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Effect of Starch-Coated Urea Fertilizer on Ammonia Volatilization and Availability of Nitrogen in Calcareous soils

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Abstract

This study was conducted to evaluate the potential of starch In producing slow-release fertilizers through coating urea fertilizer, which Is considered one of the nitrogen fertilizers with the highest nitrogen content (46%). The coating solution was prepared by mixing calculated amounts of starch, acrylic acid, and polyethylene glycol, where starch concentrations were (1, 1.5, and 2%), with fixed amounts of acrylic acid and polyethylene glycol as binding agents. The components were mixed gradually, followed by the addition of 30 mL of distilled water at room temperature with continuous stirring until a homogeneous solution was obtained.Urea fertilizer was coated by placing 100 g of urea granules In a watch glass and spraying 30 mL of the coating solution under air pressure at a rate of 0.5 mL per minute at room temperature until complete coating was achieved .The experiment was conducted on two soil types from Basrah Governorate: a clay loam soil and a sandy loam soil. Starch-coated urea was applied at concentrations of 1, 1.5, and 2%, at a rate of 1000 mg N kg^{-1} soil, to 300 g of air-dried soil placed in tightly sealed plastic containers. The treatments were moistened to field capacity for each soil type and incubated at 25°C for different time intervals (1, 2, 4, 8, 16, and 32 days).At the end of the Incubation period, ammonia volatilization and available nitrogen in the soil were determined. The results indicated that coating urea fertilizer with starch significantly reduced ammonia volatilization and increased available nitrogen In both clay loam and sandy loam soils.

Keywords: Starch, slow-release fertilizers, urea.

Introduction

Nitrogen fertilizers are among the most widely used agricultural inputs due to their essential role in improving crop productivity. Conventional nitrogen fertilizers, particularly urea fertilizer, are characterized by high water solubility and rapid nutrient release, which often leads to considerable nitrogen losses through ammonia volatilization, nitrate leaching, and denitrification. Consequently, plants may utilize only 30–50% of the applied nitrogen fertilizer, resulting in low fertilizer use efficiency and significant environmental pollution [1]. Moreover, ammonium salts, nitrates, urea, and other compounds readily dissolve following rainfall and are leached from the soil through surface runoff and groundwater movement, causing substantial environmental Impacts. Groundwater carrying these dissolved nutrients may enter drainage systems and subsequently pollute rivers and lakes.To mitigate these negative effects and reduce nutrient losses in fertilizer use, whether partially or completely, attention has been directed toward the development of specialized fertilizer types, Such as slow-release fertilizers (SRFs), controlled-release fertilizers, and fertilizers treated with nitrification and urease Inhibitors [2–4]. According to data reported by the International Fertilizer Association (IFA), the global annual consumption of synthetic slow-release fertilizers is approximately 562,000 tons, representing about 0.15% of the total global fertilizer consumption [4, 5]. These fertilizers, however, are generally more expensive than conventional fertilizers.Extensive scientific research has been conducted in countries such as the United States, Germany, and Japan to develop slow-release fertilizers [1, 3, 4], aiming to reduce production costs and enable their broader application. Nitrogen-based slow-release fertilizers are among the most widely used types. Research has identified several effective techniques to minimize nitrogen losses from fertilizer granules. One of the most common and effective approaches for controlling fertilizer behavior Is the production of coated fertilizers. In this technique, nutrient release Is regulated through a physical barrier that limits fertilizer dissolution and prolongs nutrient availability to plants. The fertilizer granules are coated with a layer of material, and the thickness of this layer Is directly proportional to the duration of nutrient release.Various materials can be used for coating; however, the most common include sulfur-coated urea (SCU), polymer-coated products (PCP), and combined sulfur–polymer coatings (PSCF) [4, 6–8]. The rate and mechanism of nutrient release from coated granules depend on the nature and thickness of the coating material. Although synthetic polymer coatings exhibit high efficiency, they are often non-biodegradable, leading to serious long-term environmental issues due to the accumulation of large polymer residues in the soil. Consequently, recent attention has focused on biodegradable natural polymers [3, 9].Starch is one of the most important biopolymers, naturally synthesized from various plant sources. It Is fully biodegradable, cost-effective, abundantly available, and can undergo polymerization after suitable modifications [9]. Starch consists of two polysaccharides, amylose and amylopectin, both of which exhibit limited solubility in water [11].The properties of starch-based coatings depend on the amylose content and the preparation conditions. Numerous studies [3, 8–12] have indicated that starch Is a suitable material for the production of controlled-release coated fertilizers, owing to the simplicity of polymer coating fabrication, the good resistance of starch films to moisture and mechanical stresses, and the possibility of modifying starch structure to obtain specific properties. Plasticizers can also be incorporated to enhance the flexibilIty of starch-based films.Other studies have reported the potential to reduce urea solubility through the use of starch-based polymers [11, 12], or by coating urea with dual-layer coatings composed of starch and polyacrylic acid [13, 14]. The development of slow-release nitrogen fertilizers using biodegradable materials such as starch represents an important step toward sustainable organic agriculture. The objective of this study is a producing a slow-release fertilizer that combines high nitrogen content with environmental compatibility is highly desirable. In this context, the use of urea as a high-nitrogen source (46.6% N), combined with starch-based coatings, represents a successful approach to improving nitrogen use efficiency while reducing nitrogen losses and associated environmental Impacts.

Materials and Methods

Preparation of Starch-Coated Urea Fertilizer: Slow-release urea fertilizers were prepared using starch-based coating formulations at concentrations of 1.0, 1.5, and 2.0%, which were designated as G1, G2, and G3, respectively. The coating solution was prepared by mixing predetermined amounts of starch with acrylic acid and polyethylene glycol, which served as binding agents. The starch concentration in the coating mixtures ranged from 1–2% depending on the treatment. Distilled water (30 mL) was gradually added to the mixture at room temperature under continuous stirring until a homogeneous coating solution was obtained.

For the coating process, 100 g of urea fertilizer was placed in a watch glass, and 30 mL of the prepared coating solution was sprayed onto the urea granules under air pressure at a spraying rate of 0.5 mL min^{-1} at room temperature until complete and uniform coating was achieved.

Laboratory Incubation Experiment:A laboratory incubation experiment was conducted using air-dried soil samples passed through a 2 mm sieve. Approximately 300 g of soil was placed into tightly sealed plastic containers. Conventional urea and starch-coated urea fertilizers (G1, G2, and G3) were applied according to the experimental treatments at a rate equivalent to 1000 mg N kg^{-1} soil, corresponding to 0.22 g fertilizer per 300 g soil sample.The soil samples were adjusted to field capacity using distilled water and incubated at 25 ± 1°C for different incubation periods (1, 2, 4, 8, 16, and 32 days).During the incubation period, volatilized ammonia (NH_3) was trapped in a 2% boric acid solution containing mixed indicators (bromocresol green and methyl red). The boric acid trapping solution was periodically replaced whenever saturation with ammonia occurred. The amount of volatilized ammonia was determined after each incubation interval. To determine total mineral nitrogen (NH_4^+, NO_2^-, and NO_3^-), 5 g of air-dried soil from each treatment was collected after each incubation period and extracted with 50 mL of 2 M KCl solution. The suspensions were shaken for 1 h and filtered through Whatman No. 42 filter paper. Subsequently, a 15 mL aliquot of the filtrate was transferred into a steam distillation unit, and 0.2 g MgO together with 0.2 g Devarda's alloy were added. The released ammonia was trapped in 2% boric acid solution and titrated with 0.005 N HCl for the determination of total mineral nitrogen according to the method described by Bremner and Edwards (1965), as reported in (Page et al.,1982).

Results and Discussion

1. **Ammonia Volatilization:** Figure (1) demonstrates that the starch-based coating formulations (G) applied to urea fertilizer significantly reduced ammonia volatilization in both studied soils. Among the treatments, G3 exhibited the lowest ammonia volatilization rates, recording 7.691 and 15.878 mg NH_3–N kg^{-1} soil in the clay loam and sandy loam soils, respectively. In contrast, the uncoated urea treatment (control) showed the highest volatilization losses, reaching 22.306 and 67.698 mg NH_3–N kg^{-1} soil in the clay loam and sandy loam soils, respectively.The reduction in ammonia volatilization observed with starch-coated urea may be attributed to the ability of the starch polymer matrix to delay urea hydrolysis by forming semi-permeable coating layers around the fertilizer granules. These polymeric films regulate water penetration and nitrogen diffusion, resulting in a gradual release of nitrogen into the soil solution and consequently lowering the accumulation and volatilization of ammonia. Furthermore, the slower dissolution of coated urea likely reduced the localized increase in soil pH surrounding the fertilizer granules, thereby minimizing NH_3 formation and loss.The greater ammonia volatilization observed in the sandy loam soil compared with the clay loam soil may be associated with the lower cation exchange capacity and reduced adsorption sites in sandy soils, which enhance nitrogen losses through volatilization. In contrast, clay loam soils possess higher surface area and greater nutrient retention capacity, contributing to reduced ammonia loss.

These findings are in agreement with previous studies conducted by Al-Samawi, Houshan, Abd Al-Sayed, and Al-Majidi, who reported that coated urea fertilizers significantly reduced ammonia volatilization compared with conventional urea fertilizers.

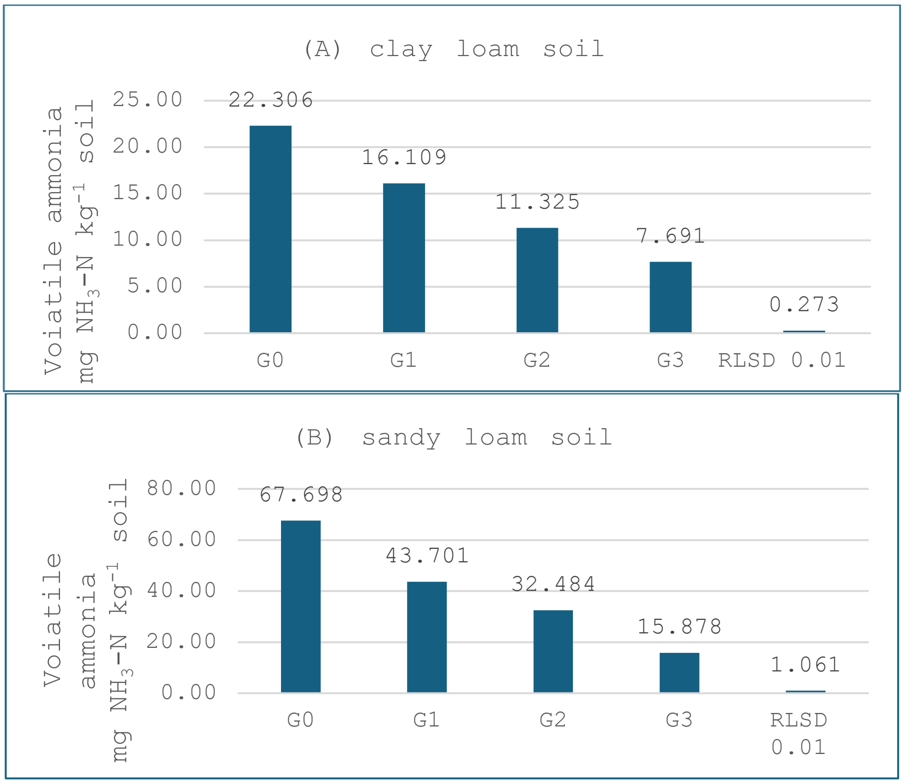

Figure 1: Effect of starch-based formulations used for coating urea fertilizer on ammonia volatilization in (A) clay loam soil and (B) sandy loam soil.

Figure (2) illustrates the effect of incubation periods on ammonia volatilization in both clay loam and sandy loam soils. The results revealed highly significant differences among the incubation periods (1, 2, 4, 8, 16, and 32 days). Ammonia volatilization rates in the clay loam soil reached 0.070, 2.369, 14.158, 15.019, 22.468, and 32.063 mg NH_3–N kg^{-1} soil, respectively, while in the sandy loam soil they reached 1.620, 26.873, 38.240, 38.908, 58.713, and 75.288 mg NH_3–N kg^{-1} soil, respectively. The results indicate that ammonia volatilization was low during the initial incubation periods, followed by a gradual increase over time. This progressive increase may be attributed to enhanced urea hydrolysis mediated by the urease enzyme with increasing incubation time, leading to ammonium accumulation in the soil. Additionally, the temporary rise in soil pH promotes the conversion of ammonium to ammonia, thereby increasing volatilization rates over time. These findings are consistent with those reported by Abd Al-Sayed (2020) and Al-Majidi (2025), who observed significant differences in ammonia volatilization rates across incubation periods.

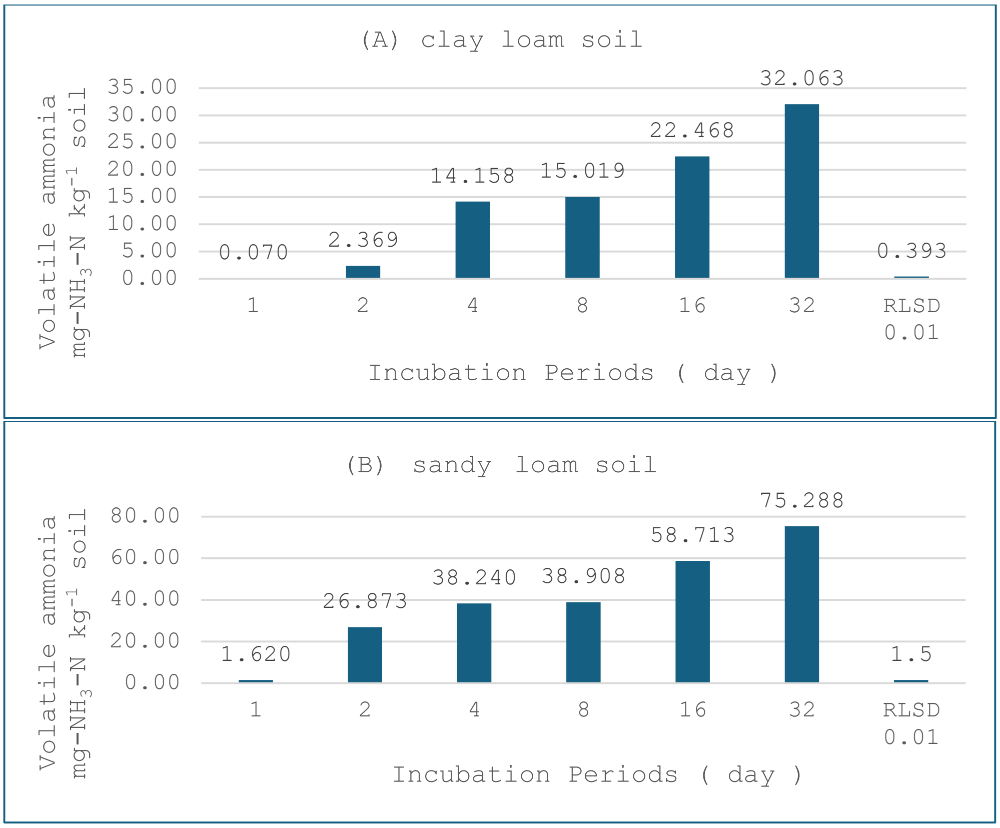

Figure 2: Effect of incubation periods on ammonia volatilization in (A) clay loam soil and (B) sandy loam soil.

Table (1) illustrates the interaction effect between starch-coated urea fertilizer formulations (G) and incubation periods on ammonia volatilization rates in the two studied soils. The results revealed a significant interaction between fertilizer coating treatments and incubation time, indicating that the effectiveness of starch-coated urea in reducing ammonia volatilization varied according to the duration of incubation.

Overall, the coated fertilizer formulations (G1, G2, and G3) significantly reduced ammonia volatilization during the early incubation periods (1, 2, 4, and 8 days) in both soils compared with the uncoated urea treatment (G0). This reduction reflects the ability of the starch-based coating materials to delay urea dissolution and hydrolysis, thereby controlling nitrogen release and minimizing rapid ammonia losses immediately after fertilizer application.

Among the tested formulations, treatment G3 exhibited the greatest efficiency in reducing ammonia volatilization throughout most incubation periods. In the clay loam soil, ammonia volatilization values under G3 were 0, 1.077, 3.020, 5.200, and 13.197 mg NH_3–N kg^{-1} soil after 1, 2, 4, 8, and 16 days of incubation, respectively. Similarly, in the sandy loam soil, the corresponding values were 0.012, 2.543, 4.557, 12.330, and 31.197 mg NH_3–N kg^{-1} soil. The superior performance of G3 may be attributed to the higher starch concentration in the coating layer, which likely enhanced the formation of a more stable semi-permeable barrier around the urea granules, resulting in slower nitrogen release and lower ammonia volatilization.

Despite the initial reduction in volatilization, ammonia losses from the coated fertilizer treatments increased during the longer incubation period (32 days), reaching 23.653 and 44.680 mg NH_3–N kg^{-1} soil in the clay loam and sandy loam soils, respectively. This increase may be attributed to the gradual degradation of the starch coating over time, which eventually allowed greater urea hydrolysis and nitrogen release into the soil system.

In contrast, the control treatment (G0) recorded the highest ammonia volatilization rates during the initial incubation periods in both soils. In the clay loam soil, volatilization values reached 0.278, 5.300, 44.123, and 40.180 mg NH_3–N kg^{-1} soil after 1, 2, 4, and 8 days, respectively, whereas the sandy loam soil exhibited substantially higher values of 5.550, 94.927, 128.380, and 92.777 mg NH_3–N kg^{-1} soil during the same periods. The elevated volatilization losses observed in the uncoated urea treatment are mainly associated with the rapid dissolution and hydrolysis of urea, leading to a sharp increase in ammonium concentration and localized soil pH around fertilizer granules, which enhances NH_3 formation and volatilization.

Ammonia volatilization in the control treatment declined during the later incubation periods (16 and 32 days), reaching 25.160 and 18.693 mg NH_3–N kg^{-1} soil in the clay loam soil and 64.597 and 19.957 mg NH_3–N kg^{-1} soil in the sandy loam soil, respectively. This decline may be related to the depletion of hydrolyzable urea and the progressive transformation of ammonium into other nitrogen forms through nitrification processes.

The consistently higher ammonia volatilization observed in the sandy loam soil compared with the clay loam soil throughout the incubation periods could be attributed to the lower cation exchange capacity, weaker nutrient retention, and reduced adsorption capacity of sandy soils, which favor greater nitrogen losses through volatilization.

Table 1): Interaction effect between starch-coated urea fertilizer formulations and incubation periods on ammonia volatilization (mg NH_3–N kg^{-1} soil) in (A)

Volatile ammonia (mg N-NH_3 kg^{-1} soil)								
Incubation Periods(day)							G	Soil texture
Mean	32	16	8	4	2	1		
22.306	18.693	25.160	40.180	44.123	5.400	0.278	G0	clay loam soil
16.109	47.900	33.210	8.563	5.317	1.667	0.000	G1	
11.325	38.003	18.307	6.133	4.173	1.333	0.000	G2	
7.691	23.653	13.197	5.200	3.020	1.077	0.000	G3	
RLSD G * T 0.787	32.063	22.468	15.019	14.158	2.369	0.070	Mean	
	RLSD T = 0.393						RLSD G =0.273	
67.698	19.957	64.597	92.777	128.380	94.927	5.550	G0	sandy loam soil
43.701	126.657	86.633	29.750	12.467	6.133	0.567	G1	
32.484	109.857	52.480	20.777	7.557	3.887	0.350	G2	
15.878	44.680	31.143	12.330	4.557	2.543	0.012	G3	
RLSD G * T 3.001	75.288	58.713	38.908	38.240	26.873	1.620	Mean	
	RLSD T = 1.500						RLSD G = 1.061	

clay loam soil and (B) sandy loam soil.

2. Available Nitrogen

Figure (3) demonstrates that the starch-coated urea formulations (G) had a highly significant effect on the concentration of available nitrogen in both studied soils. The results revealed that treatment G3 produced the highest available nitrogen concentrations, reaching 215.93 and 192.52 mg N kg^{-1} soil in the clay loam and sandy loam soils, respectively. In contrast, the control treatment (G0), representing uncoated urea, recorded considerably lower values of 140.09 and 101.85 mg N kg^{-1} soil in the clay loam and sandy loam soils, respectively.

The increase in available nitrogen associated with the coated fertilizer treatments may be attributed to the formation of a starch-based polymeric layer surrounding the urea granules. This coating functions as a semi-permeable barrier that slows urea dissolution and hydrolysis, thereby regulating nitrogen release in a gradual and sustained manner. As a result, nitrogen losses through ammonia volatilization and leaching are reduced, leading to improved nitrogen retention and greater availability of mineral nitrogen forms in the soil.

The superior performance of treatment G3 suggests that increasing the starch concentration enhanced the effectiveness of the coating layer in controlling nitrogen release. The slower and more synchronized release of nitrogen likely improved the retention of ammonium (NH_4^+) within the soil system and reduced rapid nitrogen transformations and losses. Furthermore, the higher available nitrogen concentrations observed in the clay loam soil compared with the sandy loam soil may be related to the greater cation exchange capacity and higher nutrient-holding capacity of the clay-rich soil, which enhance nitrogen retention and reduce nutrient mobility.

These findings are consistent with previous studies reporting that coating urea with biodegradable natural polymers, such as starch, improves nitrogen use efficiency by regulating nutrient release and minimizing nitrogen losses compared with conventional uncoated urea. Similar observations were reported by Li et al.,2025;Akhter et .,2021).

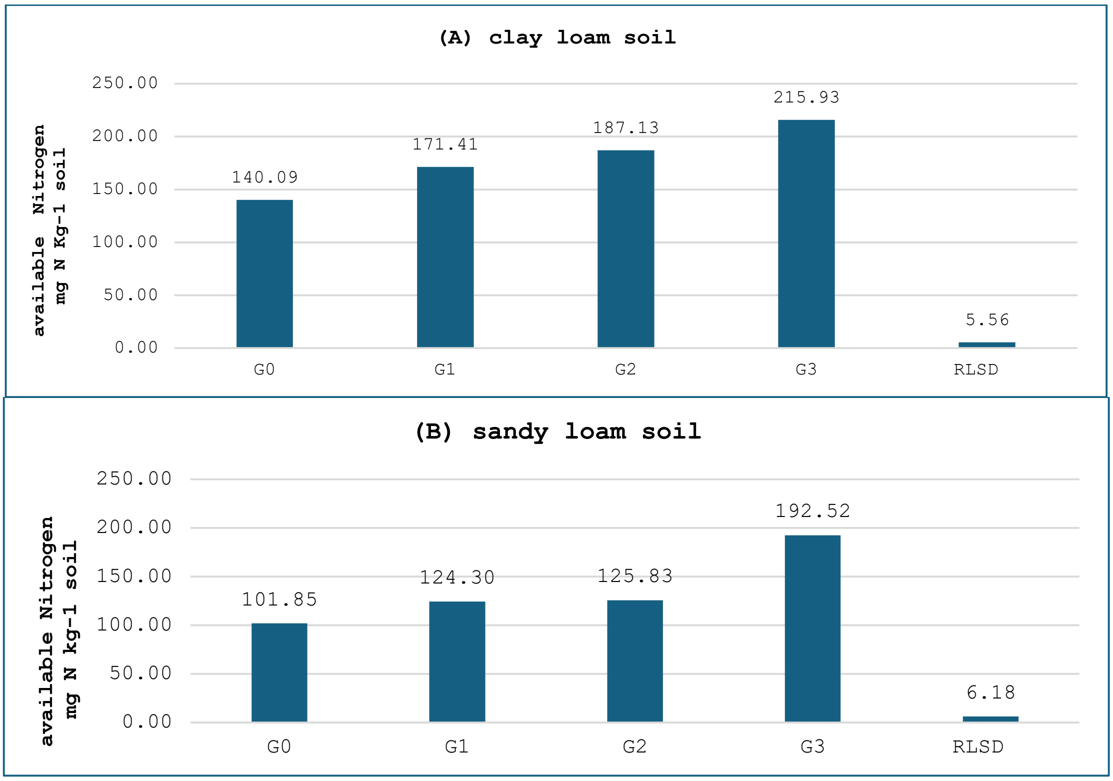

Figure 3: Effect of starch-based formulations used for coating urea fertilizer on available nitrogen in (A) clay loam soil and (B) sandy loam soil.

Figure (4) shows the effect of incubation period on available nitrogen in the two studied soils. The results revealed significant differences among incubation periods (1, 2, 4, 8, 16, and 32 days). In the clay loam soil, available nitrogen increased progressively with time, recording values of 104.72, 145.28, 164.97, 206.03, 213.44, and 237.39 mg N kg^{-1} soil, respectively. A similar trend was observed in the sandy loam soil, where available nitrogen values were 83.03, 107.64, 136.17, 143.56, 150.03, and 196.33 mg N kg^{-1} soil for the corresponding incubation periods.The continuous increase in available nitrogen over time in both soils can be attributed to the gradual release pattern of nitrogen from starch-coated urea. The coating layer likely slowed urea dissolution and hydrolysis, thereby reducing immediate nitrogen losses through ammonia volatilization and nitrate leaching during the early stages of incubation. As incubation progressed, the controlled degradation of the starch coating allowed a sustained release of urea, resulting in continuous formation of ammonium and its accumulation in the soil solution.Additionally, the progressive increase in available nitrogen reflects improved nitrogen retention within the soil matrix, particularly in the clay loam soil, which exhibited higher values than the sandy loam soil. This difference may be related to the higher cation exchange capacity and greater adsorption sites in clay-rich soils, which enhance ammonium retention and reduce nitrogen mobility.Overall, these results indicate that starch-coated urea contributes to improving nitrogen availability over time by synchronizing nitrogen release with soil processes, thereby enhancing nitrogen use efficiency under both soil conditions.

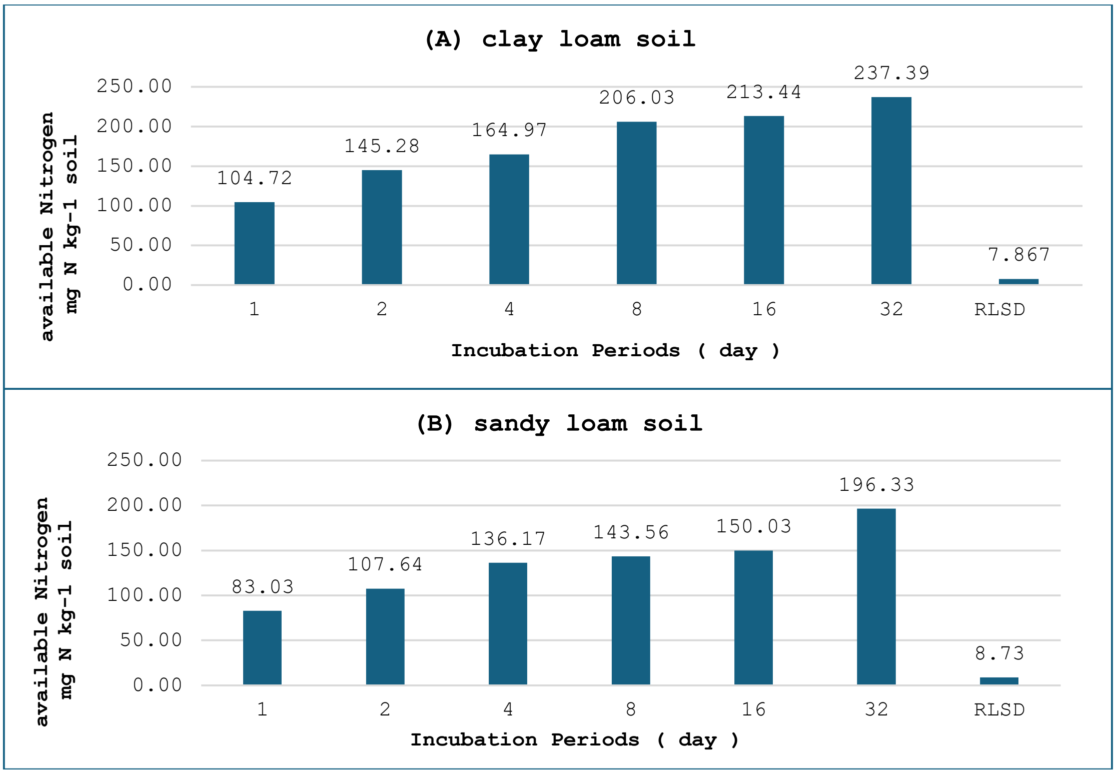

Figure 4: Effect of incubation periods on available nitrogen in (A) clay loam soil and (B) sandy loam soil.

Table 2 demonstrates significant differences in the interaction between starch-based urea coating formulations (G) and incubation periods on available nitrogen levels in the studied soils. The results indicate that treatments G1, G2, and G3 recorded the lowest available nitrogen values after one day of incubation, with values of 109.56, 104.55, and 92.56 mg N kg^{-1} soil, respectively, in the clay loam soil, and 86.67, 73.11, and 66.89 mg N kg^{-1} soil, respectively, in the sandy loam soil.Subsequently, available nitrogen increased with time, reaching the highest values after 32 days of incubation. In the clay loam soil, the values were 209.00, 273.22, and 390.67 mg N kg^{-1} soil for G1, G2, and G3, respectively, while in the sandy loam soil, they reached 219.78, 224.67, and 282.22 mg N kg^{-1} soil, respectively.The results also reveal that available nitrogen values in the clay loam soil were higher than those in the sandy loam soil. This can be attributed to the greater capacity of clay loam soil to retain ammonium ions for longer periods and reduce losses through volatilization and leaching.In contrast, the control treatment (G0) recorded the highest available nitrogen values during the early incubation periods (1, 2, and 4 days), with values of 112.22, 156.00, and 184.00 mg N kg^{-1} soil, respectively, in the clay loam soil. Thereafter, the available nitrogen decreased, reaching 76.67 mg N kg^{-1} soil after 32 days of incubation.Similarly, in the sandy loam soil, the control treatment recorded the highest available nitrogen values after 1 and 2 days of incubation, at 105.45 and 126.33 mg N kg^{-1} soil, respectively, followed by a decline to 58.67 mg N kg^{-1} soil after 32 days of incubation.

Table (2): Effect of the interaction between starch-based urea coating formulations and incubation periods on available nitrogen in (A) clay loam soil and (B) sandy loam soil.

available Nitrogen mg N kg^{-1} soil								
Incubation Periods(day)							G	Soil texture
Mean	32	16	8	4	2	1		
140.09	76.67	142.22	169.22	184.22	156.00	112.22	G0	clay loam soil
171.41	209.00	192.89	188.89	165.44	162.67	109.56	G1	
187.13	273.22	226.67	192.00	177.33	149.00	104.55	G2	
215.93	390.67	292.00	274.00	132.89	113.44	92.56	G3	
RLSD G*T 15.73	237.39	213.44	206.03	164.97	145.28	104.72	Mean	
	RLSD T = 7.867						G = 5.563 RLSD	
101.85	58.67	94.44	108.44	117.78	126.33	105.45	G0	sandy loam soil
124.30	219.78	129.56	116.22	106.89	86.67	86.67	G1	
125.83	224.67	136.56	124.00	108.44	88.22	73.11	G2	
192.52	282.22	239.55	225.56	211.56	129.33	66.89	G3	
RLSD G*T 17.467	196.33	150.03	143.56	136.17	107.64	83.03	Mean	
	RLSD T = 8.733						G =6.175 RLSD	

Conclusions:

The results of this study demonstrate the potential of starch as an effective coating material for urea fertilizer to develop a slow-release nitrogen source. The starch-coated urea significantly reduced nitrogen losses through ammonia volatilization while improving soil nitrogen availability under both studied soil types.

Among the tested formulations, the 2% starch coating (G3) exhibited the most efficient performance across all incubation periods. It consistently achieved the greatest reduction in ammonia volatilization and the highest concentrations of available nitrogen in comparison with other treatments and the uncoated urea (control). These improvements were observed in both clay loam and sandy loam soils, indicating the broad applicability of this coating approach.

Overall, the findings highlight that starch-based coatings can enhance nitrogen use efficiency by regulating nitrogen release, minimizing environmental nitrogen losses, and improving soil nitrogen retention.

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