanced plant growth and leaf production.

The number of formed maize ears ranged from 1.00 to 1.50. Among plants fertilzied with NH_4NO_3, no significant differences in ears formation were observed across different nitrogen rates (*P* < 0.05). In contrast, plants fertilized with CH_4N_2O exhibited the highest number of ears with the N_{200} nitrogen rate (1.50), with significant differences observed only when compared to control variants without nitrogen fertilization (LSD = ±0.396) (Table 1). This finding aligns with previous studies that have demonstrated the stimulating effect of nitrogen fertilization on ears production (Salem and Ali, 1979). Interestingly, the nitrogen form and source did not exert a statistically significant effect on the number of formed ears per plant (Table 2). These results emphasize the importance of proper nitrogen management in optimizing ears formation, while suggesting that other factors beyond nitrogen source may play a role in determining this aspect of maize development.

Maize plants exhibit vigorous vegetative growth, and it is essential to implement appropriate fertilization strategies to support their optimal development. Plant biomass serves as a crucial parameter for assessing growth performance. In our study, the recorded plant masses ranged from 0.24 to 0.30 kg per plant. Notably, the control variants without fertilization demonstrated the lowest plant masses at 0.24 kg per plant. Among the NH_4NO_3-fertilized plants, significant differences were observed, with the N_{200} rate exhibiting higher plant masses compared to the other tested variants (LSD=±0.054). Similarly, for the CH_4N_2O-fertilized plants, significant differences were detected among the nitrogen-fertilized variants (N_{100}, N_{150}, and N_{200}) and the control group at ой the 95% confidence level (Table 1). These findings underscore the importance of nitrogen fertilization in promoting robust plant biomass accumulation. Further investigations are needed to elucidate the underlying mechanisms responsible for the observed differences among the nitrogen fertilization treatments and their impact on maize plant biomass.

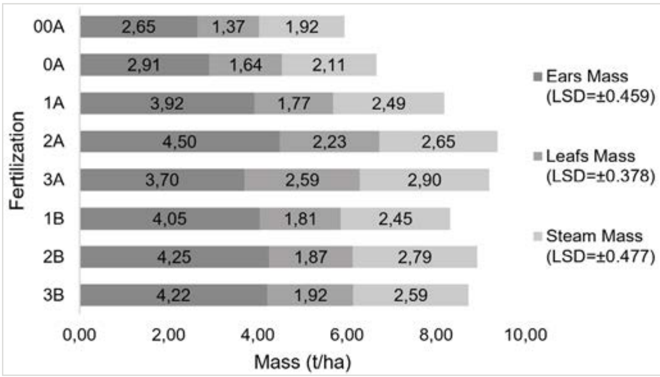


Figure 1. Effect of different nitrogen fertilization on steams, leaves and ears mass of maize

No statistically significant effect of the nitrogen source on the formed vegetative biomass of the plants was observed in our study (*P* = 0.2122 at the 95% confidence level). Nitrogen levels, and the Nitrogen levels/Nitrogen sources interaction have shown significant impact (*P* = 0.0021; *P* = 0.0230 at the 95% confidence level).

The highest plant biomass was obtained with the highest nitrogen rate, indicating a positive correlation between nitrogen application rate and plant biomass. (N_{200}) – 0.34 kg per plant (Table 2).

In the context of this study, the masses of leaves, stems, and ears were examined as important components of the overall vegetative biomass of maize plants (Figure 1).

The analysis revealed a significant effect of the nitrogen source on leaf mass (*P* = 0.008 at the 95% confidence level), while the nitrogen rate exerted a considerable influence on ear mass (*P* = 0.0092; *P* = 0.0006 at the 95% confidence level). However, no significant effect of fertilization was observed on stem mass (Table 3).

Table 3. Effect of different nitrogen sources (NS) and levels (NL) on steam, leaves, ears mass of maize

		Steam mass	Leaves mass	Ears mass	Yield
		t/ha			
NS	NH_4NO_3	2.68^a	2.19b	4.04^a	8.93^a
	CH_4N_2O	2.61^a	1.87^a	4.17^a	8.54^a
LSD		0.313	0.236	0.182	0.647
NL	N_{100}	2.47^a	1.79a	3.99^a	8.31^a
	N_{150}	2.72^a	2.05^{ab}	4.37^b	8.66^{ab}
	N_{200}	2.74^a	2.25^b	3.96^a	9.24^b
LSD		0.383	0.289	0.223	0.792
NL		0.2872^{NS}	0.0092*	0.0006*	0.0007^{NS}
NS		0.6545^{NS}	0.008*	0.1558NS	0.0023^{NS}
NL/NS		0.5063^{NS}	0.0534^{NS}	0.0052*	0.0306*

*Means within each column followed by the same letter are not significantly different at the 95% confidence level;

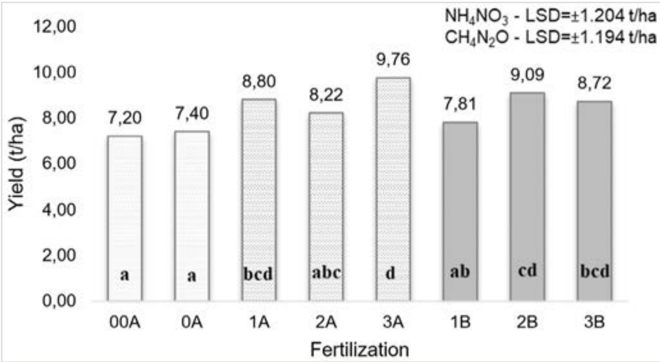
**NS, * - Non significant or significant at *P* < 0.05%, using F-test.

Maize yield

Achieving high maize yields is essential for ensuring food security, promoting economic growth, sustaining agricultural ecosystems, building climate resilience, enhancing market competitiveness, and driving innovation in the agricultural sector. Maize yields in the present study ranged from 7.20 to 9.76 tons per hectare (Figure 2), which aligns with findings reported by other researchers (Meena et al., 2012; Pangaribuan et al., 2018).

Statistical analysis revealed that the mean yield of the NH_4NO_3-fertilized variants exhibited a significant increase of 24% compared to the non-fertilized plants. Similarly, the CH_4N_2O-fertilized variants demonstrated a significant yield increase of 19%.

The highest yield was observed in the NH_4NO_3-fertilized plants at the N_{200} rate (9.76 t/ha), although the differences were not statistically significant (*P* < 0.05; Figure 2). While higher fertilizer rates are expected to result in increased yields, our study demonstrates that the nitrogen rate and source do not exert significant individual effects on yields at the 95% confidence level (Table 2). These findings are consistent with previous studies conducted by Zhang et al. (1993) and Kumar et al. (2007).



Means within each column followed by the same letter are not significantly different at the 0.005 level using LSD test

Figure 2. Effect of nitrogen fertilization on maize yield

Furthermore, a correlation analysis revealed a linear relationship between the yield of sweet maize and the applied fertilizer rates, irrespective of whether NH_4NO_3 or CH_4N_2O was used. However, the magnitude of the yield response varied (Figure 3).

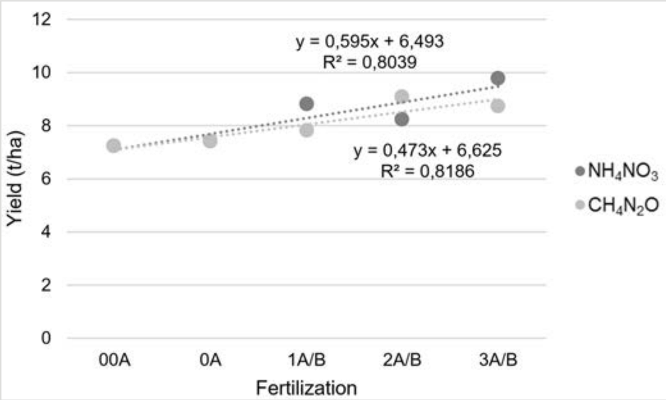


Figure 3. Relationship among maize yield and nitrogen fertilization

Soil status

To monitor the status of the soil, soil samples were taken at the end of the experiment for each tested fertilization variant. The data is summarized in Figure 4.

An increase in soil pH was observed for all CH_4N_2O fertilization treatments. This is likely attributable to the process of urea hydrolysis, with which hydroxyl anions (OH^-) are released in the soil, leading to an increase in pH (Figure 4a). Conversely, a slight acidification of the soil was observed in the plots fertilized with NH_4NO_3, which is possibly due to the hydrogen ions (H^+) released during nitrification.

The content of total nitrogen in the soil at the end of the experiment varied, but in the variants fertilized with CH_4N_2O, a clear growth trend was observed with an increase in the fertilization rate (Figure 4b). These results suggest that, under the specific conditions, a rate between 150-200 kg N/ha is suitable to satisfy the plant needs during the vegetation, and to retain the soil in good condition.

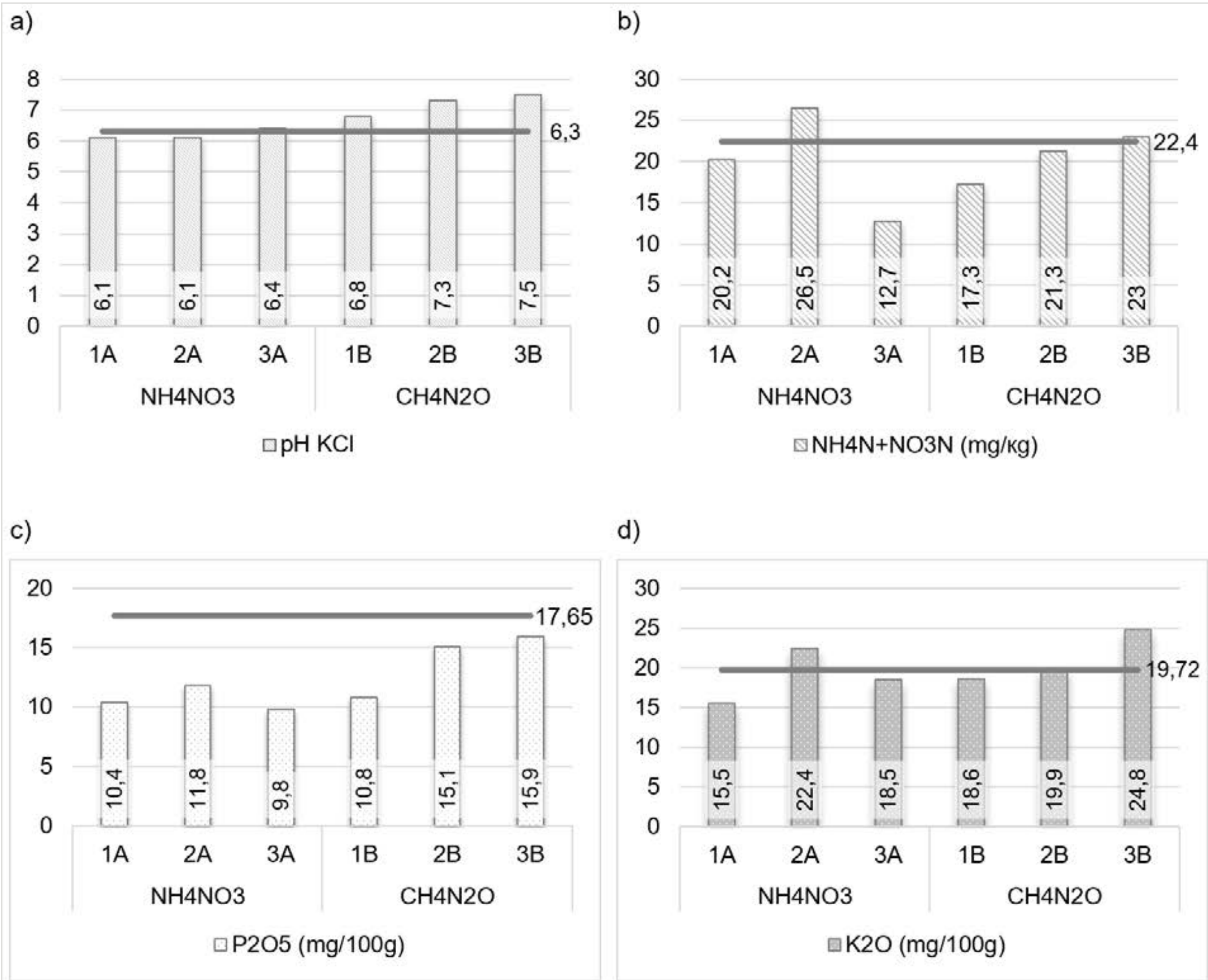


Figure 4. Effect of nitrogen fertilization on soil status after the experiment

A similar trend is observed for P_2O_5, but the P_2O_5 rates are low and the residual contents are lower than those measured before the experiment. The P_2O_5 content was found to be higher in the plots fertilized with CH_4N_2O (Figure 4c), which could be due to changes in soil pH. The K_2O data obtained is in line with the reported yields (Figures 2 and 4d). The potassium rate of 50 kg K/ha is appropriate for the specific conditions.

These results highlight the positive impact of nitrogen fertilization on maize yield and underline the importance of nutrient management strategies to optimize crop production. In addition to achieving high yields, sustainable land use and maintaining soil fertility are among the most important challenges of our time, and this mandates for careful selection of fertilizers.

CONCLUSION

Significantly higher values for most of the assessed growth parameters in sweet maize were observed with the application of NH_4NO_3. However, the statistical analysis did not reveal a significant effect of the nitrogen source as a factor on these parameters. The exception was the internode number per plant, where the nitrogen source showed a significant impact. These findings suggest that while NH_4NO_3 may have a positive influence on various growth parameters, its overall effect as a nitrogen source may not be statistically significant.

The findings of this study demonstrated a significant influence of nitrogen levels on leaf number, internode number, and plant mass. Moreover, the choice of nitrogen source also had a significant effect on leaf number per plant and leaf mass. These results indicate that both nitrogen levels and nitrogen sources play a crucial role in influencing various growth parameters of the maize plants.

The highest maize yield was observed in the NH_4NO_3-fertilized plants at the N_{200} rate, reaching 9.76 tons per hectare. However, these results were not statistically significant at the 95% confidence level. Although higher fertilizer rates are generally associated with increased yields, our results indicate that the specific nitrogen rate and source did not have a significant individual effect on maize yields in our study. These findings highlight the complexity of yield determination in maize and suggest that other factors may play a more influential role.

Understanding the intricate interplay between nitrogen levels, nitrogen sources, and various growth parameters in maize is paramount for implementing effective fertilization practices. By optimizing nutrient management strategies, farmers can enhance maize yield, promote sustainable agriculture, and contribute to global food security. Continued research and knowledge exchange are essential for refining fertilization recommendations and adapting them to local conditions, ensuring the long-term success and sustainability of maize production systems.

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