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Research Article

Impact of Neem-Coated Urea on NO_3-N and NH_4-N Availability and Growth Performance of Maize in Saline and Non-Saline Soils

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ABSTRACT

This study investigates the effects of neem-coated granular urea on nitrogen volatilization and leaching in maize (*Zea mays* L.), focusing on nutrient availability (NO3-N and NH4-N) in both normal and saline soils. The pot experiment was conducted in a glass-panelled wire house CRD design with three replications. The experimental treatments included T1 (control without fertilizer), T2 (0.05 % neem-coated granular urea @ 200 kg ha^{-1} + recommended P and K), T3 (0.08 % neem-coated granular urea @ 200 kg ha⁻1 + recommended P and K), T4 (0.01 % neem-coated granular urea @ 200 kg ha-1 + recommended P and K), and T5 (recommended NPK: 200 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, and 60 kg K_2O ha^{-1}). Soil samples were taken prior to planting, one month later, and following harvest in order to examine key chemical components. The results demonstrated that maize growth and nutrient uptake were significantly enhanced by T3 (0.08 % neem-coated urea). Under T3, there was an increase of 34.32 % in shoot length, 50.48 % in fresh weight, and 22.40 % in dry weight. There were notable increases in root length, fresh weight, and dry weight of 36.68 %, 21.32 %, and 46.53 %, respectively. Additionally, in comparison to the control, the T3 treatment increased the plant membrane stability index (MSI), chlorophyll content, and nitrate retention by 21.32 %, 22.13 %, and 17.29 %, respectively. Treatment T3 enhanced potassium content, phosphorus absorption, and nitrogen concentration. According to data, applying 0.08 % neem-coated urea along with recommended levels of potassium and phosphate enhances maize growth, and overall crop productivity. This makes it a feasible substitute for long-term and effective fertilizer application in both normal and salinized soils.

Keywords: Neem-coated Urea; Nitrogen Volatilization; Nitrogen Leaching; Maize Growth: Salinity-stressed Soils; Membrane Stability Index.

INTRODUCTION

Food security is still largely dependent on agriculture, especially in developing nations like Pakistan where sustainable agricultural methods are increasingly challenged by population growth and rising food demands (Ghafoor et al., 2022). However, a number of factors, including deficiencies in soil nutrients and environmental stresses, especially salinity, frequently limit the productivity of agricultural land in Pakistan (Munns, 2005). These problems are made worse by the inefficient use of fertilizers, particularly nitrogen (N), which results in low nitrogen use efficiency (NUE) and large nitrogen losses through denitrification, volatilization, and leaching (Raun and Johnson, 1999; Robertson and Groffman, 2024).

One of the most important nutrients for plant growth is nitrogen, and crop yields are largely dependent on the availability of nitrogen in the soil. Because of its great solubility and low cost, urea which has a nitrogen content of about 46% is the most widely used nitrogen fertilizer in the world (Jackson et al., 1988). Nevertheless, ammonia volatilization and nitrate leaching losses a large amount of applied urea, especially in saline soils (Sandilya et al., 2023). Approximately 20% of the irrigated land globally is affected by salinity, which significantly limits plant growth by changing nutrient availability and producing ion toxicity (Munns, 2005). Soil salinity is a significant barrier to agricultural productivity in Pakistan, particularly in arid and semi-arid areas where poor irrigation techniques aggravate the issue (Sandilya et al., 2023).

Maize (*Zea mays* L.) is a vital cereal crop that, because of its high starch content and nutritional profile, greatly contributes to both livestock feed and global food security (Ghafoor et al., 2022). With 11.4 million hectares under cultivation and a production of 5.5 million tonnes in 2020–2021, maize is a crucial crop in Pakistan's agricultural sector (Ahmad et al., 2022). However, environmental stressors like soil salinity, nutrient imbalances, and inefficient nitrogen use frequently limit productivity (Ghafoor et al., 2021). Ineffective nitrogen management exacerbates environmental problems such as ammonia volatilization and nitrate leaching, which lower water quality and raise greenhouse gas emissions (Ghafoor et al., 2021; Ghafoor et al., 2022; Sandilya et al., 2023). For sustainable maize production in both normal and saline conditions, methods to increase nitrogen use efficiency—like applying urea coated with neem—are essential (Ahmad et al., 2022; Ramappa et al., 2022).

This study intends to assess the effectiveness of neem-coated urea (NCU) in providing a sustained release of NO_3-N and NH_4-N in both normal and saline soil conditions, given the critical role that nitrogen plays in crop production and the increasing need to mitigate environmental impacts. The investigation of NCU's effects on maize (Zea mays L.) growth and yield is another goal of the study, one of Pakistan's most important cereal crops that makes a substantial contribution to food for both people and animals. This study attempts to shed light on how well NCU performs in relation to conventional urea in order to improve fertilizer sustainability and efficiency in agriculture, especially when salinity is a stressor. Our hypothesis in this study is that in both normal and saline soils, neem-coated urea will perform better than conventional urea due to its ability to reduce nitrogen losses and improve nitrogen uptake. The anticipated results are higher crop growth, better soil retention of nitrogen, and higher maize yields. This provides farmers with a workable solution to address salinity and nutrient loss problems in their fields. The results of the study will also add to the expanding body of information on sustainable nitrogen management strategies, especially in light of the effects of climate change and rising soil degradation.

MATERIALS AND METHODS

The purpose of the experiment was to determine how neem-coated urea (NUE) affected maize growth in both normal and salinized soils. A pot trial was conducted at the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, in a glass-enclosed curtain house. The experiment employed a completely randomized design (CRD) with three replications. Pots were filled with 20 kg of sandy loam soil that contained 27 %, 32 % silt, and 48 % sand. Before sowing, the following properties of the soil were assessed: total nitrogen content was 0.053 %, organic matter was 0.73 %, extractable potassium was 140 mg kg^{-1}, available phosphorus was 5.8 mg kg^{-1}, pH was 8.42, electrical conductivity (ECe) was 1.2 dS m^{-1}, indicating non-saline conditions, and $CaCO_3$ content was 18.6 %. In order to simulate the salinity stress conditions that are typical of saline soils, salt was artificially added to the soil to raise the salinity levels.

Neem-coated urea was prepared under laboratory conditions by coating urea granules with neem oil. The process involved evenly applying neem oil to urea particles, drying the coated granules under a polyethylene plastic sheet in a shaded area to prevent contamination, and storing them in suitable conditions. This method ensures uniform coating and preserves the effectiveness of the neem oil as a nitrification inhibitor.

The treatment groups included a control (T_1), neem-coated granular urea applied at 200 kg ha^{-1} with phosphorus and potassium (T_2), neem-coated urea at kg ha^{-1} with phosphorus and potassium (T_3), and neem-coated urea at the same rate with phosphorus and potassium (T_4). The final treatment, T_5, consisted of the recommended doses of nitrogen, phosphorus, and potassium. A parallel experiment was conducted under saline soil conditions using comparable treatments. Additionally, loam soil was utilized in incubation studies without seedlings to evaluate the leaching of ammonium (NH_4-N) and nitrate (NO_3-N) over a one-month period with sampling at fifteen-day intervals.

Initial P and K doses of fertilizer were applied in two separate batches at planting. Three applications of urea coated in neem were made: one third at seeding, two thirds at seedling emergence, and the last third 15 days later. Water from pipe wells or canals was used to provide irrigation.

Chlorophyll content, fresh and dry weight, and shoot and root length were among the plant parameters that were measured. Using a lever bar, the shoot's length was measured from the base to the flag leaf. After harvesting, the length of the roots was measured by washing the soil. After harvesting, the samples were dried for 24 hours at 65 ± 5°C, and the fresh weights of the roots and shoots were measured 30 minutes later. Using a SPAD-501 chlorophyll meter, the amount of chlorophyll was measured during the vegetative stage. Readings were obtained from three locations on the second leaf.

Leaf samples that were kept at -20°C were subjected to chemical analyses for potassium and sodium before being centrifuged to extract leaf juice. After dilution, potassium and sodium ions were measured with a Sherwood 410 Flame Photometer. By measuring the electrical conductivity (EC) of leaf samples both before and after they were heated to 40°C and 100°C, the Membrane Stability Index (MSI) was calculated using the Sairam et al. (2000). The formula MSI = [1-(C1/C2)]*100 was applied.

By weighing leaves both before and after they were soaked in distilled water for four hours and then again after they were dried at 72°C, the Relative Water Content (RWC) was determined. The Relative Water Content (RWC) was determined following the method described by Weatherly (1947), calculated using the formula: RWC = (FW-DW)/(TW-DW)*100. The amount of chlorophyll was assessed subsequent to the third fertilizer split.

After harvest, the contents of potassium, phosphorus, and nitrogen were examined. The Micro Kjeldahl method (Reitemeier, 1963), which includes titration and distillation, was used to determine the nitrogen content. Using the yellow method of spectrophotometry, phosphorus was measured (Olsen, 1954), and potassium was measured in accordance with Reitemeier (1963) using a flame photometer. The analysis of the data was conducted utilizing ANOVA methods outlined by Steel et al. (1997). Subsequently, the Duncan multiple range test was employed for the comparison of means at a 5% probability threshold. Microsoft Excel served as the tool for data manipulation and visualization through the creation of graphs.

RESULTS

Growth Parameters of Maize

Shoot length

The effect of neem-coated urea treatments on maize shoot length is shown in Figure 1. The findings show that, in comparison to the control (T_1), treatment T3 (0.08 % neem-coated urea) significantly increased shoot length. T_3 demonstrated a 28% increase in shoot length in saline conditions, demonstrating neem's capacity to promote plant growth. The fact that all treatments especially, T_3 show a significant increase in shoot length highlights the efficiency of neem coated urea in encouraging the growth of maize shoots.

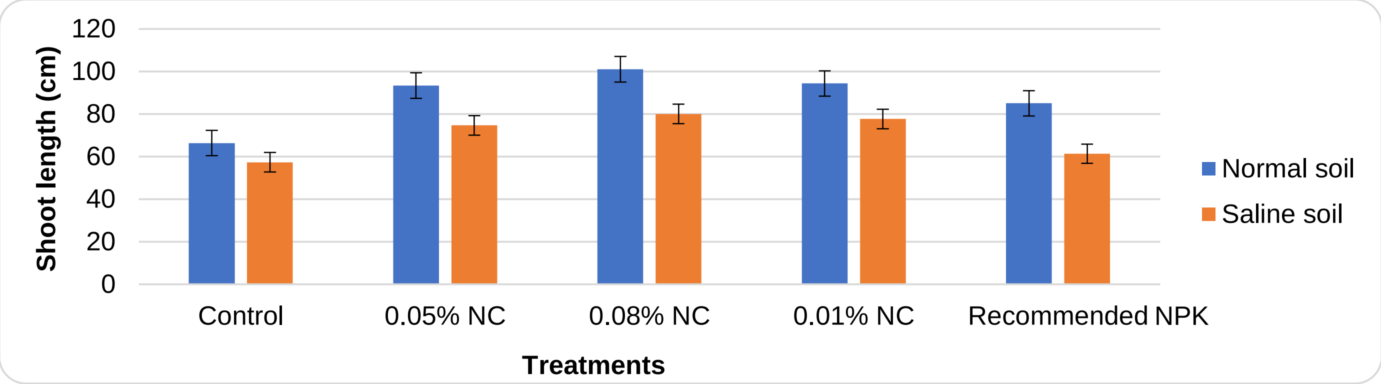

Figure 1. Effect of neem coated urea treatments on shoot length of maize.

Shoot fresh weight

The shoot fresh weight of maize under various treatments is shown in Figure 2. Particularly in saline soil conditions, treatment T_3 (0.08 % neem-coated urea) produced the highest fresh weight and outperformed the control (T1). The graph indicates that T_3 shoot fresh weight increased by 50% in normal soils and by 40% in saline soils. These findings imply improved nutrient efficiency since neem coated urea significantly increases shoot biomass, especially in saline soil conditions.

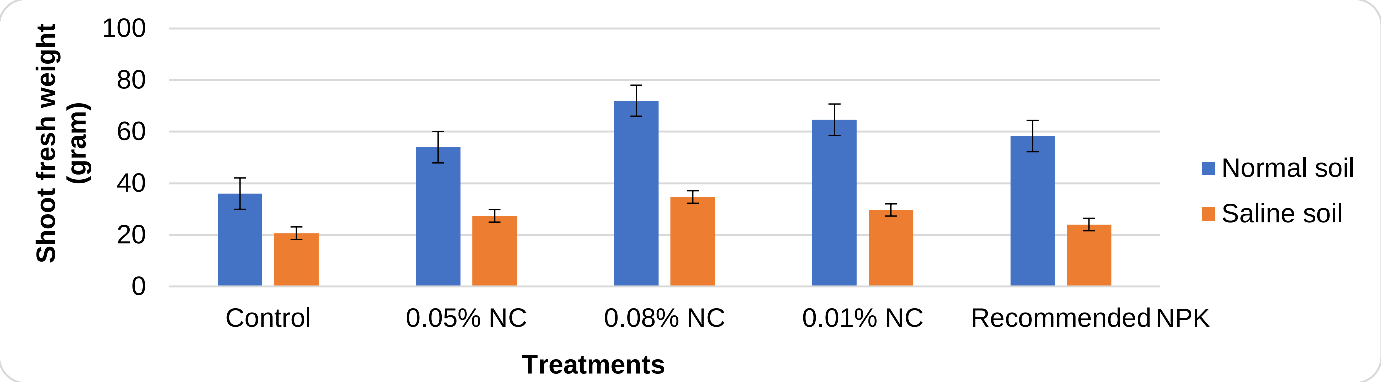

Figure 2. Effect of neem coated urea treatments on shoot fresh weight of maize.

Shoot dry weight

The shoot dry weight of maize under various treatments is shown in Figure 3. With an increase of 41.73 % in normal soil conditions and 46 .12 % in saline conditions, treatment T3 (0.08 % neem-coated urea) significantly outperformed the control (T_1). The outcomes highlight neem-coated urea's superior impact on the accumulation of dry biomass. This increase in dry weight, particularly for T_3, highlights the effectiveness of neem-coated urea by indicating improved growth sustainability and nutrient uptake in both soil conditions.

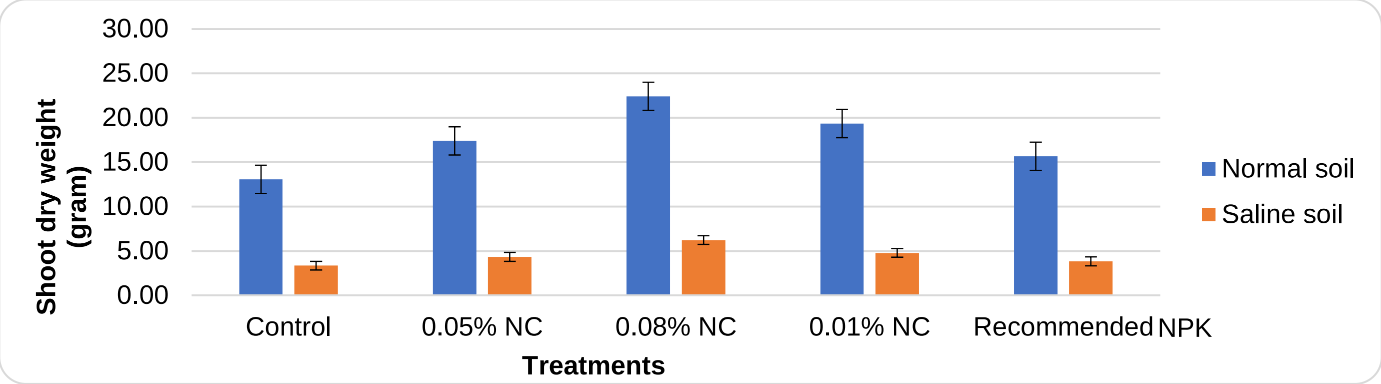

Figure 3. Effect of neem coated urea treatments on shoot dry weight of maize.

Root length

The root length of maize plants under various treatments is shown in Figure 4. With T_1, a 46.79 % increase in root length over the control in saline soils, treatment T_3 (0.08 % neem-coated urea) demonstrated the most notable improvement. This noteworthy development emphasizes how neem-coated urea helps to encourage deeper root systems, which are necessary for the absorption of nutrients and water. The longer roots in T_3 indicate improved resilience and general plant health in saline soil.

Root fresh weight

The root fresh weight of maize under various treatments is shown in Figure 5. In comparison to the control (T_1), treatment T_3 (0.08 % neem-coated urea) exhibits a notable increase in root fresh weight, with a 21.32 % increase in normal soil and an astounding 47.38 % increase in saline soil. These results highlight how well neem-coated urea works to increase root biomass, especially in salinized soil. T3's larger roots suggest better nutrient uptake and plant stability, both of which are essential for overall growth

Root dry weight

The root dry weight of maize under various treatments is shown in Figure 6. In comparison to the control (T_1), treatment T_3 (0.08 % neem-coated urea) exhibits the largest increase in root dry weight, rising 46 .53 % in normal soil and an astounding 70.37 % in saline soil. This notable expansion implies that neem-coated urea greatly enhances the retention of root biomass, especially in difficult conditions. The findings highlight the function of T_3 in enhancing root structure, which improves nutrient storage and general plant health.

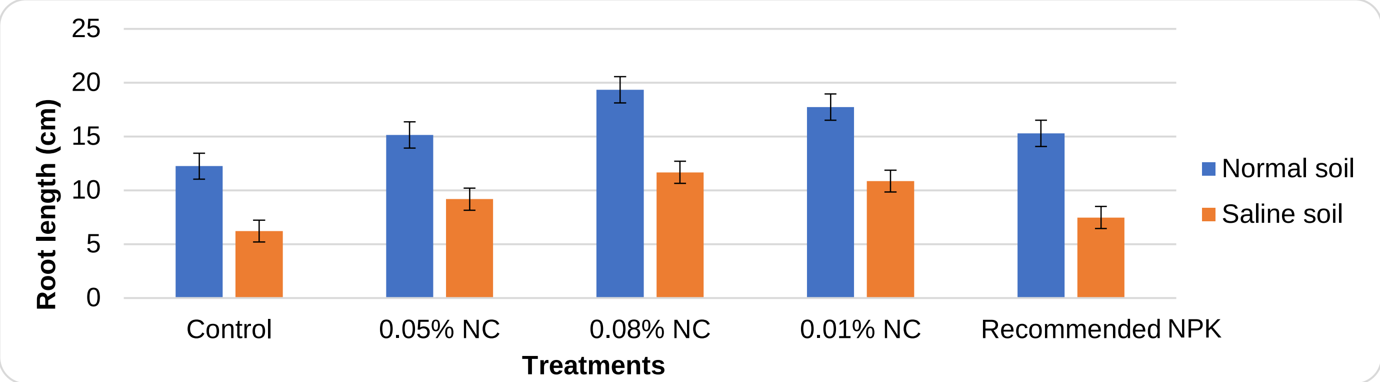

Figure 4. Effect of neem coated urea treatments on root length of maize.

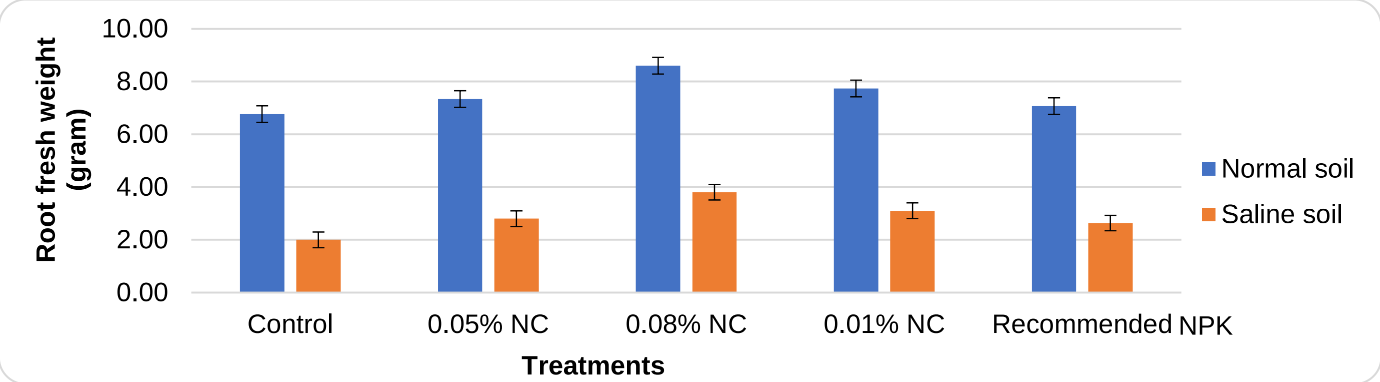

Figure 5. Effect of neem coated urea treatments on root fresh weight of maize.

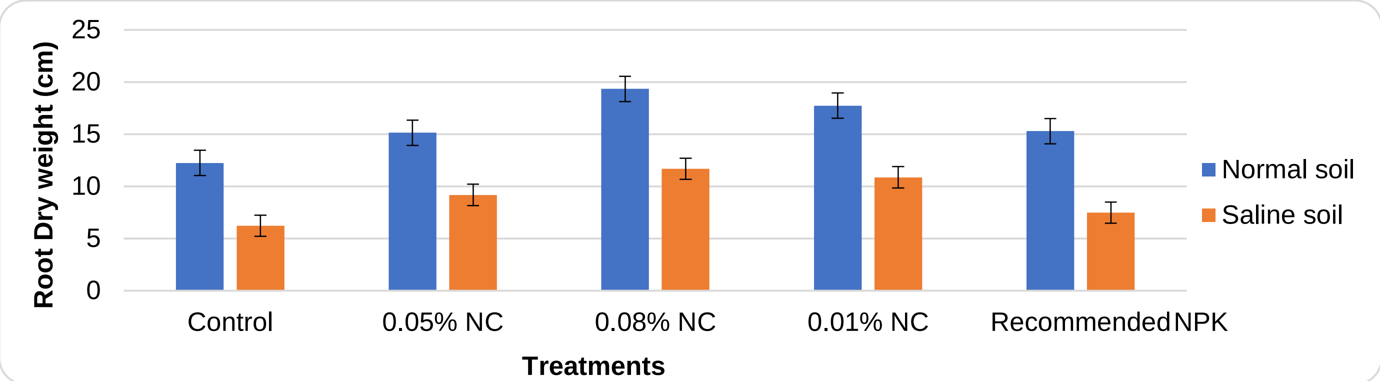

Figure 6. Effect of neem coated urea treatments on root dry weight of maize.

Chemical Characteristics of Maize

Membrane stability index

The membrane stability index of maize treated with different neem-coated urea formulations is shown in Figure 7. Compared to the control (T_1), treatment T_3 (0.08 % neem-coated urea) exhibits a noteworthy improvement, with a notable rise of 47.38 % in saline soil and a 21.32 % increase in normal soil. Better cell integrity and stress tolerance, especially in saline conditions, are indicated by this increased membrane stability. The outcomes demonstrate the protective function of neem-coated urea on plant cells, increasing their resistance to unfavorable environmental circumstances.

Relative water contents

The relative water content of maize plants under various treatments is shown in Figure 8. In comparison to the control (T_1), treatment T_3 (0.08 % neem-coated urea) showed a significant increase, rising 21 . 32 % in normal soil and 47. 38 % in saline soil. This implies that T_3 significantly improves the plant's capacity to retain water, especially in salinized soils. Better hydration and cell turgidity are indicated by the higher water content, which enhances overall plant growth and stress tolerance.

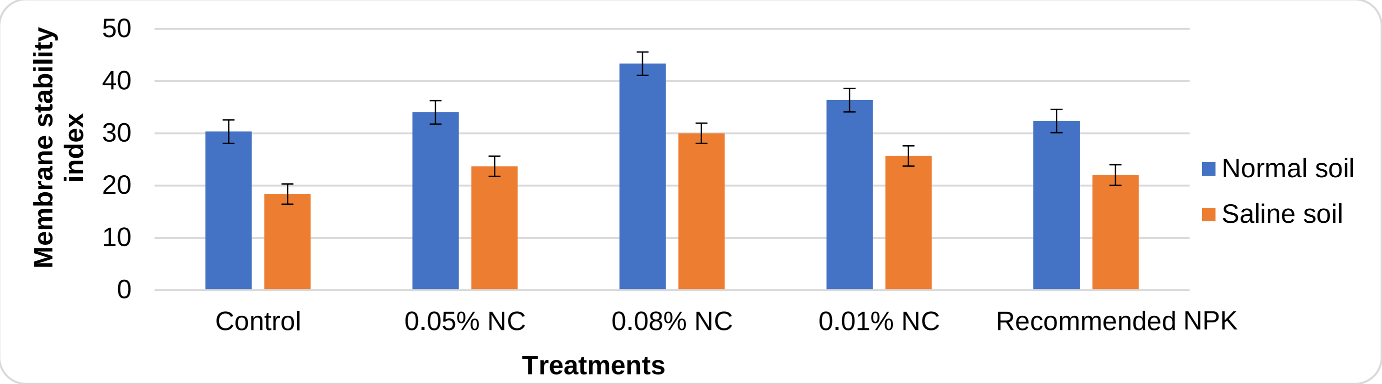

Figure 7. Effect of neem coated urea treatments on membrae stability index of maize.

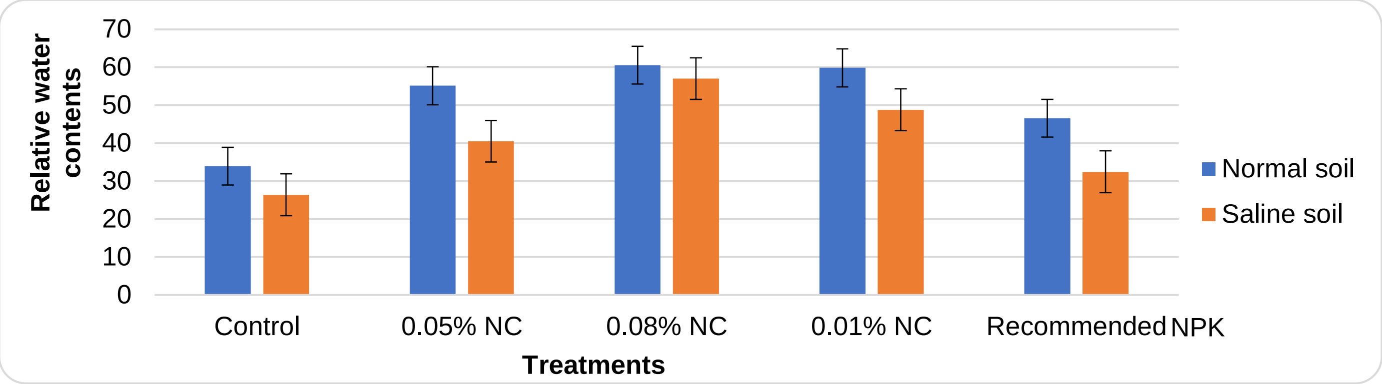

Figure 8. Effect of neem coated urea treatments on relative water contents of maize.

Chlorophyll contents (SPAD)

The chlorophyll content (SPAD) of maize under various treatments is displayed in Figure 9. In comparison to the control (T_1), treatment T_3 (0.08 % neem-coated urea) produced the highest chlorophyll content, rising 22.13 % in normal soil and 38.44 % in saline soil. This increase in chlorophyll content, especially in saline conditions, suggests more effective photosynthesis and nutrient utilization. The findings highlight the function of neem-coated urea in raising chlorophyll levels, which improves plant health and productivity.

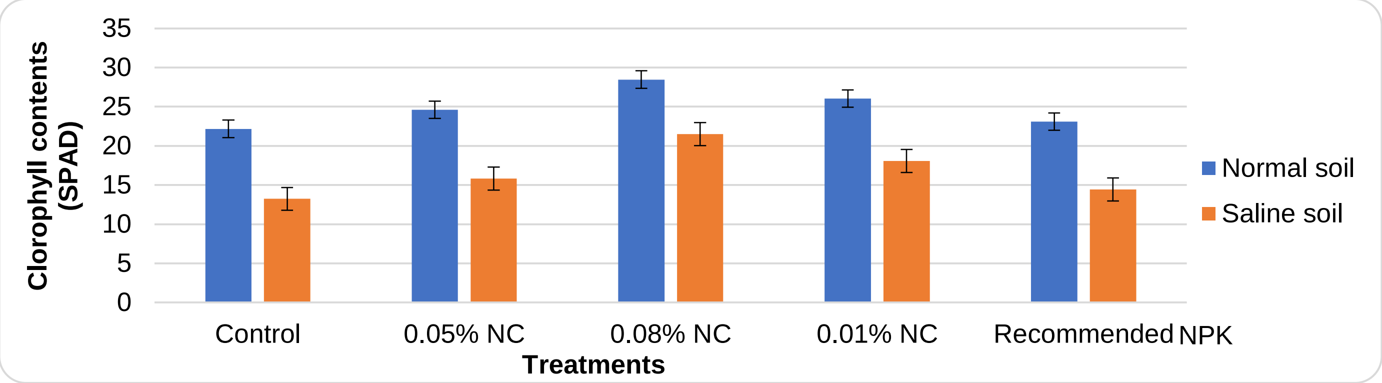

Figure 9. Effect of neem coated urea treatments on chlorophyll contents (SPAD) of maize.

Soil and Plant Analysis

Nitrate in soil

The concentration of nitrate in soil under different treatments is shown in Figure 10. In comparison to the control (T_1), treatment T_3 (0.08 % neem-coated urea) exhibited a moderate rise in nitrate levels, with a 17.29 % rise in normal soil and a similar trend in saline soil. This implies that the nitrification process is slowed down by neem-coated urea, resulting in more stable nitrate levels. The way that T_3 releases nitrates under control demonstrates how well it works to minimize nitrogen loss and increase the amount of nitrogen that is available for plant uptake.

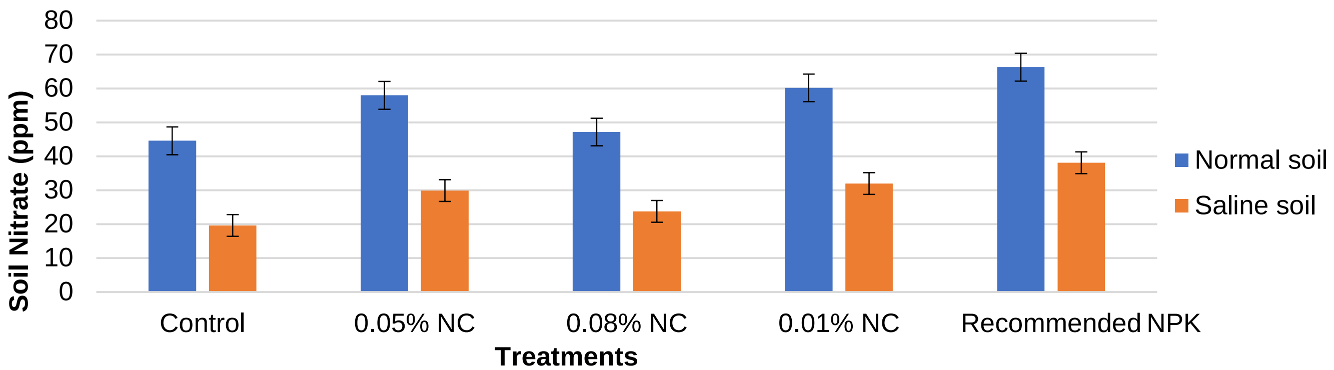

Figure 10. Effect of neem coated urea treatments on soil nitrate (ppm) of maize.

Ammonium in Soil

The ammonium concentration in soil under various treatments is shown in Figure 11. In comparison to the control (T_1), treatment T_3 (0.08 % neem-coated urea) significantly raised ammonium levels, rising 17.29 % in normal soil and 48.47 % in saline soil. These findings imply that urea coated with neem slows the conversion of ammonium, extending the availability of nitrogen. The increased ammonium content in T_3 indicates how effective it is at enhancing nitrogen retention, especially in salinized soils, which eventually promotes improved plant nutrient uptake.

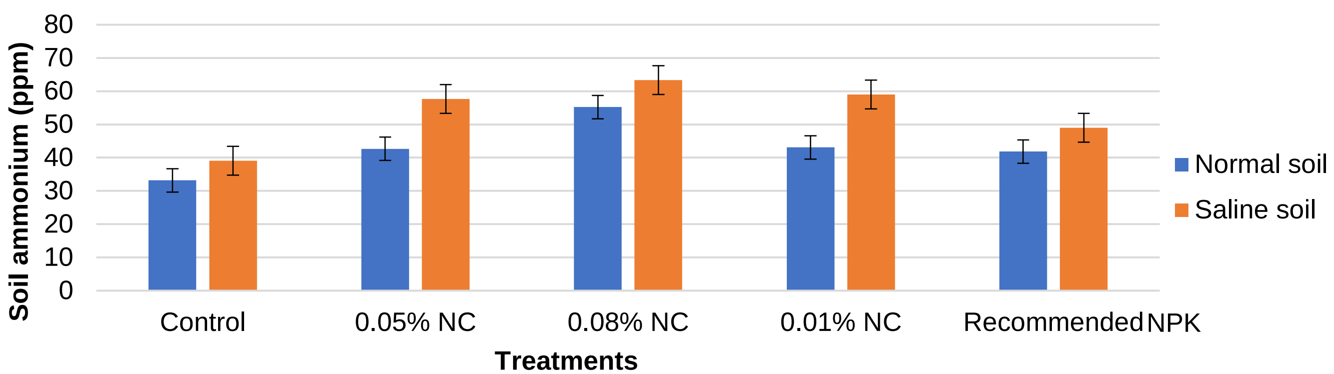

Figure 11. Effect of neem coated urea treatments on soil ammonium (ppm) of maize.

Nitrogen concentration in stalk

The nitrogen content of maize stalks under various treatments is shown in Figure 12. With a 43.6 % increase over the control (T_1), treatment, T_3 (0.08 % neem-coated urea) displayed the highest nitrogen concentration. This significant increase suggests that urea coated with neem enhances nitrogen uptake and retention in plants, especially in the stalk, which is essential for growth and structural development. T_3-treated plants have higher nitrogen levels, which show better nutrient efficiency and increase overall plant vigor and productivity.

Phosphorus Concentration in Stalk

The concentration of phosphorus in maize stalks under different treatments is shown in Figure 13. The highest increase was seen in treatment T_3, (0.08 % neem-coated urea), where the phosphorus concentration increased by 23% over the control (T_1). This notable improvement demonstrates how neem-coated urea can improve the stalks' absorption of phosphorus, which is essential for growth processes and energy transfer. According to the findings, T3-treated plants have improved nutrient uptake, which promotes healthier, more vigorous growth.

Potassium Concentration in Stalk

The potassium content in maize stalks under various treatments is displayed in Figure 14. The highest potassium levels were seen in treatment T_3 (0.08 % neem-coated urea), which increased by 35 % over the control (T_1). This notable increase suggests that potassium uptake in the stalks is enhanced by neem-coated urea, which is crucial for preserving cellular processes and water balance. The higher potassium concentration in T_3-treated

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plants demonstrates how well this treatment increases nutrient absorption, especially in difficult soil situations, improving overall plant health.

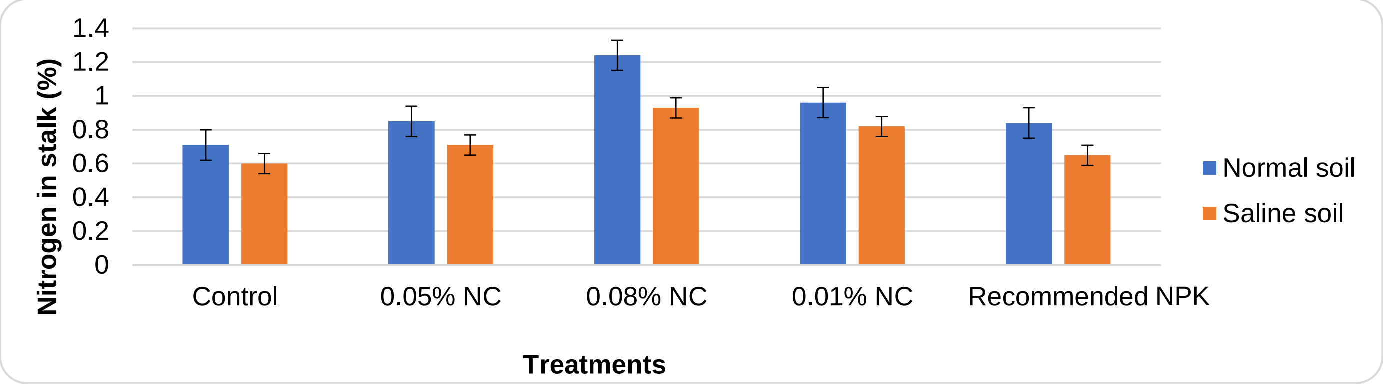

Figure 12. Effect of neem coated urea treatments on nitrogen in stalk of maize.

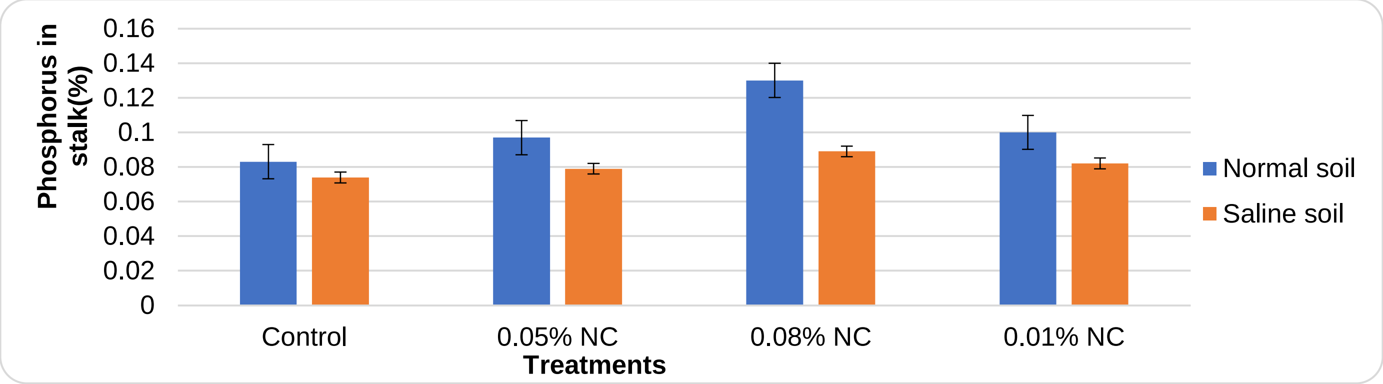

Figure 13. Effect of neem coated urea treatments on phosphorus concentration in stalk of maize.

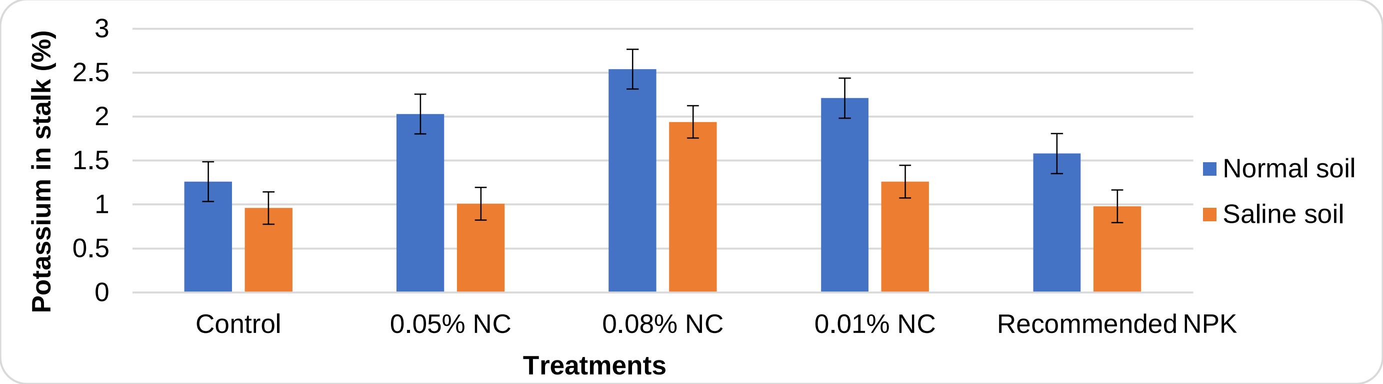

Figure 14. Effect of neem coated urea treatments on potassium concentration in stalk of maize.

DISCUSSION

The findings of this study show that in both normal and saline soils, the application of neem-coated urea (NCU), especially at the 0.08 % concentration (T3), greatly improves maize growth and nutrient uptake. According to earlier studies, slow-release nitrogen fertilizers are effective at increasing crop yield, nutrient utilization efficiency, and soil health (Abbasi et al., 2011; Azeem et al., 2014). According to Raun and Johnson (1999), NCU gives plants a more steady supply of nitrogen by lowering nitrogen losses from volatilization and leaching. This improves root development, vegetative growth, and crop yield overall.

Improved shoot and root growth in saline and non-saline soils

When comparing treatment T_3 (0.08 % NCU) to the control (T_1), the study's most noteworthy improvement was the notable increase in shoot length. In saline soils, where shoot length rose by 28%, this increase was especially noticeable. Similar results from studies on nitrogen-use efficiency under stress conditions support the idea that neem-coated urea may help reduce salt stress by enhancing nutrient availability and water retention (Akhtar et al., 2012; Azeem et al., 2014). In areas where salinity is a major obstacle to agricultural productivity, NCU's capacity to increase shoot length and fresh weight in both normal and saline soils is essential for maintaining maize production.

Along with shoot growth, T_3 also markedly increased root length, especially in saline conditions, where an increase of 46–79 % was noted. In saline soils, where ion toxicity and osmotic stress frequently limit nutrient availability, this increase in root biomass is essential for nutrient and water uptake. NCU can encourage more robust root systems, which are necessary for plant resilience in stressful situations, as evidenced by the increase in root length and fresh and dry root weights (Akiyama et al., 2010; Munns, 2005).

Enhanced membrane stability and water retention

The maize plants treated with NCU, particularly in T_3, had notably higher relative water content (RWC) and membrane stability index (MSI) than the control. T3-treated plants showed a 47.38 % increase in MSI in saline soils, indicating improved cell integrity under stress. This result validates the theory that NCU, which is prevalent in saline soils, lessens the effects of osmotic stress to preserve cellular homeostasis (Meena et al., 2019; Sairam et al., 2000). According to Banik et al. (2023) and Ahmad et al. (2022), the increased RWC in NCU-treated plants indicates that they were able to hold onto more water, which improved their resistance to drought and general stress.

In saline soils, where high salt concentrations limit water availability, improved water retention is essential. These physiological gains demonstrate how NCU protects plants and increases their resilience in both normal and saline soils. Plants treated with NCU were better able to withstand environmental stresses, especially salinity, which frequently results in a water deficit and poor nutrient uptake, by stabilizing cell membranes and holding onto water (Munns, 2005).

Increased chlorophyll content and photosynthetic efficiency

In this study, T_3-treated plants showed a notable increase in chlorophyll content, with levels of chlorophyll rising by 38–44 % in saline soils. According to this, NCU enhances chlorophyll synthesis, which is necessary for light absorption and energy production during photosynthesis, thereby promoting increased photosynthetic activity (Sandilya et al., 2023; Yang et al., 2023). Since nitrogen is an essential component of chlorophyll molecules, the higher chlorophyll content is probably the result of improved nitrogen availability. The capacity of NCU to increase chlorophyll content is especially crucial in saline environments because salt stress frequently results in nutrient imbalances that lower photosynthetic efficiency (Ahmad et al., 2022).

These results are consistent with earlier studies that demonstrated slow-release nitrogen fertilizers can support plants' increased chlorophyll levels, which improves light absorption and energy conversion (Han et al., 2008). Neem traeted plants plants maintained higher growth and productivity even in saline soils, where photosynthetic activity and nutrient availability are generally decreased, by increasing photosynthetic efficiency (Akhtar et al., 2012).

Improved nitrogen retention and nutrient uptake

Higher levels of ammonium (NH_4^+) and nitrate (NO_3^-) in T_3-treated soils relative to the control show that neem-coated urea greatly enhanced nitrogen retention in the soil. T3 caused a 48.47 % increase in ammonium levels and a 17.29 % increase in nitrate levels in saline soils. This implies that NCU reduces nitrogen losses through volatilization and leaching by slowing the conversion of ammonium to nitrate (Abbasi and Adams, 2000). Particularly in saline soils where nitrogen losses are usually high due to denitrification and leaching, NCU offers a more stable and reliable source of nitrogen for plant uptake by keeping more nitrogen in the soil (Akiyama et al., 2010).

The study's enhanced nitrogen retention is in line with previous research showing that neem-coated fertilizers slow down the nitrification and volatilization processes, thereby reducing nitrogen losses (Abbasi et al., 2003; Sandilya et al., 2023). NCU-treated soils promote improved nutrient uptake by offering a more reliable source of nitrogen, which is essential for maintaining plant growth under stressful soil conditions (Balkcom et al., 2003).

Increased potassium and phosphorus uptake

Neem Coated Urea (NCU) improved not only nitrogen retention but also potassium (K) and phosphorus (P) uptake in maize plants. Comparing T3-treated plants to the control, there was a 35% increase in potassium concentration and a 23% increase in phosphorus concentration. According to this, NCU increases the essential nutrients' solubility and availability in the soil, especially in saline conditions where ion imbalances frequently limit nutrient uptake (Aziz et al., 2011). For the support of numerous physiological processes, including energy transfer, osmoregulation, and enzyme activation, which are necessary for plant growth and stress tolerance, NCU's capacity to increase potassium and phosphorus absorption is crucial (Ramappa et al., 2022).

The enhanced nutrient uptake found in this study is in line with earlier studies that demonstrate how neem-coated fertilizers increase the soil's availability of macro- and micronutrients (Ghafoor et al., 2021). Neem Coated-treated plants were more resilient to environmental stresses because they were able to better absorb potassium and phosphorus, especially in saline soils where nutrient deficiencies are common (Han et al., 2008).

Systemic impact on nutrient translocation

The increased concentrations of nitrogen, phosphorus, and potassium found in the maize stalks of T_3-treated plants demonstrated the systemic effect of neem-coated urea on nutrient translocation. Given that nitrogen is necessary for both structural development and general plant vigor, the increase in nitrogen concentration is especially noteworthy (Raun and Johnson, 1999; Waris et al., 2023), The increased amounts of nitrogen in T_3-treated plants imply that NCU offers a more reliable and long-lasting supply of nitrogen, encouraging steady plant growth over time.

The conclusion that neem-coated urea improves nutrient mobility within the plant is further supported by the improved translocation of potassium and phosphorus in NCU-treated plants. While potassium is essential for preserving cellular homeostasis and water balance, phosphorus is necessary for root development and energy transfer (Leininger et al., 2006). The fact that T_3-treated plants had higher concentrations of these nutrients suggests that NCU facilitates more effective nutrient uptake and distribution, which is crucial for preserving plant health and productivity in stressful environments (Irshad et al., 2005).

Mechanism behind the superior performance of 0.08% neem-coated urea:

The study's findings demonstrated that, in comparison to the 0.05 and 0.01 % neem-coated urea treatments, 0.08 %t neem-coated urea (NCU) produced the increased gains in maize growth, nutrient uptake, and biomass. A number of important factors are responsible for this improved performance. In order to guarantee that the plants' nutritional requirements were satisfied throughout the growth cycle, the 0.08 % formulation most likely offered a more balanced and prolonged release of nitrogen, phosphorus, and potassium. This was especially crucial in stressful situations where nutrient availability is frequently limited, like salinity (Nasar et al., 2023; Prasad et al., 1999). Furthermore, by lowering nitrogen losses from volatilization and leaching, neem-coated urea at a concentration of 0.8 % probably increased nitrogen use efficiency (NUE) (Leininger et al., 2006). The fertilizer's controlled release characteristics guaranteed that nitrogen would be available to the plants for an extended period of time, enhancing nutrient uptake and reducing nitrogen losses to the environment. Additionally, the increased neem-coated urea concentration probably encouraged improved root and shoot growth, resulting in improved nutrient and water absorption—a crucial factor in saline soils. An essential part of the neem-coated urea, neem oil inhibits nitrification(Kiran et al., 2010; Munns, 2005), and the concentration of 0.08 % might have reduced nitrate by more efficiently slowing the conversion of ammonium (NH_4^+) to nitrate (NO_3^-).

CONCLUSION

The study shows that under both normal and saline soil conditions, neem-coated urea (NCU), especially at 0.08 % concentration, significantly improves the growth and nutrient uptake of maize. The Neem Coated Urea slows the release of nitrogen, which lowers leaching and volatilization and increases shoot and root biomass while also improving nitrogen retention. These benefits are more noticeable in saline soils because NCU improves water retention, membrane stability, and chlorophyll content to lessen the effects of salt stress.

The results indicate that applying NCU at a concentration of 0.08% in conjunction with the recommended dosages of potassium and phosphorus can significantly increase maize productivity. Farmers are urged to use NCU as a sustainable substitute for conventional urea in practical applications, especially in areas with saline soils. The Neem Coated Urea's slow-release characteristics minimize environmental impact by supplying crops with a consistent supply of nitrogen, thus minimizing the need for frequent fertilizer applications. In addition to increasing crop yields and soil health, this practice also helps with more effective fertilizer use, which makes it a useful tool for raising agricultural productivity and sustainability.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

The authors declare no competing interests.

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