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Sustainable Availability Of Nitrogen And Phosphorus Promoted By Polymer Coated Nitrogenous And Phosphatic Fertilizers For Growth And Yield Of Maize (Zea Mays L.)

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ABSTRACT
The increasing global population demands more food and shelter, placing significant pressure on the agricultural sector. To meet these needs, higher fertilizer inputs are often required; however, substantial nutrient losses through volatilization, leaching, denitrification, fixation, and runoff limit crop yields and contribute to environmental pollution. Polymer-coated nitrogenous and phosphatic fertilizers have been shown to improve nitrogen (N) and phosphorus (P) use efficiency due to their slow and controlled nutrient release. In this field trial, the performance of polymer-coated urea and

diammonium phosphate (DAP) was evaluated for enhancing maize growth, yield, and N and P use efficiency compared with uncoated fertilizers. Treatments were applied at rates of 180, 135, and 135 kg ha^{-1} following a randomized complete block design (RCBD) with three replications. Standard protocols were used to assess various growth and yield parameters. Results indicated that ammonia emissions were notably higher in plots receiving conventional urea, whereas polymer-coated urea significantly reduced emissions. Agronomic traits, particularly grain yield and nutrient uptake, were markedly improved in treatments with polymer-coated urea. The findings suggest that polymer-coated urea is a more efficient nutrient source for maize and can effectively enhance both crop yield and nutrient utilization.

Introduction

Maize (Zea mays L.) is one of the most important cereal crops cultivated across the globe for food, feed, and industrial purposes. In Pakistan, it covered about 1.41 million hectares in 2012, contributing 2.1% to national revenue and 0.6% to GDP (Shah et al., 2014). Its grains are rich in carbohydrates, protein, fiber, and essential nutrients, providing nearly 365 kcal of energy per 100 g (Nuss & Tanumihardjo, 2010; Begam et al., 2018). Beyond serving as a staple food for millions, maize residues and by-products are a vital source of livestock and poultry feed, supporting rural livelihoods (Khatam et al., 2013). More than 900 million people worldwide depend on maize as a major component of their diet (Shiferaw et al., 2011). With the global population steadily increasing and agricultural resources under pressure, maintaining and improving maize productivity is essential for food security and economic stability.

High maize yields depend heavily on mineral fertilizers, particularly nitrogen (N) and phosphorus (P). Nitrogen is indispensable for photosynthesis, protein synthesis, and vegetative development, and nearly half of the world's population relies directly or indirectly on nitrogenous fertilizers to sustain food supplies (Soares et al., 2012). Cereals such as rice, wheat, and maize account for over 90% of global nitrogen use Despite its centrality, N is often used inefficiently because substantial portions of applied fertilizer are lost through volatilization, leaching, denitrification, and runoff. Urea, the most common N source, is especially prone to ammonia (NH_3) volatilization, with losses of up to 40% under hot, dry conditions compared with 10–19% in temperate climates (Soares et al., 2012; Bouwman et al., 2002). These losses reduce nitrogen-use efficiency (NUE), increase production costs, and contribute to environmental pollution. Excess ammonium and nitrite near the seed can also damage emerging seedlings and hinder early maize growth (Pinheiro et al., 2016).

Phosphorus is the second most important macronutrient after nitrogen. It supports photosynthesis, energy transfer, cell division, root initiation, and reproductive growth (Reddy et al., 2002). Adequate P supply improves seedling vigor, crop quality, resistance to diseases, and grain formation (Wu et al., 2005). Yet P-use efficiency (PUE) remains low in many regions, particularly in the calcareous soils common in Pakistan, where P readily reacts with calcium and magnesium to form insoluble complexes such as apatite and octa-calcium phosphate (Tisdale et al., 1985; Barrow, 2012). Similar immobilization occurs in acidic soils due to interactions with iron and aluminum (Gyaneshwar et al., 2002). As a result, only a small portion of applied P remains available to plants, while the rest becomes fixed in stable pools. Given the high cost of phosphatic fertilizers and limited financial resources of farmers, improving P efficiency is critical for sustaining maize production in developing countries (Zaib et al., 2023).

Efficient management of N and P fertilizers is therefore central to enhancing maize yields while reducing environmental risks. Practices such as split application, deep placement, or irrigation after broadcasting urea can lower NH_3 losses (Zaman et al., 2008). Urease inhibitors like N-(n-butyl) thiophosphoric triamide (NBPT) can slow urea hydrolysis, but their ability to maintain nutrient supply throughout the growing season is limited. In recent years, controlled-release fertilizers (CRFs) have emerged as a promising alternative to conventional sources. These fertilizers, often formulated by coating urea or diammonium phosphate (DAP) with synthetic, biodegradable, or recyclable polymers, release nutrients gradually through diffusion controlled by soil moisture and temperature (Knight et al., 2007; Morgan et al., 2006). By synchronizing nutrient release with plant uptake, CRFs reduce leaching and volatilization, enhance NUE and PUE, and lower nutrient fixation in soils (Zahrani, 2000; Trenkel, 2010).

The effectiveness of CRFs depends on coating thickness, composition, and permeability. A well-designed coating creates a semi-permeable barrier that regulates the movement of water into the granule and the diffusion of dissolved nutrients into the soil. This slow, steady supply of N and P matches crop requirements, reduces the number of applications needed, and minimizes nutrient losses (Shaviv & Mikkelsen, 1993). Beyond improving fertilizer efficiency, CRFs can reduce labor and energy costs, contributing to sustainable intensification of agriculture (Zebarth et al., 2009). Nevertheless, their adoption is often limited by the high cost of conventional polymer coatings (Trenkel, 2010). Current research seeks to develop more affordable and environmentally friendly materials that retain favorable release properties while minimizing production expenses (Ribeiro et al., 2020). Combining micronutrients with CRFs is another emerging strategy for addressing secondary nutrient deficiencies in intensive cropping systems.

Polymer-coated urea (PCU) and polymer-coated diammonium phosphate (PCDAP) are among the most advanced CRF formulations and hold considerable potential for improving maize productivity in regions where nutrient losses and soil fixation constrain fertilizer performance. By extending the availability of N and P in the soil, these fertilizers may enhance nutrient uptake, reduce ammonia volatilization, and improve maize growth and grain yield under diverse agro-ecological conditions. However, empirical evidence on their performance in South Asian maize-based systems remains scarce, particularly under calcareous soils where volatilization and P fixation markedly reduce fertilizer efficiency. To address this gap, the present study evaluates the comparative effectiveness of polymer-coated and uncoated N and P fertilizers in maize production. It focuses on quantifying ammonia volatilization, examining maize growth and yield responses, and assessing nutrient uptake efficiency under field conditions. By clarifying the agronomic and environmental benefits of polymer-coated fertilizers, this research aims to provide practical insights for enhancing nutrient-use efficiency, reducing losses, and supporting sustainable maize production in Pakistan and similar environments.

MATERIALS AND METHODS

A field experiment was conducted at the Research Farm of the Institute of Soil and Environmental Sciences (ISES), University of Agriculture Faisalabad (UAF), in collaboration with Engro Fertilizers Ltd., to investigate the effectiveness of polymer-coated diammonium phosphate (DAP) and urea in improving maize (Zea mays L.) growth and yield while reducing nitrogen (N) losses. The experiment was laid out in a randomized complete block design (RCBD) with three replications, comprising six

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fertilizer treatments that included a control (DAP + MOP), conventional combinations with urea, value-added commercial fertilizers (Zabardast urea and Zarkhez Plus NPK), and polymer-coated DAP and urea. Each experimental unit had a net plot size of 65 m^2.
The maize variety DK-6789 was sown at a seed rate of 10 kg $acre^{-1}$ following standard land preparation practices. Fertilizer application rates were maintained at 175 kg N ha^{-1}, 125 kg P_2O_5 ha^{-1}, and 125 kg K_2O ha^{-1}. Phosphorus and potassium were supplied as a basal dose at sowing using DAP and muriate of potash (MOP), while nitrogen from urea was applied in three equal splits corresponding to the first three irrigations at 15-day intervals. A 1% polymer solution was prepared by the Soil Fertility and Plant Nutrition Laboratory, ISES, and used to coat conventional DAP and urea granules for the polymer-based treatments. Canal water was used for irrigation, a pre-emergence herbicide was applied to suppress weeds, and insecticidal treatment was undertaken to control fall armyworm infestation.
Growth and physiological attributes were recorded at crop maturity to assess the comparative performance of the fertilizer treatments.

Table 1 Physicochemical Properties of Soil

Properties	Units	Readings
Texture	-	Loam
Saturation Percentage	%	34
Organic matter	%	0.87
pH	-	8.4
ECe	dS m^{-1}	2.24
Nitrogen	%	0.05
Available Phosphorus	mg kg^{-1}	14
Available Potassium	mg kg^{-1}	140

CHAPTER 4
RESULTS

In terms of production, maize comes in second place to wheat among grain crops worldwide. A field experiment was conducted at the University of Agriculture Faisalabad (UAF) research farm of the Institute of Soil and Environmental Sciences (ISES) to evaluate the role of polymer coated DAP and urea in improving the nitrogen and phosphorus use efficiency, yield, and growth of maize with reduced nitrogen losses in the atmosphere. This experiment was done to contrast polymer-coated DAP and urea with other value-added and commercially available N and P fertilizers. Moreover, this experiment was conducted in collaboration with Engro fertilizer Ltd. Several maize crop parameters were assessed at as the crop started growing. Based on data evaluation utilizing the statistical test of analysis of variance (ANOVA), the results of testing crop parameters are described below.

Plant height (cm)

Plant height was shown in Figure 4.1, which showed that plant height was significantly increased in all treatments with zabardast urea, with the highest increase of 26% in zarkhez plus NPK with zabardast urea treatment compared to control. While the use of DAP with urea resulted in the smallest increase (24%) in comparison to the control. In DAP-treated plots, zabardast urea enhanced plant height over urea. Coated DAP and urea outperformed all of the treatments with the highest increase in plant height, which was 37%. When comparing all of the treatments, coated DAP and urea treatment was significantly different from all other treatments. Moreover, a non-significant difference was found between all treatments.

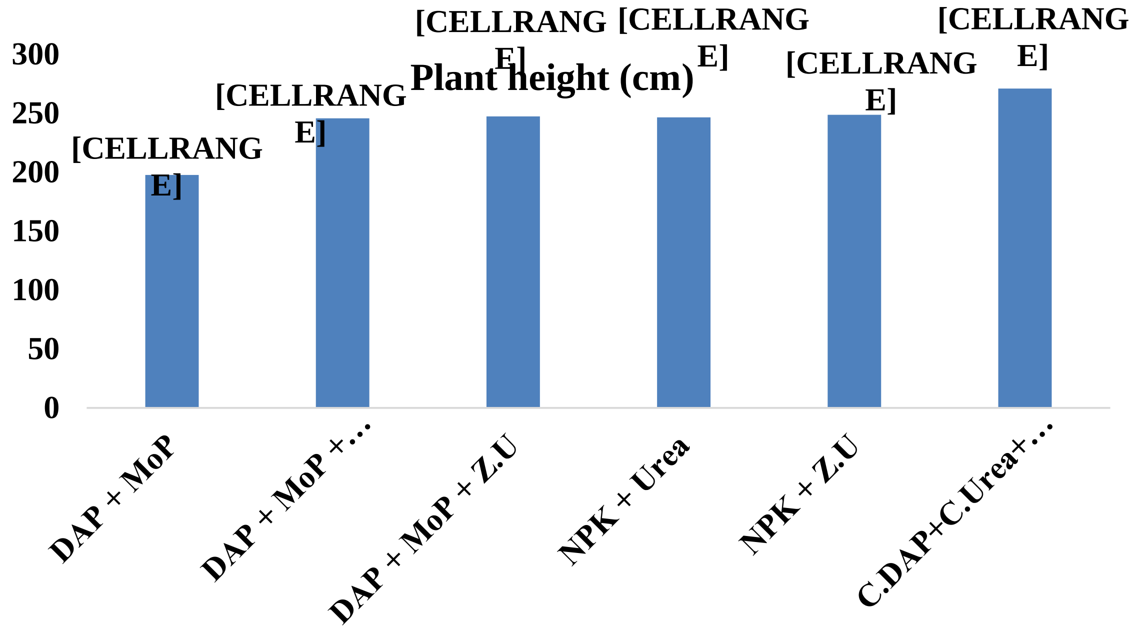

Figure 4.1 Effect of sustainable availability of nitrogen and phosphorus through polymer coated nitrogenous and phosphatic fertilizers on plant height (cm) of maize

Dry biological yield (kg ha^{-1})

Figure 4.7 shows that the data on the dry biological yield followed the same trend as the data on the stalk yield. The dry biological yield was increased by 206.5% with the coated DAP and urea treatment compared to the control, 72.94% with the DAP and urea, 71.2% with the DAP and zabardast urea, 39.95% with the zarkhez plus NPK and urea, and 30.41% with the zarkhez plus NPK and zabardast urea treatments. When conventional urea was mixed with DAP, the dry biological yield was increased by up to 77.26% compared to the control. When zabardast urea was mixed with DAP, the dry biological yield was increased by 79.06% in contrast to the control. When compared to the DAP with zabardast urea-treated plots, the zarkhez with NPK-treated plots with the zabardast urea treatment increased the dry biological yield by up to 31.27%. Similarly, the zarkhez with NPK with urea treatment produced 23.56% more than the DAP with urea. Also, it was discovered that the coated DAP and urea treatment considerably differed from all other treatments.

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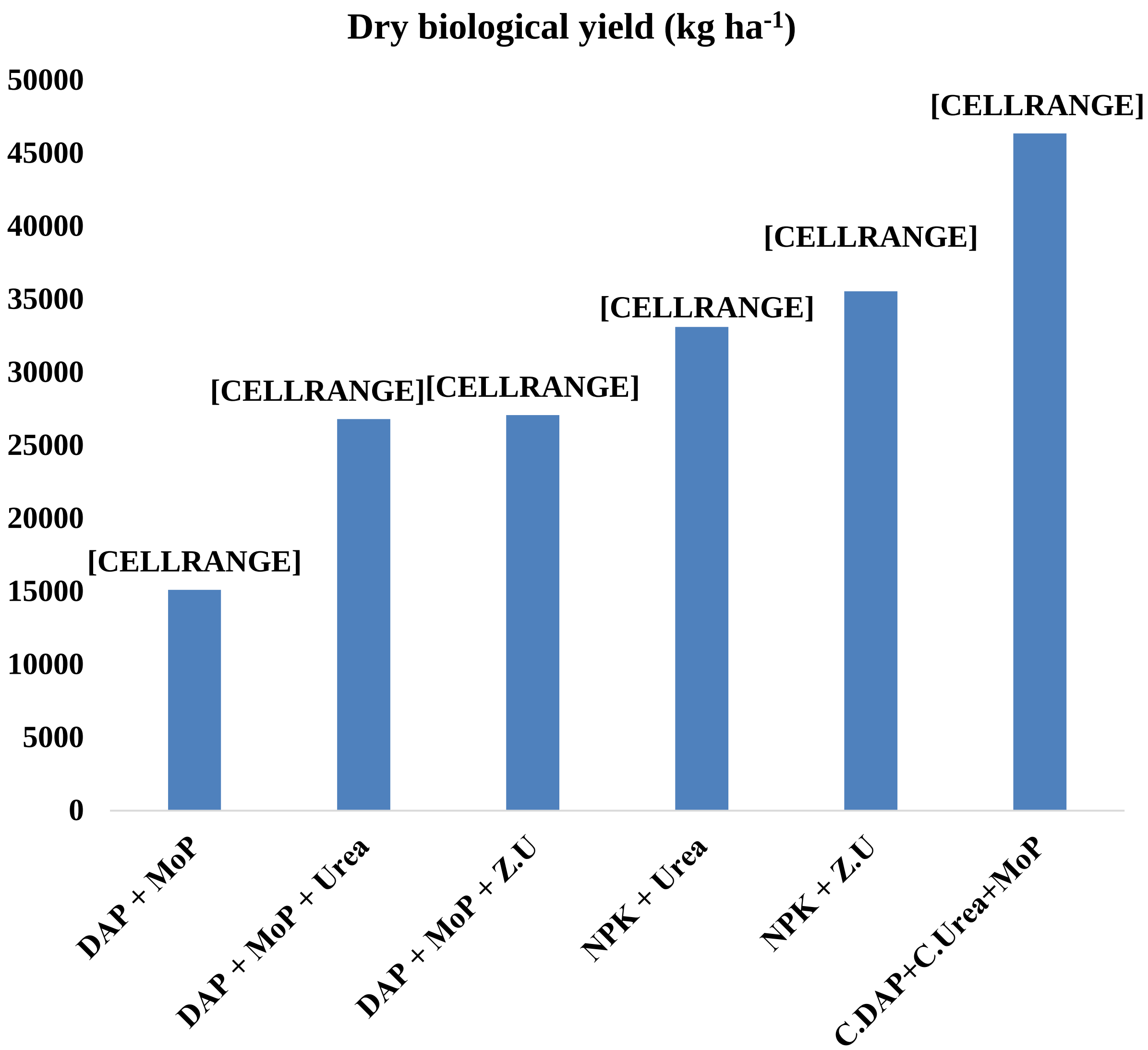

Figure 4.7 Effect of sustainable availability of nitrogen and phosphorus through polymer coated nitrogenous and phosphatic fertilizers on dry biological yield (kg ha^{-1}) of maize

1000 grain weight (g)

The data clearly showed that zabardast urea enhanced 1000-grain weight significantly when compared to the common urea treatments. The coated DAP and urea treatment outperformed all the other treatments and compared to the control and all other treatments, had a substantial impact on 1000-grain weight. Zabardast urea induced a grain weight of 26.78 g per 1000 grains in DAP-treated plots, which was significantly higher than common urea with the same phosphatic fertilizer, which was 25.48 g. A maximum increase in 1000-grain weight was given by coated DAP and urea treatment (303.10g). While zarkhez plus NPK along with zabardast urea gave 10.8% more 1000-grain weight in comparison to DAP with urea treatment (Figure 4.11).

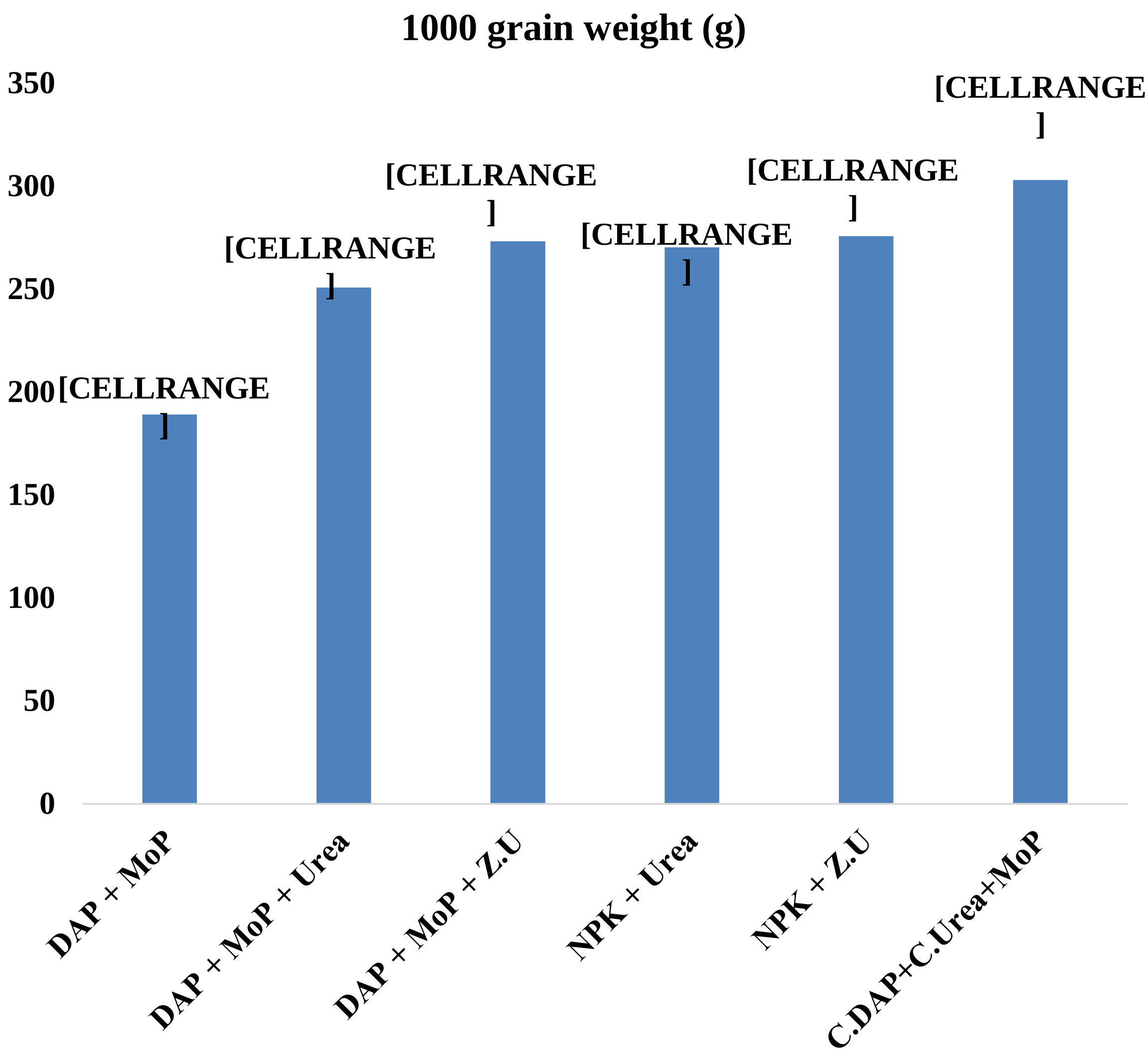

Figure 4.11 Effect of sustainable availability of nitrogen and phosphorus through polymer coated nitrogenous and phosphatic fertilizers on 1000 grain weight (g) of maize

Chlorophyll contents (SPAD)

When contrasted with the control and all other treatments, the coated DAP with urea treatment had a big effect on the amount of chlorophyll in the plants (Figure 4.14). The zabardast urea treatment led to a large increase in chlorophyll content in both the DAP and zarkhez plus NPK amended plots. The coated DAP with urea treatment showed the highest increase (6.8%) in chlorophyll content. Comparing the DAP with urea treatment to the zarkhez with NPK and zabardast urea treatment, the rise in chlorophyll content was the greatest, reaching 18.63%. Similarly, when comparing the zarkhez plus NPK along with urea treatment to the DAP and urea combination, the second-highest value of chlorophyll contents of about 9.99% was observed. Comparing all treatments with the exception of zarkhez with NPK and the zabardast urea treatment, the coated DAP and urea treatment had a substantial impact on the chlorophyll concentration.

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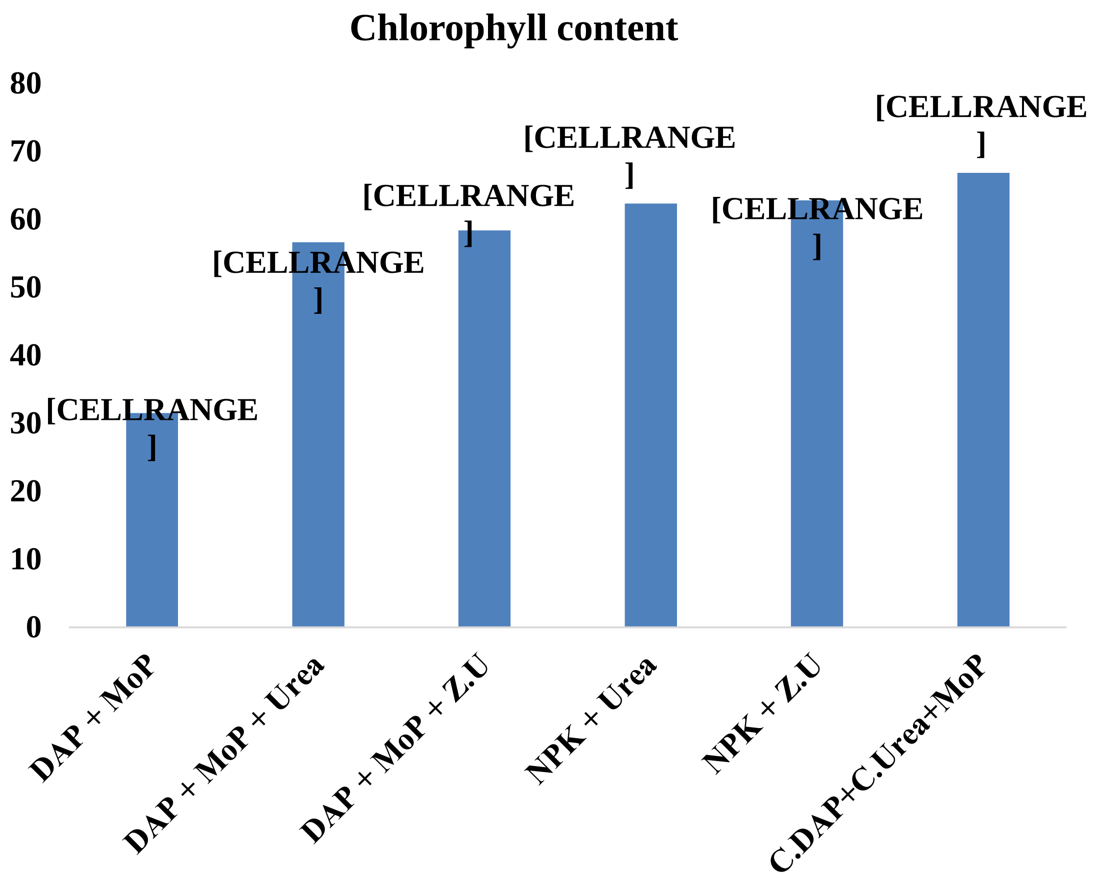

Figure 4.14 Effect of sustainable availability of nitrogen and phosphorus through polymer coated nitrogenous and phosphatic fertilizers on Chlorophyll contents (SPAD) of maize

Nitrogen concentration in maize grains (%)

The effect of value-added fertilizer combinations on the nitrogen content of maize grains is shown in Figure 4.17. According to the data, the nitrogen content in maize grains was much higher in the treatment with polymer-coated nitrogenous and phosphoric fertilizers than in the control and all other treatments. Application of polymer-coated DAP with polymer-coated urea in treatment showed a significantly different outcome from all other treatments. The second-highest value of nitrogen content in maize grains was seen in the zarkhez plus NPK with zabardast urea treatment and showed a significantly greater difference than in zarkhez plus NPK with urea treatment. In the case of simple DAP with urea and zabardast urea, there was a significantly greater difference than DAP with urea and control treatments. Polymer-coated DAP with polymer-coated urea improved the nitrogen content in maize grains more than other commercially available fertilizers combinations because of the slow and consistent release of nitrogen and phosphorus from polymer-coated fertilizers.

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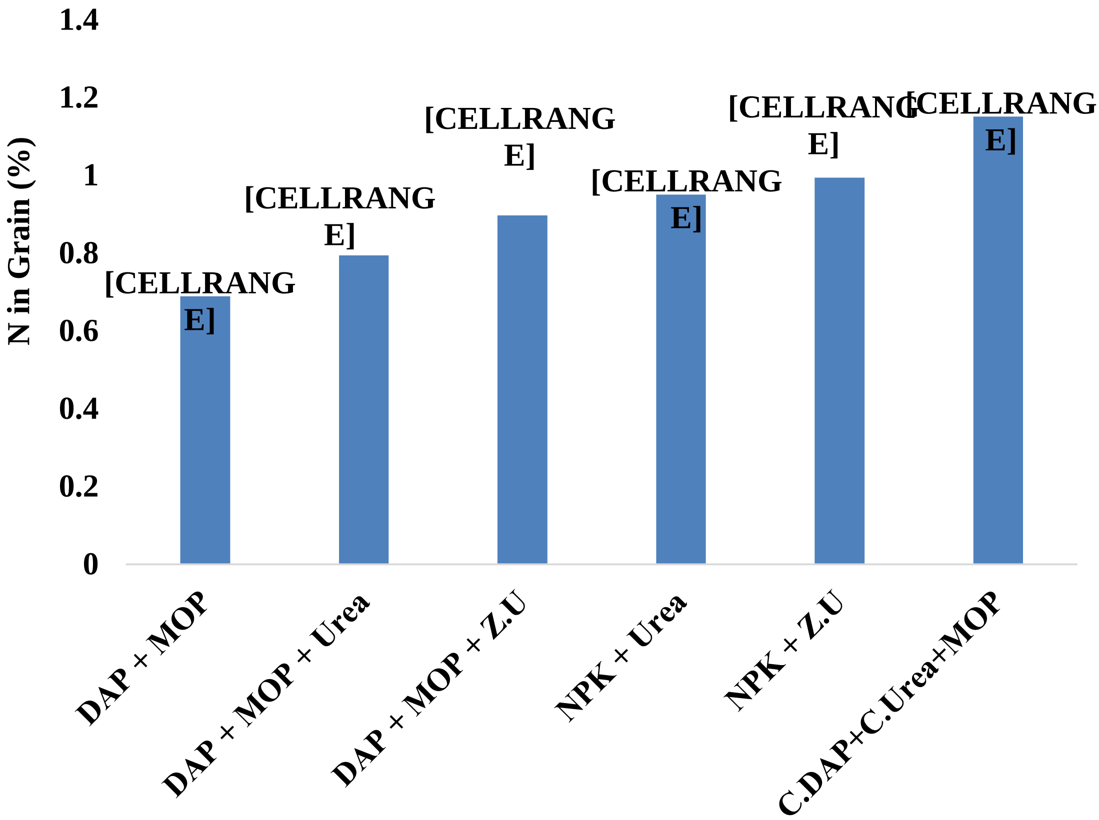

Figure 4.17 Effect of sustainable availability of nitrogen and phosphorus through polymer coated nitrogenous and phosphatic fertilizers on N in grain (%) of maize

Phosphorus concentration in grains (%)

The effect of value-added fertilizer combinations on the phosphorus content of maize grains is shown in Figure 4.20. According to the data, the phosphorus content in maize grains was much higher in the treatment with polymer-coated nitrogenous and phosphoric fertilizers than in the control and all other treatments. Application of polymer-coated DAP with polymer-coated urea in treatment showed a significantly different outcome from all other treatments. The second-highest value of phosphorus content in maize grains was seen in the zarkhez plus NPK with zabardast urea treatment and showed a non-significant difference from the zarkhez plus NPK with urea treatment. In the case of simple DAP with urea and zabardast urea, there was a significantly greater difference between the treatments. Polymer-coated DAP with polymer-coated urea improved the phosphorus content in maize grains more than other commercially available fertilizers combinations because of the slow and consistent release of phosphorus from polymer-coated fertilizers.

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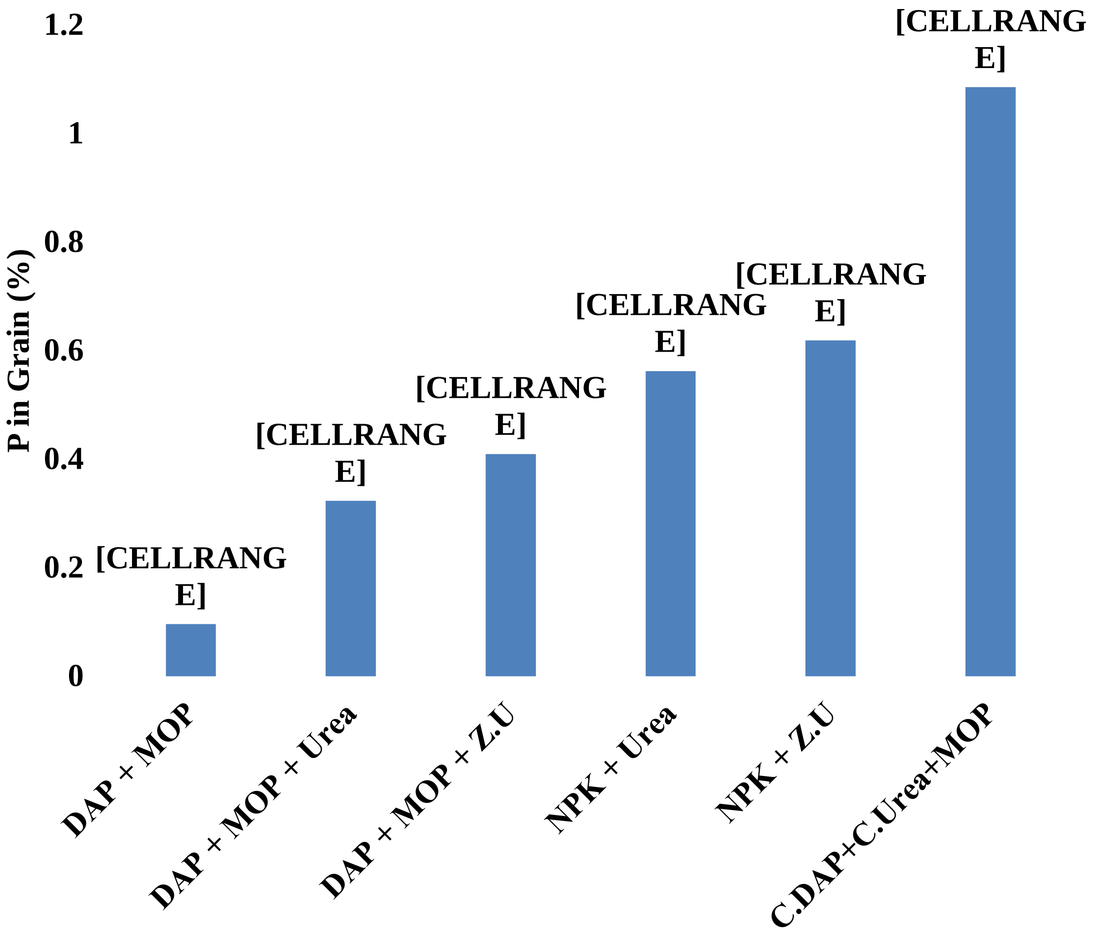

Figure 4.20 Effect of sustainable availability of nitrogen and phosphorus through polymer coated nitrogenous and phosphatic fertilizers on P in grain (%) of maize

Potassium concentration in grains (%)

Potassium contents in grain were shown in figure 4.23, which showed that the k contents were significantly increased in all treatments with zabardast urea, with the highest increase of 43.47% in zarkhez plus NPK with zabardast urea treatment compared to control. While the use of DAP with urea resulted in the smallest increase (17.39%) in comparison to the control. In DAP-treated plots, zabardast urea enhanced k contents over urea. Coated DAP and urea outperformed all of the treatments with the highest increase in k contents, which was 1.05%. When comparing all of the treatments, coated DAP and urea treatment were significantly different from all other treatments. Moreover, a non-significant difference was found between DAP with zabardast urea and NPK with urea treatments.

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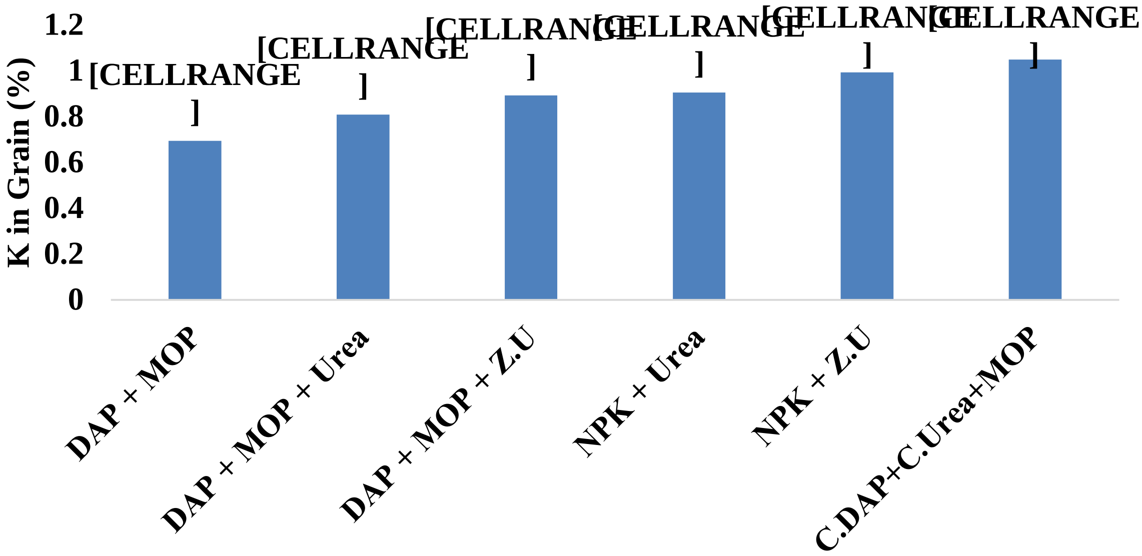

Figure 4.23 Effect of sustainable availability of nitrogen and phosphorus through polymer coated nitrogenous and phosphatic fertilizers on K in grain (%) of maize

CHAPTER 5
DISCUSSION

The steady rise in global population continues to place significant pressure on farmers to increase food production (Shakoor et al., 2020). To meet this demand, modern agriculture has relied heavily on fertilizers, particularly nitrogen (N) and phosphorus (P). However, maximizing the efficiency of these inputs while minimizing their environmental footprint remains a major challenge Considerable effort has therefore been directed toward improving existing fertilizers or developing new formulations that synchronize nutrient availability with crop uptake (Trenkel et al., 1988). Advances in coating technologies, such as polymer-coated fertilizers, offer promising solutions by regulating nutrient release according to soil and climatic conditions (Bröckel & Hahn, 2004) Because plants primarily absorb N as nitrate or ammonium from the soil solution, enhancing the efficiency of mineral N sources is difficult; controlled-release N (CRN) fertilizers are particularly valuable for optimizing N availability (Xiang et al., 2008).

In the present field study, polymer-coated urea and diammonium phosphate (DAP) markedly improved plant growth and yield attributes compared with conventional sources. Treatments receiving polymer-coated fertilizers produced the tallest plants, whereas the control (no supplemental N) recorded the shortest height, underscoring the importance of adequate N supply. Among conventional materials, the combination of Zarkhez + NPK with Zabardast urea also enhanced plant height, while Zabardast urea alone performed better than standard urea when both were applied with DAP.

Yield components such as cob length, cob diameter, and grains per cob were consistently superior in plots treated with polymer-coated urea and DAP. Zabardast urea improved these parameters relative to uncoated urea, but the highest values were achieved with coated fertilizers. Root development followed a similar trend: the longest roots were recorded in plots supplied with polymer-coated fertilizers, whereas the control showed the shortest root length. These findings suggest that polymer coatings not only extend nutrient availability but also promote vigorous root systems, supporting greater above-ground biomass.

Grain yield, biological yield, stalk yield, and 1000-grain weight responded strongly to N fertilization. The absence of any N source in the control resulted in the lowest values for all yield parameters, whereas applying N alongside P, whether as urea or Zabardast urea, significantly improved performance. Zabardast urea outperformed conventional urea, and Zarkhez + NPK surpassed DAP when combined with either N source. Nevertheless, polymer-coated urea and DAP produced the highest biological, straw, and grain yields, confirming their superiority in enhancing crop productivity.
Fertilizer treatments also influenced canopy development and physiological traits. Leaf area index (LAI) increased sharply with N application compared with the control, with polymer-coated fertilizers producing the maximum LAI. Zarkhez + NPK demonstrated better performance than DAP when paired with either N source, indicating its value as an enriched P fertilizer. Chlorophyll content showed a comparable response, again with coated fertilizers achieving the greatest improvement. Transpiration rates remained largely unaffected by most treatments, except for polymer-coated fertilizers, which significantly increased transpiration relative to other sources. Similarly, photosynthetic activity was highest with polymer-coated urea and DAP, followed by Zarkhez + NPK and Zabardast urea.
Nutrient concentration in plant tissues reflected the differences in fertilizer sources. The lowest N, P, and K contents were recorded in plants receiving only DAP and MOP, while the addition of urea or Zabardast urea substantially increased macronutrient uptake. Zarkhez + NPK also improved N, P, and K concentrations compared with DAP, but polymer-coated fertilizers delivered the greatest enhancement in nutrient accumulation. These results highlight the role of coating technology in sustaining nutrient supply, reducing losses, and supporting balanced nutrition.
Overall, the findings demonstrate that polymer-coated urea and DAP outperform both conventional and other value-added fertilizers in improving maize growth, physiological performance, nutrient uptake, and yield. By synchronizing nutrient release with crop demand, coated fertilizers enhance NUE and PUE while minimizing environmental risks. Their adoption in maize production under calcareous soils could therefore contribute to higher productivity and more sustainable nutrient management.

Conclusion

The study demonstrated that polymer-coated urea and DAP significantly improved maize growth, yield components, and nutrient uptake compared to conventional fertilizers. Treatments with polymer-coated fertilizers recorded maximum plant height, cob size, grain weight, and overall biological yield. These fertilizers enhanced N, P, and K concentrations in grains, roots, and shoots due to their slow and sustained nutrient release. Reduced ammonia emissions highlighted their environmental benefits by minimizing nutrient losses and improving nitrogen use efficiency. Enhanced nutrient recovery, agronomic efficiency, and physiological efficiency contributed to better crop performance. Zarkhez Plus NPK and Zabardast urea also improved yield and nutrient uptake but were less effective than polymer-coated fertilizers. Overall, polymer-coated urea and DAP proved superior in boosting maize productivity while mitigating environmental pollution. Their adoption can support sustainable nutrient management and higher farm profitability in maize-based systems.

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