

ARTICLE

Effect of Starch-Coated Urea Fertilizer on Soil Nitrogen Availability and Growth of Maize (*Zea mays* L.)

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ABSTRACT

The prompt nitrogen loss of soil is one huge problem which faced the agri-product, so the slow-release is considered among the most highly effective strategies. The impact investigation the starch-coated urea fertilizer on residual soil available nitrogen and growth of maize (*Zea mays* L.) were aimed. The trail was carried out under greenhouse belong to Department of Soil Science and Water Resources, College of Agriculture, University of Basrah in March, 2025). Trial was applied using four nitrogen rates (0, 150, 250, and 350 Kg N/ha⁻¹) coated by three starch coating kevels (0, 1, and 2%) on two soil (clay loam and sandy loam). The pots contain 5 kg of dry soil utilized and sown by local maize cultivar seeds. Plant height and shoot dry weight were measured. Nitrogen concentration in plant tissue and residual soil available nitrogen post-harvest was determined. The results displayed that starch-coating urea significantly enhanced plant height, shoot dry weight, shoot nitrogen concentration, and significantly increased residual soil available nitrogen compared to conventional uncoated urea. The 350 kg N ha⁻¹ application and 2% starch coating had yielded the highest results. In the clay loam and sandy loam soils, plant height reached 86.45 and 83.83 cm, shoot dry weight was 6.50 and 6.29 g pot⁻¹, shoot nitrogen concentration was 52.22 and 45.25 g N kg⁻¹ DW, respectively. While, the nitrogen uptake was recorded 67.93, and 56.93 mg N kg⁻¹ soil, respectively.

Keywords:, Coated-Fertilizers; Slow-Release; Enhance Plant development; Agri-product

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INTRODUCTION

Growth and development shoot and root system of plant depended on nitrogen as essential macronutrient, and deficiency induces a range of physiological and morphological disorders (Brady and Weil, 2010). Nitrogen deficiency symptoms in plants are observed first in old-leaves, with the yellowing spreading from the leaf tip along the veins towards the base leaf, so nitrogen is therefore considered a readily mobile element within plant tissues (Brady and Weil, 2010). In addition to leaf yellowing, a decrease in plant protein content coupled with an increase in saccharides content is among the most significant physiological changes caused by nitrogen deficiency. Nitrogen deficiency impairs the uptake of carbon structures in photosynthesis, thus affecting plant protein synthesis. Sustainable strategies prioritize maximizing field crop productivity while simultaneously regulating nitrogen use efficiency, particularly in advanced agriculture. Nitrogen use efficiency is traditionally defined as the ratio of nitrogen uptake and storage in plant tissues to the total amount of nitrogen fertilizer applied. Previous studies have assessed nitrogen use efficiency based on growth indicators comparing fertilized and unfertilized crops, as well as evaluating nitrogen uptake in aboveground biomass (Cassmann *et al.*, 2022). Adopting a set of indicators that serve as an agricultural assessment framework provides a clear view of the factors effecting nitrogen uptake

and application efficiency.

This framework also facilitates comparisons between different environments and practices that can improve fertilization management. Moreover, the choice of an effective and simple framework in terms of cost makes it suitable for estimating the efficiency of nitrogen use in field trials (Dobermann, 2005). The limited ability of plants to utilize added nitrogen, despite high fertilizer application rates, is attributed to the saturation of root absorption system, a condition known as low nitrogen use efficiency (NUE). This underscores the importance of monitoring nitrogen fertilizer behavior within the agricultural ecosystem and assessing nitrogen use efficiency and its actual contribution to crop yield (Wang *et al.*, 2024). It has been found that a significant portion of added nitrogen is lost before being absorbed by plants due to the rapid solubility of urea, a common nitrogen fertilizer. Studies indicate that approximately 40-70% of added nitrogen remains unutilized by plants, significantly reducing its efficiency (Latifa *et al.*, 2019). Consequently, repeated fertilization is required to meet crop needs, increasing production costs and exacerbating native environmental impacts. These impacts include soil nitrogen imbalance and increased losses through nitrate (NO_3^-) leaching, ammonia (NH_3) volatilization, and denitrification processes (Tufa *et al.*, 2022).

To reduce nitrogen loss, literature has pursued promising new practices to retain nitrogen for longer periods while improving efficiency. One such technique involves encapsulating urea with organic materials to enhance nitrogen utilization efficiency by regulating its solubility in the soil to align with the plants actual inorganic nitrogen requirements (Wu *et al.*, 2025). Coated urea, as a slow-release fertilizer, is one of the most effective practices for reducing nitrogen loss. It has been found that coated urea provides nitrogen gradually and continuously for longer period than typically required by the plants physiological needs during its development stages. Choosing the suitable coating material reduces the rate of nitrogen release, thus delaying nitrogen release in the soil (Bortoletto-Santos *et al.*, 2020). The coating material acts as a barrier around the urea granules, regulating their release and allowing for the gradual dissolution of nitrogen after application (Guo *et al.*, 2005). Furthermore, the use of coated urea slows nitrogen release under field conditions, reducing nitrate leaching into groundwater and ammonia volatilization into the atmosphere (Thind *et al.*, 2009). The physical properties of the chosen coating material and its crucial role in regulating nitrogen release behavior in the soil have also been highlighted. The interaction of the coating materials with soil conditions and the mechanism of release of coated urea are of critical importance for achieving optimal efficiency of coated fertilizers (Mulder *et al.*, 2011). Compared with uncoated urea, coated urea reduces the cost of frequent fertilization, especially in annual crops such as leafy vegetables; by releasing nitrogen in a controlled manner that meets the plant's needs. Furthermore, coated urea helps minimize nitrogen loss, seed toxicity, harmful gas emissions, and leaf death. It also contributes to improving certain physical and chemical properties of the soil and increasing seed germination rates, which positively impacts plant growth and productivity (Azeem *et al.*, 2014; Bordoloi *et al.*, 2020).

Studies have indicated that starch is a suitable material for producing coated fertilizers due to its availability, ease of manufacturing, success in polymer coating production, and the resistance of the starch film to moisture and mechanical stress in soil (Ibrahim *et al.*, 2020; Gupta *et al.*, 2020). Organic coating fertilizers contribute significantly to sustainable agriculture. In light of this, the study aimed to synthesize starch-coated urea granules using a stable, slow-release method and examine their impact on maize plant growth and soil nitrogen content.

MATERIALS AND METHODS

Urea Starch-Coated Preparation

To prepare starch coating, two measured quantities of clean starch (1% and 2%) were prepared separately. The

prepared starch was homogenized with measured quantities of acrylic acid and polyethylene glycol (PEG) as bonding agents.

The mixture was thoroughly mixed, and then 30 mL of room-temperature distilled water was added while stirring continuously until a completely homogeneous mixture was obtained. The mixture was then stored until used. The method described by [Sherman and Anggoro \(2011\)](#) was followed with minimal modification for the purpose of coating the urea granules with the prepared starch mixture. One hundred grams of homogenized urea fertilizer granules were placed in a watch glass. Then, 30 mL of the prepared coating solution was sprayed homogeneously onto the urea granules under air pressure at a constant flow rate of 0.5 ml/min at 25 °C and heft until the urea granules were completely and homogeneously coated.

Soil and Trial Preparation

Two textures of agricultural soils (Clay loam and Sandy loam) were prepared, air-dried, and then sieved through a 4 mm sieve. The initial physical and chemical properties of the soils were determined pre-planting (Table 1). The 5 k of each soil textures were transferred to plastic pots and moved to the greenhouse at the College of Agriculture in early March 2025. Three fertilizer formulations were applied: uncoated urea (G0), and two starch-coated urea formulations with coating rate of 1% (G1), and 2% (G2). These formulations were applied concurrently with four nitrogen rates (0, 150, 250, and 350 kg N ha⁻¹), denoted by (L). In addition, a base dose of phosphorus was applied at a rate of 200 kg p/ha in the form of concentrated superphosphate (20.21% P), and potassium was applied at a rate of 180 kg/ha⁻¹ in the form of potassium sulfate (43% k). The fertilizers were incorporated evenly into the top 5 cm of soil in each pot.

Five seeds of local maize (*Zea mays* L.) variety were sown into each pot. The pots were watered as needed, and soil moisture was maintained at field capacity throughout the trial, based on periodic weighing. Tap water with an electrical conductivity (EC) of 2 dS/m⁻¹ was used to compensate for moisture deficiency. The pots were thinned (1 seedling/ pot) when the seedlings reached to the three-true-leaf stage.

Sixty day post-germination, plant height was measured utilizing measuring tape. The plant shoot were harvested by cutting the stems 1 cm above the soil surface. The harvested shoots were washed by distilled water, air-dried, and then oven-dried at 65 °C until a constant weight, and then the shoots dry weight was recorded.

To estimate the plants nitrogen content, the method described by [Krisser and Parsons \(1979\)](#) was followed. A specific weight of dry maize leaf tissue was ground in an electric mill and subjected to wet boneization. A 0.2 g powder of the ground plant tissue was treated with 5 mL of concentrated sulfuric acid (H₂SO₄) and incubated overnight. The mixture was then heated at 350 °C for 30 min. After cooling, 3 mL of an acidic mixture (4% HClO₄+H₂SO₄) was added. And heating was resumed until a clear, colorless digestate was obtained. The final volume was then topped up to 50 mL with distilled water. The total nitrogen concentration in the plant digestate was determined using the steam distillation method described by [Bremnr \(1970\)](#). Nitrogen uptake was calculated by multiplying the shoot dry weight by the shoot nitrogen concentration.

Soil-available residual Nitrogen

Soil sample from pots in maize growing trial were collected and brought to laboratory. A 5 g of air-dried soil samples were extracted from each experimental until using 50 mL of 2 KCl solution. The suspension was shaken thoroughly for 1 h and then filtered using Whatman No. 42 filter paper. A 15 mL portion of the filtrate was transferred to a steam distillation unit, where 0.2 g of magnesium oxide (MgO) and 0.2 g of Devarda's alloy were added. Volatile ammonia was collected in 2% boric acid solution and then titrated by 0.005 N Hydrochloric acids (HCl). The total

available inorganic nitrogen (NH_4^+ , NO_2^- , and NO_3^-) in the soil sample was determined according to the method of Bremner and Edwards (1965) as reported in Page *et al.* (1982).

Table (1) Physico-chemical properties of the two soil textures studied

Parameter	Unit	Soil	
		Clay Loam	Sandy Loam
pH (1:1)		7.59	7.45
EC	dS m^{-1}	3.32	2.51
Total carbonates	gm kg^{-1}	435	255
CEC	Coml+ kg^{-1}	23.9	6.50
Total nitrogen (TN)	gm kg^{-1}	0.55	0.43
Available nitrogen (N)	mg kg^{-1}	25.12	17.3
Available phosphorus (P)	mg kg^{-1}	19.50	6.40
Available potassium (K)	mg kg^{-1}	113	86.16
organic matter (OM)	gm kg^{-1}	10.76	6.50

Statistical Analysis

The trial was conducted utilizing a completely randomized design (CRD) with 2-factors, replicated three times. Data were analyzed utilizing SPSS statistical software (Version 11.0). The (RLSD) test was utilized at a probability level of $p \leq 0.05$ to determine the difference among the trial treatment means.

RESULTS AND DISCUSSION

Plant Height

Findings displayed the impacts of combinations of starch-coated urea fertilizer and nitrogen application rates on maize plant height across the studied soil (Table 2). The data revealed a significant impact of the urea starch-coated (G) on the average of the maize plant height. The G2 treatment outperformed the other combinations, recording the highest plant height rate of 71.05 and 67.54 cm in the clay loam and sandy loam soils, respectively. Compared with the control, the uncoated urea (G0) exhibited the lowest mean values of 66.83 in the clay loam soil, and 62.34 cm in the sandy loam soil. Data revealed that the highest application (350 kg N ha^{-1}) exhibited the maximum mean of plant height of 83.96 and 80.39 cm in the both clay loam and sandy loam soils, respectively. While, the 0 kg N ha^{-1} treatment (unfertilized) exhibited the lowest mean of maize plant height, yielding of 53.63 and 51.11 cm in the both soil textures clay loam and sandy loam, respectively.

Furthermore, the interaction between fertilizer coated and nitrogen application rates exhibited a significant effect on maize height (Table 2). The combination of the 2% starch-coated urea (G2) and the highest nitrogen rate (350 kg N ha^{-1}) outperformed all other interactions, recording the maximum plant height of 86.54 cm in the clay loam soil, and 83.83 cm in the sandy loam soil. The lowest plant height had observed under the absolute control treatment (G0 and 0 kg N ha^{-1}), of 53.33 and 50.67 cm in the both of clay loam and sandy loam soils, respectively. The increase in maize height is attributed to the continuous release of nitrogen from the soil due to starch encapsulation, allowing the plant to obtain sufficient nitrogen during its growth stages.

The direct impact of nitrogen availability on vegetative growth contributes to the synthesis of amino acids, chlorophyll, and proteins, which positively impacts vegetative growth. Several studies have reported the role of coated urea fertilizers in significantly enhancing vegetative growth and increasing plant height compared to conventional uncoated urea (El-Hadidi *et al.*, 2021; Ghafoor *et al.*, 2022).

More recently, starch has emerged as one of the best organic materials for coating urea, a crucial approach to solving the problem of rapid nitrogen fertilizer lysis in the soil and its incomplete utilization by plants (Hagos *et al.*, 2025).

Table (2) Impact of starch-coated urea and nitrogen fertilizer rates across two soil texture in the plant height of maize

Soil texture	Coating level (G)	Plant height (cm)				Mean G
		Nitrogen application level (L) (kg N ha ⁻¹)				
		0	150	250	350	
Clay Loam	G0	53.33	60.67	72.33	81	66.83
	G1	54.33	65.67	74.68	84.33	69.75
	G2	53.23	66.75	77.67	86.54	71.05
	Mean L	53.63	64.36	74.89	83.96	
RLSD G = 0.997		RLSD L = 1.151	RLSD G*L = 2.440			
Sandy Loam	G0	50.67	59	64	75.67	62.34
	G1	51	57	69.67	81.67	64.84
	G2	51.67	61.33	73.33	83.83	67.54
	Mean L	51.11	59.11	69	80.39	
RLSD G = 1.543		RLSD L = 1.701	RLSD G*L = 2.025			

Shoot Dry Weight

The impacts of starch-coated urea fertilizer combination (G) and nitrogen application rates (L) on the shoot dry weight of maize are illustrated in Table 3. The data indicated a significant effect of the starch-coated formulation (G) on shoot dry weight. Both of G1 and G2 treatments outperformed the control; G1 recorded dry matter weights of 4.25 and 4.55 g pot⁻¹ in both of clay loam and sandy loam soils, respectively. While, the G2 exhibited dry matter weights of 3.73 and 3.91g pot⁻¹ in both of clay loam and sandy loam soils, respectively. In compared with the control, the uncoated urea (G0) exhibited the lowest mean dry weights, yielding 3.80 and 3.41g pot⁻¹ in the clay loam and sandy loam soils, respectively.

Furthermore, the data exhibited a great significant effect of different nitrogen rates on the maize shoot dry weight (Table 3). The results indicated that the highest application rate (350 kg N ha⁻¹) outperformed the other rates, recording the maximum mean dry matter weights of 6.17 and 5.88 g pot⁻¹ in the clay loam and sandy loam soils, respectively. Conversely, the unfertilized control rate (0 kg N ha⁻¹) exhibited the lowest shoot dry weight values, yielding 2.21 and 2.08g pot⁻¹ in the clay loam and sandy loam soils, respectively.

Regarding the interaction between fertilizer combinations (G) and nitrogen application rates (L), the findings revealed that the combination both of (G2) treatment with (350 kg N ha⁻¹) exhibited the highest mean shoot dry weight, recording 6.50 and 6.29g pot⁻¹ in the clay loam and sandy loam soils, respectively. In contrast, the lowest shoot dry weight was recorded under the absolute control treatment (G0 + 0 kg N ha⁻¹), which yielded 2.20 and 2.01 g pot⁻¹ in the

clay loam and sandy loam soils, respectively.

Our findings of starch-coated urea and nitrogen application impact on the plant parameters are consistent with several authors, including (Babalar *et al.*, 2010; Salim *et al.*, 2012). Rapid nitrogen loss due to evaporation and leaching causes nutrient deficiencies in plant, negatively impacting their vitality and growth. Therefore, adding slow-release fertilizers improves plant vegetative and root parameters by controlling the quantity and continuity of nitrogen availability and preventing rapid loss in a controlled manner, thus maximizing the period required for nitrogen exposure (Hoshan, 2012; Al-Majidi, 2025). The availability of nitrogen in the soil increases the dry weight of maize plant. Since nitrogen is a key component in the synthesis of proteins, amino acids, and chlorophyll, increased nitrogen availability promotes biomass accumulation and stimulates vegetative growth (Yaseen, 2010; Jameel, 2012).

Table (3) Impact of starch-coated urea fertilizer and nitrogen application rates on the shoot dry weight of maize

Shoot dry weight (g pot ⁻¹)						
Soil texture	Coating level (G)	Nitrogen application level (L) (kg N ha ⁻¹)				Mean G
		0	150	250	350	
Clay Loam	G0	2.2	3.09	4.26	5.63	3.8
	G1	2.21	3.54	4.87	6.37	4.25
	G2	2.22	3.93	5.55	6.5	4.55
	Mean L	2.21	3.52	4.89	6.17	
		RLSD G = 0.175	RLSD L = 0.203	RLSD G*L = 0.351		
Sandy Loam	G0	2.01	2.69	3.53	5.42	3.41
	G1	2.11	2.77	4.12	5.93	3.73
	G2	2.13	2.79	4.42	6.29	3.91
	Mean L	2.08	2.75	4.02	5.88	
		RLSD G = 0.177	RLSD L = 0.188	RLSD G*L = 0.412		

Shoot Nitrogen Concentration

Effects of starch-coated urea fertilizer combinations (G) and nitrogen application rates on the shoot nitrogen concentration of maize are illustrated in Table 4. The data cleared that the starch-coating formulations exerted a highly significant effect on shoot nitrogen content. The G1 and G2 treatments outperformed the control; The G1 recorded the highest mean nitrogen contents of 33.57 and 34.64g N kg⁻¹ DW in the clay loam and sandy loam soils, respectively. While, the G2 exhibited mean nitrogen content of 29.92 and 31.71 g N kg⁻¹ DW in the clay loam and sandy loam soils, respectively. In contrast, the control used uncoated (conventional urea, G0) exhibited the lowest mean shoot nitrogen content, yielding 28.44 and 26.34g N kg⁻¹ DW in the clay loam and sandy loam soils, respectively.

Table 4 also displayed a significant role of nitrogen application rates on the shoot nitrogen content of maize. The treatment of 350 kg N ha⁻¹ showed the maximum mean nitrogen content, reaching 47.84 and 42.26 g N kg⁻¹ DW in the clay loam and sandy loam soils, respectively. Conversely, the unfertilized control rate (0 kg N ha⁻¹) exhibited lowest shoot nitrogen content, reaching 11.39 and 10.01g N kg⁻¹ DW in the clay loam and sandy loam soils, respectively.

The data in the Table 4 revealed highly significant differences regarding the interaction between urea-coated fertilizer (G) and nitrogen application rates (L). The combination of the G2 formulation and the 350 kg N ha⁻¹ rate outperformed all other interactions, recording the highest mean shoot nitrogen content of 52.22 and 45.25g N kg ha⁻¹

DW in the clay loam and sandy loam soils, respectively. In contrast, the lowest shoot nitrogen content was exhibited under the control treatment (G0+ 0 kg N ha⁻¹), which reaching 11.23 and 10.03g kg N ha⁻¹ DW in the clay loam and sandy loam soils, respectively. The high nitrogen content in plants is attributed to its concentration and continuous presence in the soil. This is where the role and effectiveness of the starch coating come in. Starch-coating acts as a physical barrier, slowing the leaching and loss of urea and retaining small amounts of nitrogen, which are then continuously replenished in the soil.

This approach increases nitrogen storage and acts as a nitrogen bank, allowing for the release of readily absorbable nitrogen in the soil. Unlike conventional urea, that it may lose through deep leaching into the soil, leaching from irrigation or rainwater, or volatilization as ammonia gas. Coated-urea significantly increases nitrogen content in plants compared with uncoated urea (Al-Bourky and Al-Taher, 2020). In addition to being an economical method, using coated-urea improves nitrogen content in barley stems compared to conventional urea (Hoshan, 2012; Al-Maliki, 2018). Furthermore, the increase in nitrogen content in plants is consistent with higher nitrogen fertilization rates (Jameel, 2010).

Table (4) Impact of starch-coated urea fertilizer and nitrogen application rates on maize nitrogen content

Plant nitrogen concentration (g N kg ⁻¹ dry weight)						
Soil texture	Coating level (G)	Nitrogen application level (L) (kg N ha ⁻¹)				Mean G
		0	150	250	350	
Clay Loam	G0	11.23	27.56	33.98	40.97	28.44
	G1	11.65	33.8	38.49	50.34	33.57
	G2	11.3	34.45	40.64	52.22	34.65
	Mean L	11.39	31.94	37.7	47.84	
		RLSD G = 0.649	RLSD L = 0.750	RLSD G*L = 1.361		
Sandy Loam	G0	10.03	26.17	30.34	38.8	26.34
	G1	10.06	31.26	35.63	42.73	29.92
	G2	9.93	32.8	38.87	45.25	31.71
	Mean L	10.01	30.08	34.95	42.26	
		RLSD G = 0.395	RLSD L = 0.456	RLSD G*L = 0.790		

Nitrogen Uptake

The effects of starch-coated urea fertilizer combinations (G) and nitrogen application rates on nitrogen uptake by maize are illustrated in Table 5. The results revealed a highly significant effect of the fertilizer combinations on nitrogen uptake. Specifically, formulations G1 and G2 exhibited a significant increase, recording mean values of 32.68 and 36.28 mg N kg⁻¹ soil in the clay loam soil, respectively, and 25.41 and 28.44 mg N kg⁻¹ soil in the sandy loam soil, respectively. In contrast, the uncoated control treatment (G0) recorded the lowest mean nitrogen uptake, yielding 24.26 and 20.37 mg N kg⁻¹ soil in the clay loam and sandy loam soils, respectively.

These findings are consistent with Yan *et al.* (2025), who reported that the application of slow-release fertilizers significantly enhances nitrogen uptake by maize plants. This enhancement is attributed to the mitigation of nitrogen losses and the increased retention of nitrogen in the soil compared to the use of conventional (uncoated) urea. Furthermore, Table 5 also exhibited the effect of nitrogen application rates on nitrogen uptake. The highest application rate (350 kg N ha⁻¹) outperformed the other rates, recording the maximum mean values of 59.40 and 49.89 mg N kg⁻¹

soil in the clay loam and sandy loam soils, respectively.

Meanwhile, the (0 kg N/ha⁻¹) treatment recorded the lowest nitrogen uptake rates of 5.03 and 4.16 mg N/kg⁻¹ soil in the clay loam and sandy loam soils, respectively. Regarding the interaction between fertilizer combinations (G) and nitrogen application rates (L), the results revealed highly significant differences in shoot nitrogen uptake. The combination of the G2 formulation and the 350 kg N ha⁻¹ rate achieved the highest mean values, reaching 67.93 and 56.93 mg N kg⁻¹ soil in the clay loam and sandy loam soils, respectively. In contrast, the lowest nitrogen uptake was recorded under the absolute control treatment (G0 at 0 kg N ha⁻¹), which yielded 4.94 and 4.02 mg N kg⁻¹ soil in the clay loam and sandy loam soils, respectively.

Studies have shown that applying high levels of nitrogen to the soil increases its uptake by maize roots (Li *et al.*, 2017; Al-Majidi, 2025). Study also indicated a direct correlation between nitrogen uptake in tomato roots and increased nitrogen fertilizer application (Al-Ansari, 2020). Furthermore, as noted by Geisseler *et al.* (2020), variations in nitrogen uptake are fundamentally driven by changes in both plant nitrogen concentration and dry matter weight; thus, total nitrogen uptake increases as a direct function of the simultaneous enhancement of both shoot dry weight and nitrogen concentration.

Table (5) Impact of starch-coated urea fertilizer and nitrogen application rate on nitrogen uptake by maize

Nitrogen uptake (mg N kg ⁻¹ soil)						
Soil texture	Coating level (G)	Nitrogen application level (L) (kg N ha ⁻¹)				Mean G
		0	150	250	350	
Clay Loam	G0	4.94	16.99	28.97	46.13	24.26
	G1	5.15	23.93	37.52	64.13	32.68
	G2	5.01	27.05	45.14	67.93	36.28
	Mean L	5.03	22.66	37.21	59.4	
		RLSD G = 1.825	RLSD L = 2.107	RLSD G*L = 3.823		
Sandy Loam	G0	4.02	14.06	21.34	42.03	20.37
	G1	4.24	17.32	29.36	50.71	25.41
	G2	4.22	18.28	34.33	56.93	28.44
	Mean L	4.16	16.55	28.34	49.89	
		RLSD G = 1.060	RLSD L = 1.224	RLSD G*L = 2.222		

Nitrogen Uptake

(Table 6) illustrates the effects of starch-coated urea fertilizer combinations (G) and nitrogen application rates on residual soil available nitrogen. The results in Table 6 revealed a highly significant effect of the fertilizer combinations (G) on post-harvest nitrogen availability. Specifically, treatments G1 and G2 outperformed the control, recording the highest mean values of 31.84 and 33.87 mg N/kg⁻¹ soil in the clay loam soil, respectively, and 23.90 and 27.56 mg N/kg⁻¹ soil in the sandy loam soil, respectively.

On the other hand, the uncoated urea treatment (G0) failed to retain residual nitrogen, with both clay loam and sandy loam soils recording the lowest residual nitrogen concentration of 26.71 and 19.32 mg N Kg⁻¹ soil, respectively. Studies have indicated higher levels of available nitrogen in agricultural soils when applying urea granule coating technology with certain plant extracts compared to commercial urea (Mousa, 2022). It was also observed that the urea coated with gelatin hydrogel improved the soils ability to retain available nitrogen at a higher level than conventional, uncoated urea (Al-Majidi, 2025).

Table (6) illustrates the significant impact of nitrogen fertilization rates on the level of available residual nitrogen in agricultural soils. The fertilization treatment (350 kg N ha⁻¹) recorded the highest residual nitrogen levels, at 43.97 and 38.95 mg N ha⁻¹ soil for both clay loam and sandy loam soils, respectively. Conversely, the unfertilized treatment (0 kg N ha⁻¹) recorded the lowest residual nitrogen levels, at 9.98 and 8.99 mg N ha⁻¹ soil for both clay loam and sandy loam soils, respectively.

The increase in soil availability is attributed to the increased fertilization rates, which play a positive role in the direct relationship between increased nitrogen fertilization and soil availability (Al-Zubaidi, 2015; Abdul-Khaliq, 2015).

Regarding the combination of coated fertilizers and nitrogen application rates, the results showed a statistically significant difference between the treatments in the average available residual nitrogen. The combination (G2) and (350 kg N ha⁻¹) recorded the highest nitrogen, reaching 47.84 and 43.54 mg N kg⁻¹ soil in the clay loam and sandy loam soils, respectively.

Conversely, the combination (G0) and (0 kg N ha⁻¹) recorded the lowest nitrogen, at 9.77 and 8.76 mg N kg⁻¹ soil in the clay loam and sandy loam soils, respectively. The results demonstrated the significant role of starch coating in slowing urea decomposition, thereby delaying nitrification. Starch coating technology effectively controls the retention of available nitrogen forms in the soil and economically reduces losses due to ammonia volatilization and nitrate leaching.

Table (6) Impact of Starch-coated urea and nitrogen fertilizer rates across two soil textures on residual available nitrogen level in soil

Residual available nitrogen in soil (mg N kg ⁻¹ soil)						
Soil texture	Coating level (G)	Nitrogen application level (L) (kg N ha ⁻¹)				Mean G
		0	150	250	350	
Clay Loam	G0	9.77	24.04	34.45	38.58	26.71
	G1	10.14	31.67	40.06	45.49	31.84
	G2	10.02	34.51	43.09	47.84	33.87
	Mean L	9.98	30.07	39.2	43.97	
		RLSD G = 0.896		RLSD L = 1.034		RLSD G*L = 1.877
Sandy Loam	G0	8.76	13.76	22.53	32.23	19.32
	G1	9.03	14.34	31.18	41.07	23.9
	G2	9.18	24.01	33.49	43.54	27.56
	Mean L	8.99	17.37	29.07	38.95	
		RLSD G = 8.30		RLSD L = 0.958		RLSD G*L = 1.660

CONCLUSIONS

The combination of applying 350 kg N/ha-1 with 2% urea starch-coated had achieved the highest rates of residual and available nitrogen in the soil, along with a decrease in soil pH and EC. For maize, the combination achieved the highest both height plant and shoot dry weight, with a significant boots to both shoot nitrogen concentration and total nitrogen uptake. Our findings indicated that the starch urea coating effectively reduced ammonia loss in the plant and soil. However, further research is needed to investigate the impacts of different coatings on various soil textures and their application to different field crops.

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