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Enhancing the Efficiency of Maize (*Zea mays* L.) Nutrient Utilization through Nitrogen and Phosphorus Sources Integration

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ABSTRACT

Phosphorus (P) and Nitrogen (N) are important macronutrients for plant growth, and their deficiencies represent major constraints to agricultural productivity across the globe. Thus, this study explores the synergistic effects of nitrogen and phosphorus fertilizers on enhancing the efficiency of nutrient utilization of maize. A pot experiment was conducted using Single super phosphate (SSP) and diammonium phosphate (DAP) as phosphorus sources while, urea, sulfur-coated urea (SCU), and calcium ammonium nitrate (CAN) were utilized as nitrogen sources. The findings demonstrate that the interactive effects of N and P fertilizers significantly enhanced above-ground biomass, root biomass, and grain yield. Specifically, the Combination of SCU and CAN with DAP resulted in 41% and 30% higher above-ground biomass and grain yield, respectively, compared to urea. Root biomass was notably improved by 46% with the CAN and DAP combination. Additionally, the synergistic application of CAN and SCU with DAP led to a 25% increase in nitrogen concentration within plant tissues than urea plus DAP. Phosphorus accumulation in soil was significantly higher (15%) under DAP treatments compared to SSP. Our findings showed that the combination of DAP with SCU or CAN is an effective strategy for enhancing the nutrient utilization and yield of maize.

Keywords: Fertilizer sources, Nitrogen, Phosphorus, Agronomic parameters, Nutrient utilization

INTRODUCTION

Among the cereals in Pakistan, maize is the third most important crop after wheat and rice. It is used as a food, feed, and fodder source, whereby millions of farmers and their families depend on the maize crop (Khan *et al.*, 2011). Better management practices and seed development programs together have significantly improved maize grain yield during the last century. Maize production has been on the rise in Pakistan, especially in recent years due to the use of better germplasm, proper management practices, and rising consumption in poultry and animal feed industries. Pakistan also has a considerable maize (corn) production that serves as a vital input for agriculture and forms an imperative ingredient of the country's economy. According to the Finance Division, Govt. of Pakistan, the expansion in maize cultivation from 1,653 thousand hectares to 1,720 thousand hectares during

2022-23 reflects a positive trend in agricultural production, driven by various factors influencing farmers' decisions to grow maize. Maize contributed 2.9% to agriculture value-added products and 0.7% to GDP. It produced about 9.8 million tons in 2023-2024 after being planted on approximately 1.6 million hectares (Govt. of Pakistan, 2024). Maize is very responsive to NPK applications, exhibiting greater whole-plant biomass and grain yield with higher nutrient content. Macronutrients application significantly increased growth and productivity of maize (Ray *et al.*, 2018).

Phosphorus has a critical role in cell division, and root development, as well as in flower, fruit, and seed settings. It enhances resistance in plants to cope the abiotic stresses and controls physiological functions (Khan *et al.*, 2023; Razaq *et al.*, 2017). Phosphorous concentration whichever alone or in combination with

nitrogen, plays a vital role in plant photosynthesis rate and dry matter accretion in maize (Banerjee *et al.*, 2015). A sufficient concentration of phosphorus is significant for sustaining a higher rate of photosynthesis (Marschner, 2012). Nitrogen is an integral part of chlorophyll, amino acids, and nucleic acids. It has a key role in many important physiological processes, such as cell division, protein synthesis, and photosynthesis. (Fathi, 2022; Zayed *et al.*, 2023). An increase in N supply may decrease the remobilization of vegetative N (at pre-silking stage) to the grain, and therefore does not necessarily increase grain N concentration (Fowler, 2003; Peng *et al.*, 2017).

Plant nutrient deficiency, especially N and P, causes to reduction growth and yield of maize. Insufficiency of both nutrients decreases root, shoot, and leaf elongation, and growth at the seedling stage (Assuero *et al.*, 2004; Imran *et al.*, 2013; Wang *et al.*, 2022). Optimal N and P fertilization boost maize productivity by improving root growth and nutrient absorption (Fosu-Mensah and

Mensah, 2016; Razaq *et al.*, 2017). Especially in soils with restricted nutrients, the synergy between N and P fertilization is essential for optimizing maize yield potential. Given the conditions, the main objective of our study is to explore the impact of nitrogen and phosphorus sources integration on the efficiency of nutrient use and maize yield.

MATERIALS AND METHODS

A pot experiment was carried out at the University of the Punjab's Faculty of Agricultural Sciences farm in Lahore. To get a consistent particle size distribution, the topsoil (0-15 cm) was collected from the field area and sieved through a 2 mm pore size. Before filling the pots, a composite soil sample was collected and analyzed for soil physical and chemical characteristics (Table 1). The sieved soil (10 kg per pot) was filled in polythene-lined earthen pots, each having a diameter of 20 cm and a length of 36 cm.

Table 1: Physio-chemical characteristics of soil used in pots.

Parameters	Value
Sand	23.7%
Silt	58.3%
Clay	18.1%
Textural Class	Sandy Loam
Organic Matter	1.02%
pH	7.8
Electrical Conductivity (ECe)	0.75 dSm ⁻¹
Available Phosphorus	16.33 mg kg ⁻¹ soil

The experiment was conducted according to a completely randomized design (CRD) with factorial arrangements and each treatment having three replications. The types of phosphorus fertilizers like diammonium phosphate (DAP) and single super phosphate (SSP) were considered as factor 1, whereas the types of nitrogenous fertilizers such as urea, calcium ammonium nitrate (CAN), and sulfur-coated urea (SCU) were considered factor 2. Five seeds of maize variety DK 6321 were sown per pot. At two leaf stage, two uniform

seedlings per pot were maintained by uprooting the extra plants. Potassium (K) was used at recommended rates of 91 kg ha⁻¹. All of the P and K were given at sowing whereas N application was split into three parts i.e. at sowing, 5-6 V, 8-10 V, and flowering stages.

Agronomic parameters such as plant height, no. of leaves, root biomass, root length, above-ground biomass, and grain yield were measured at the final harvest. The nitrogen concentrations in plant tissue were determined by digesting the plant samples using H₂SO₄-H₂O₂,

followed by the distillation through the Kjeldahl apparatus. Phosphorus concentration was estimated by dissolving the plant samples in HCl, followed by mixing of color reagent and then the estimation of color intensity at 430 nm through a spectrophotometer (Baker and Thompson, 1992). A saturated soil paste was prepared and left overnight. The pH of the paste was assessed using a standardized pH meter. After the determination of soil pH the paste was extracted with a vacuum extraction assembly and the EC of the extract was measured by a standardized EC meter. Soil organic

Results

Agronomic parameters

The interactive effect of nitrogenous and phosphorus fertilizers on above-ground biomass was significant (figure 1). Sulfur-coated urea (SCU) and calcium ammonium nitrate (CAN) emerged as more favorable nitrogen sources that in combination with both diammonium phosphate (DAP) and single superphosphate (SSP) showed 41% and 30% higher above-ground biomass yields respectively, as compared to urea. The interaction between phosphorus and nitrogen sources in influencing root biomass was also significant (figure 2). Application of CAN with DAP resulted in 46% higher root biomass than urea and SCU which had the lowest values. Under SSP treatment, nitrogenous fertilizers were not significantly different; however, on average, urea showed 10% higher root biomass than that of SCU and CAN. Additionally, the combination of urea with DAP led to a 30% increase in root biomass compared to SSP.

Different sources of nitrogen significantly increased the grain yield of maize (figure 3). Treatments where SCU and CAN were applied with a combination of DAP exhibited 24% higher grain yield in comparison to treatments where urea plus DAP was applied. It was further noted that CAN and SCU increased grain yield up to 18% more than that of urea.

matter was quantified using the Walkley and Black method by adding 1 g of soil to potassium dichromate, sulfuric acid, and distilled water, followed by titration with ferrous sulfate to a green endpoint (Bahodori and Tofighi, 2017).

Statistical analyses

The data were analyzed using analysis of variance (ANOVA) and means were performed by using Tukey's HSD test at $p < 0.05$ through Statistix-8.1 software to evaluate the difference among collected attributes means (Steel and Torrie, 1997).

N and P contents in plant and soil

The interaction between N and P sources in affecting plant nitrogen concentration was significant (figure 4). CAN and SCU applied with DAP demonstrated 25% higher nitrogen contents in plant tissues, than urea. Conversely, when applied with SSP, the nitrogen sources did not significantly differ in their effect on nitrogen concentration in maize plants. The effect of nitrogen sources on phosphorus accumulation in plants was significant (figure 5). On average, the application of SCU resulted in 21% higher phosphorus concentration compared to urea and CAN. However, the phosphorus sources alone and the interaction between phosphorus and nitrogen sources did not significantly influence plant phosphorus content.

Results indicated a significant difference in soil phosphorus levels between DAP and SSP treatments, with DAP resulting in 15% higher phosphorus accumulation in soil (figure 7). Maximum phosphorus accumulation in soil was noted with urea application which was statistically similar to SCU. Both fertilizers yielded a 37% increase in soil phosphorus compared to CAN (figure 6). No significant effects of N and P sources, whether applied alone or in combination, were observed on plant height, number of leaves, root length, electrical conductivity (EC), pH, and organic matter of soil.

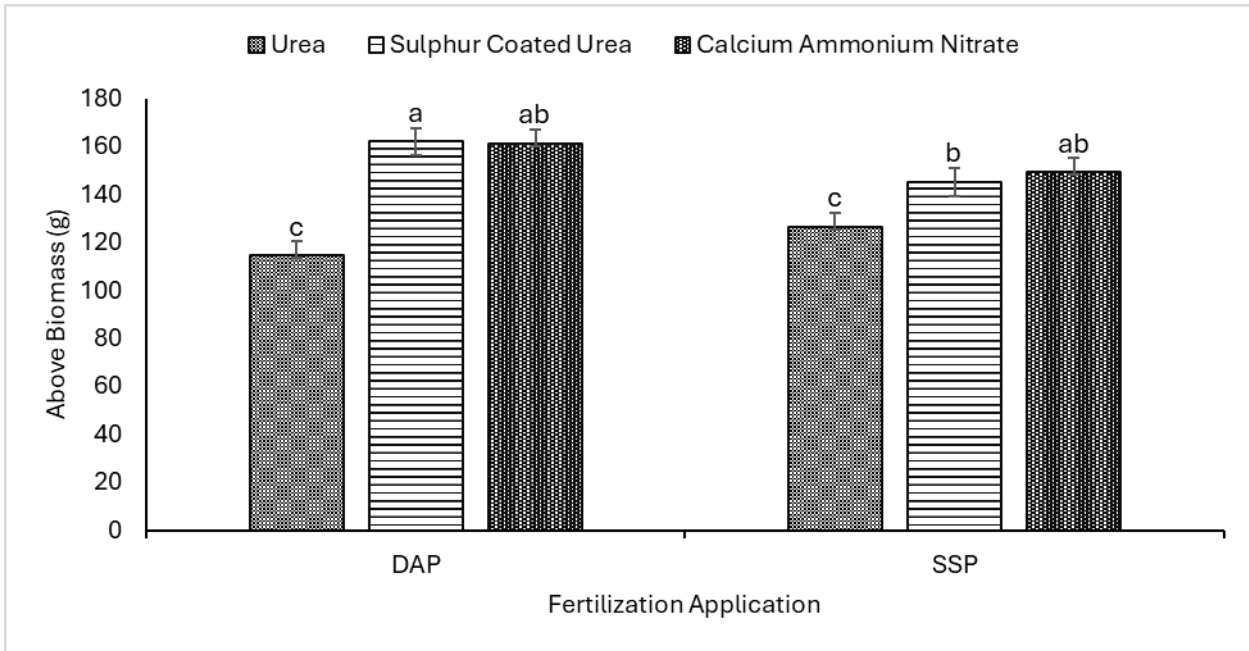


Figure.1. Impact of nitrogen and phosphorus fertilizers combinations on above-ground biomass (g) of maize plant

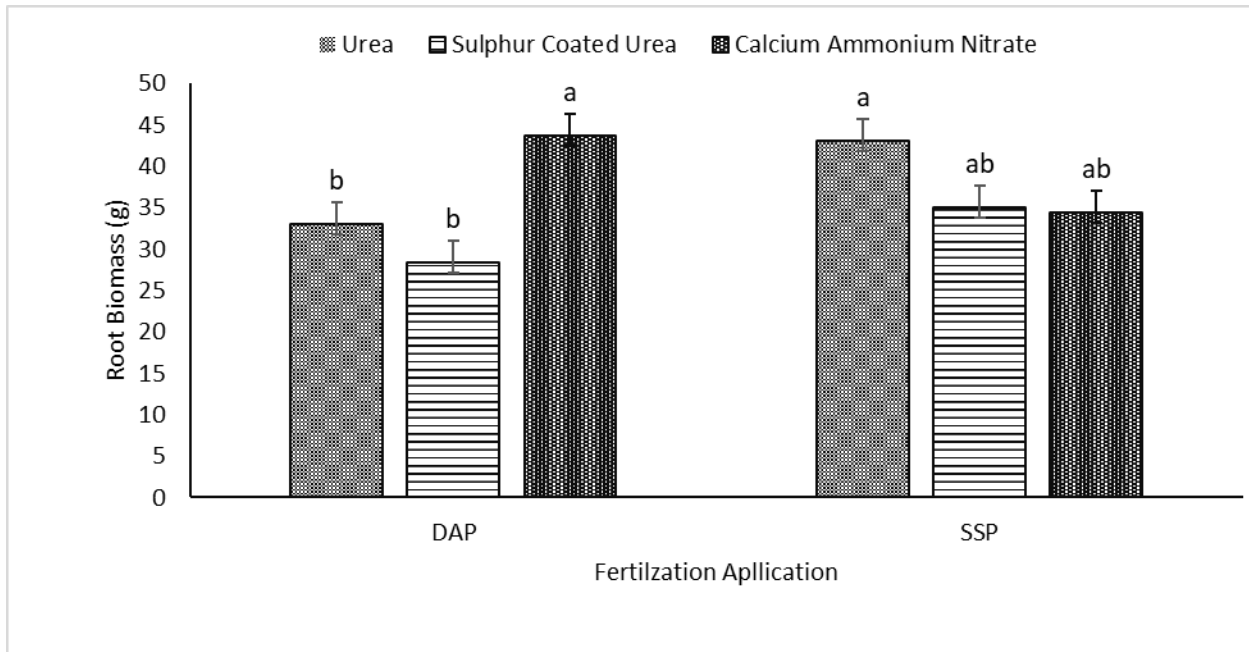


Figure.2. Impact of nitrogen and phosphorus fertilizers combinations on root biomass (g) of maize plant

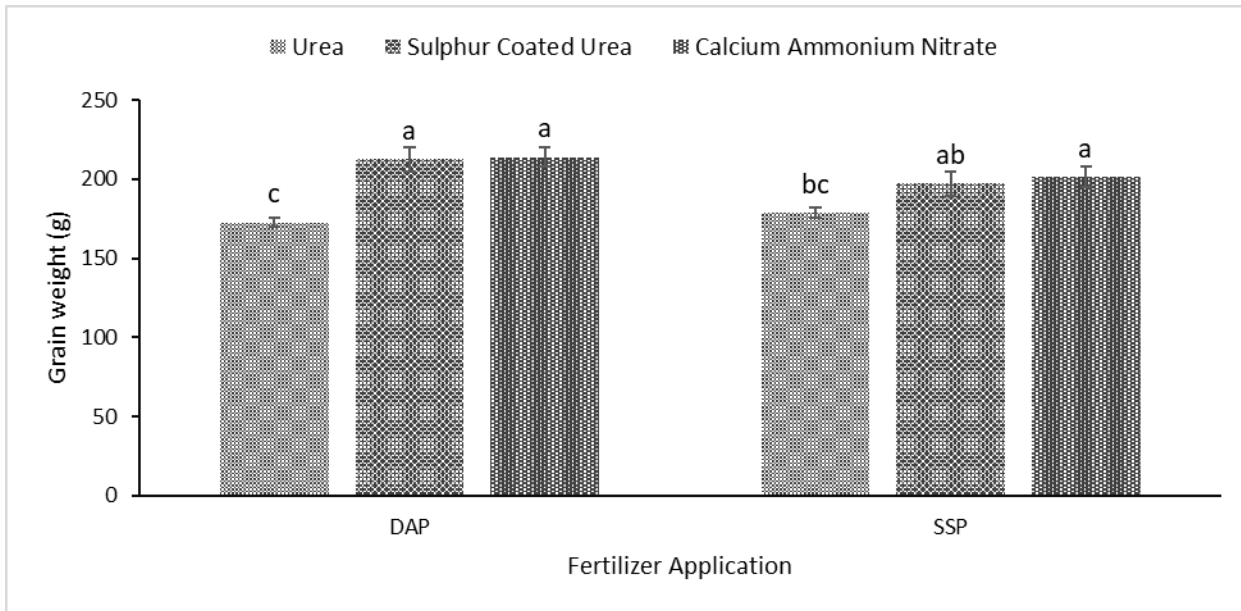


Figure.3. Impact of nitrogen and phosphorus fertilizers combinations on grain weight (g)

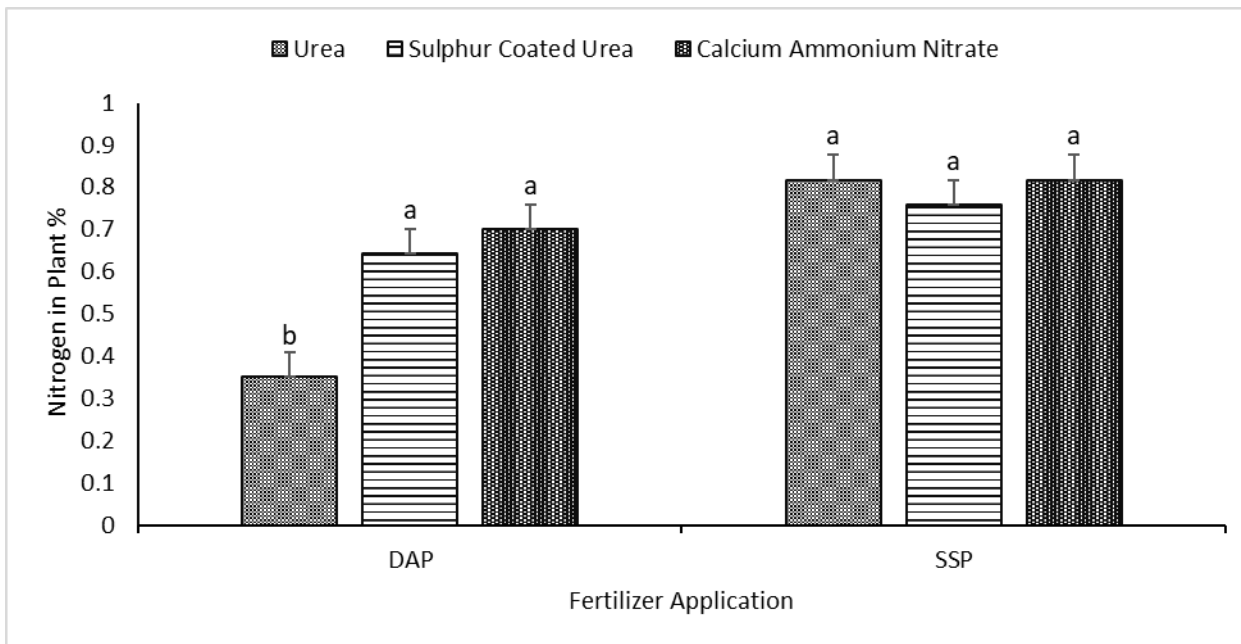


Figure.4. Impact of nitrogen and phosphorus fertilizers combinations on plant nitrogen (%) concentration of maize

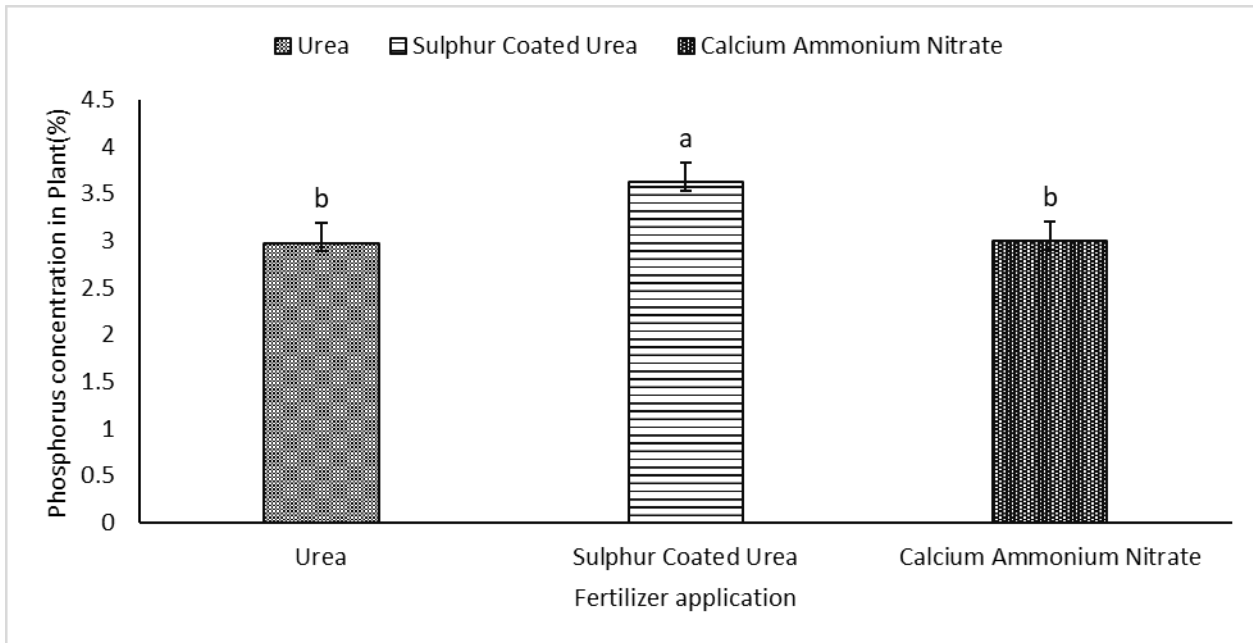


Figure.5. Impact of nitrogen and phosphorus fertilizers combination on plant phosphorus content

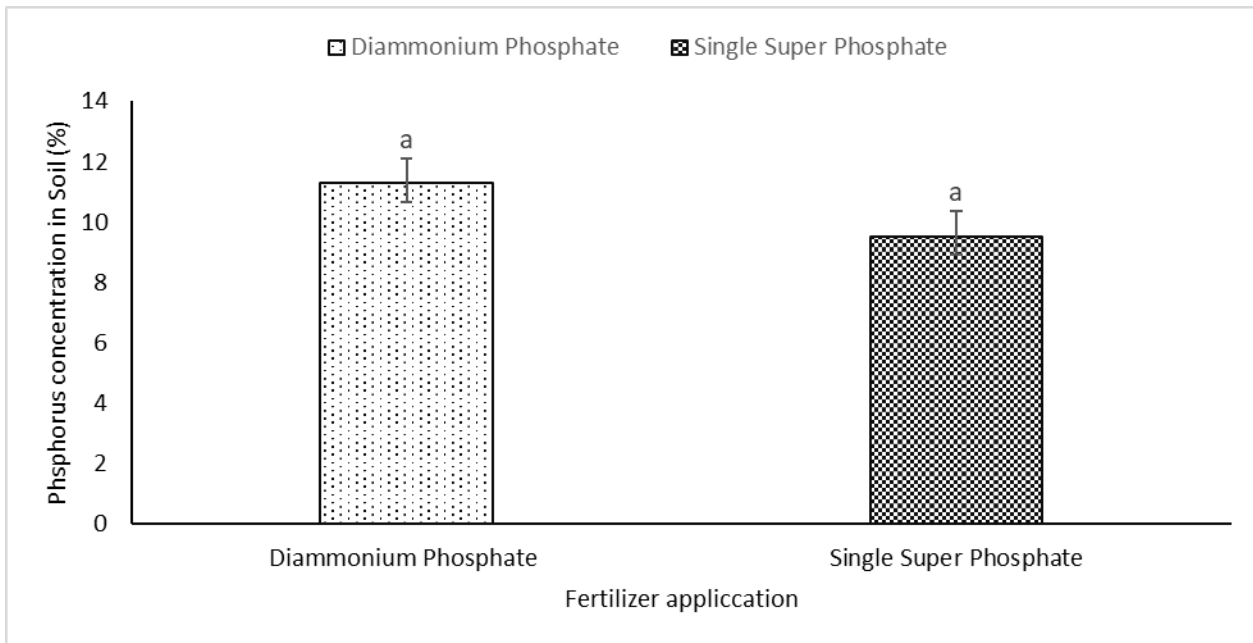


Figure.6. Impact of nitrogenous fertilizers on soil phosphorus contents

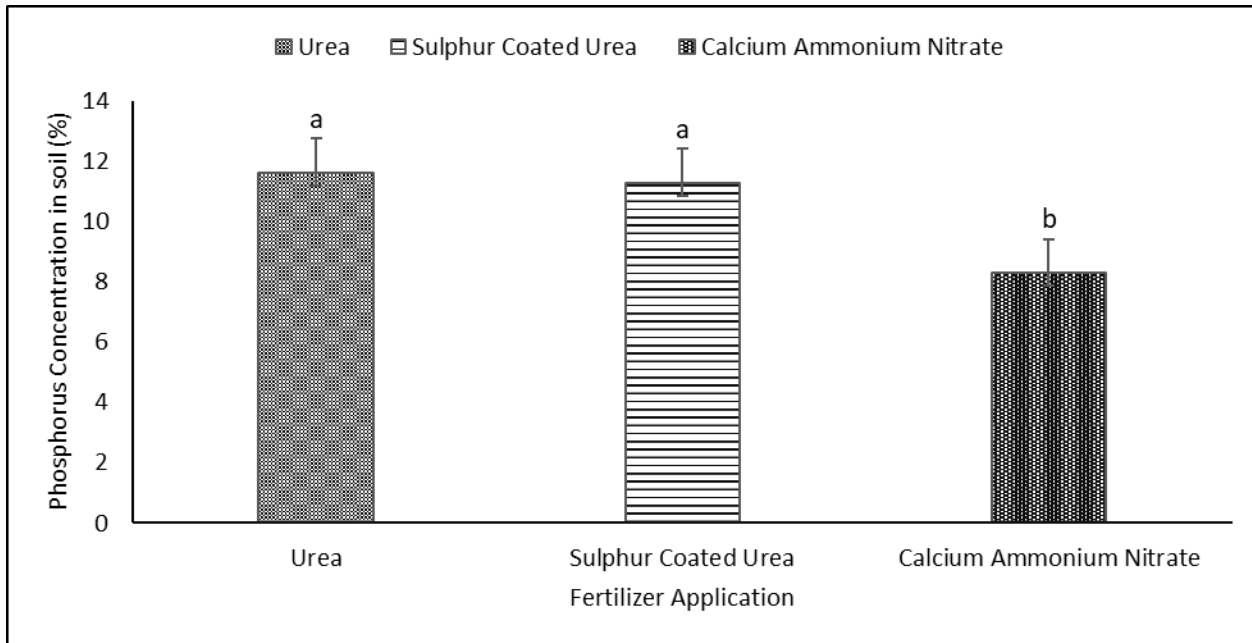


Figure.70. Impact of phosphorus fertilizers on soil phosphorus contents

Discussion

The present study examined the interactive effects of phosphorus and nitrogen sources on various parameters of maize, including, plant height, number of leaves, aboveground biomass, grain weight, root biomass, plant nitrogen concentration, and plant phosphorus contents. The findings highlight the complex relationship between these nutrients and how they affect the many components of maize cultivation.

CAN and SCU in combination with DAP significantly increased grain yield and above-ground biomass as compared to urea. An increase in yield could be due to the consistent supply of nitrogen by SCU during the grain-filling stage (Dawar *et al.*, 2024; Grant *et al.*, 2012). Similar trends were observed in this study, as sulfur-coated urea emerged as a more favorable nitrogen source, leading to significantly higher biomass yields when applied in conjunction with DAP (figure 1). Wang *et al.* (2023) reported that CAN supplies both nitrogen and calcium as well as improves the vigor of plant tissues which may contribute to increased grain yield. Our findings align with previous research that macronutrient SCU and CAN significantly increased grain yield (figure 3). Sha *et al.* (2020) demonstrated that SCU and CAN also improve nitrogen use efficiency

due to slow-release patterns and cellular processes, respectively, which are important for biomass formation. Rapid volatilization could cause lower biological and grain yield in the case of urea. Sources of phosphorus such as DAP and SSP showed similar results in affecting biomass which are in alignment with this study's findings (Figure 5).

A combined application of CAN and DAP demonstrated higher root biomass than both urea and SCU with DAP. It could be attributed to the provision of nitrogen as well as calcium, both of the plant nutrients are vital for root development. Urea plus SSP showed maximum root biomass in comparison to SSP combinations both with SCU and CAN. It might be because urea is an immediate source of nitrogen, providing the nutrient at a rapid rate which leads to better nutrient uptake and root development (Chen *et al.*, 2020) as shown in Figure 2.

Application of SSP resulted in significantly higher nitrogen contents in plants than DAP which is attributed to improvement in soil nutrient balance and uptake by plants (Fageria *et al.*, 2016; Zayed *et al.*, 2023). Sources of nitrogen CAN and SCU showed similar results in affecting nitrogen utilization which are in line with previous findings (Figure 4). Both CAN and SCU paired with DAP significantly improved N contents in maize

plants, which may be due to the consistent availability of these nutrients. It was also noted that all nitrogenous fertilizers in combination with SSP did not show any variation in enhancing plant nitrogen contents, suggesting that SSP may have a role in stabilizing nitrogen uptake (Geng *et al.*, 2024; Wang *et al.*, 2023). Nitrogenous fertilizers had a significant impact on plant phosphorus contents, with the treatments where SCU was applied showing maximum phosphorus concentration in plants than that of urea and CAN. SCU creates an acidic environment in the plant rhizosphere, which may have enhanced the availability and uptake of phosphorus by maize plants (Yang *et al.*, 2024; Zhang *et al.*, 2020). Among the phosphate fertilizers, DAP significantly increased soil phosphorus accumulation compared to SSP. A higher soil phosphorus pool could be because DAP is a quick source of phosphorus which releases phosphorus at a higher rate and concentrated form in the soil. Secondly, slow release nature of SSP may have caused more absorption of phosphorus by

plants and consequently reduction in soil (Zafar *et al.*, 2013). Gao *et al.* (2015) demonstrated SCU greatly increased phosphorus concentration in soil. Mustafa *et al.* (2022) reported that coating of fertilizer causes slow release and extended availability of nitrogen which may delay the phosphorus uptake by plants, thereby increasing soil level. These previous findings align closely with the current study's results (Figures 6, and 7).

The individual and interactive effect of different nitrogen (N) and phosphorus (P) sources was non-significant for plant growth parameters like plant height, number of leaves, root length, or soil properties such as EC, pH, and organic matter. These results are in line with previous studies conducted by different researchers (Barlóg *et al.*, 2022; Lizcano-Toledo *et al.*, 2021). Soil parameters such as pH and organic matter are not much affected over a short period by the application of different nitrogenous or phosphate fertilizers (Leroy *et al.*, 2008; Wei *et al.*, 2016; Yang *et al.*, 2024).

CONCLUSION:

The findings of this study demonstrate that application of sulfur-coated urea (SCU) and calcium ammonium nitrate (CAN) coupled with diammonium phosphate (DAP) significantly enhanced maize biomass, growth, and grain yield. Therefore, combined application of SCU and CAN with DAP can be an optimal way to increase maize yield and nutrient efficiency.

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