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Comparative study of nitrogen release from compound fertilizers in silty loam and sandy loam soils

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Abstract Most Thai farmers cultivate field crops on coarse-textured soils that are inherently low in fertility and highly susceptible to nutrient leaching, resulting in low nitrogen use efficiency. The results indicated that the Hin Kong (Hk) soil series exhibited greater ammonium-N and urea-N release than the Chanthuk (Cu) soil series, reaching 624 and 54.4 mg N kg^{-1}, respectively. In contrast, the Cu soil series showed higher nitrate-N release, with 364 mg N kg^{-1}. Among the fertilizer formulations, 15-7-18 produced the highest ammonium-N, urea-N, and available nitrogen release, although these values were not significantly different from those of the 15-5-20 formulation. Conversely, the 15-5-20 formulation generated the highest nitrate-N release (536 mg N kg^{-1}), but its ammonium-N and available N release remained statistically comparable to the 15-7-18 formulation. The 15-7-18 fertilizer consistently promoted early-stage ammonium accumulation, reflecting its relatively ammonium-based composition, whereas the 15-5-20 formulation favoured rapid nitrate build-up in the Cu soil. The 16-8-8 formulation exhibited a more gradual release pattern in both soils, maintaining available N at later stages and suggesting slower transformation and solubilization rates compared with the other formulations. These findings indicate that nitrogen release dynamics are jointly governed by fertilizer formulation and soil properties—including not only soil texture but also organic matter content, cation exchange capacity, and soil acidity. Temporal patterns further revealed an initial rapid nitrogen release followed by stabilization, reflecting the combined effects of soil physical structure, chemical characteristics, microbial activity, and fertilizer traits. Selecting an appropriate fertilizer formulation is therefore essential for improving nitrogen use efficiency in coarse-textured soils.

Keywords: Nitrogen accumulation, Nitrogen release, Compound fertilizers, Leaching

Introduction

In 2023, Thailand had approximately 23.63 million hectares of agricultural land, of which 4.75 million hectares were dedicated to field crops (Office of Agricultural Economics, 2025). Most of these crops are grown on coarse-

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textured soil type e.g. sandy loam and silty loam soils. The low fertility of coarse-textured soil is therefore a critical constraint to crop productivity (Brady and Weil, 2017). Those soils typically contain insufficient levels of organic matter, nitrogen (N), and phosphorus (P) to support optimal plant growth, which significantly reduces crop yields (Saentho *et al.,* 2022). Continuous cultivation in the same areas over extended periods can further accelerate soil degradation. To address this, the application of both fertilizers, chemical and organic fertilizer, is recommended to improve soil fertility and enhance plant growth (Vityakon *et al*, 2000). However, organic fertilizers alone are often inadequate. The use of chemical fertilizers is therefore an essential practice to increase yields. Nevertheless, excessive application of chemical fertilizers can adversely affect nutrients imbalance; thus, their use should be carefully managed to ensure appropriate application rates (Zhu *et al*., 2005). Among the primary nutrients, nitrogen is frequently deficient in coarse-textured soils and is highly susceptible to losses. Therefore, the application of nitrogen fertilizers is considered essential.

Nitrogen is a key nutrient limiting crop productivity, yet most soils lack adequate available N. Intensive cropping systems rely heavily on N fertilizers to improve yield and quality (Bai *et al*., 2022; Li *et al*., 2022), but recovery efficiency is low, resulting in environmental losses such as via ammonia volatilization, nitrate leaching, and denitrification, releasing greenhouse gases such as N_2O (Zhang *et al*., 2013; Robertson *et al*., 2000; Yu and Shi, 2015). These processes are strongly affected by soil pH, temperature, moisture, texture, microbial activity, and fertilizer management practices (Motasim *et al*., 2024). Soil texture significantly influences N cycling by regulating aggregation, aeration, and water dynamics, which affect N transformation, retention, and leaching (Bechtold and Naiman, 2006; Yao *et al*., 2019). Nitrogen availability is supplied mainly in the form of urea, ammonium-N (NH_4^+), or nitrate-N (NO_3^-) which differing in soil transformation, plant uptake, and assimilation pathways (Bloom, 2015). Urea-N, the most applied form, rapidly hydrolyzes to NH_4^+ and is quickly nitrified to NO_3^-, making the balance and transformation among N forms critical for availability, leaching, and retention (Hessini *et al*., 2019). Advances in the production technology of compound fertilizers containing ammonium and nitrate have led to practices such as blending nitrogen sources, ammonium nitrate, or urea, within a single formula, as well as the applying various coatings that extend availability of nitrogen, especially in the coarse-textured soils.

The Northeastern region of Thailand, which contains the largest area of field crop cultivation (~2 million hectares), is dominated by sandy and sandy loam soils (Office of Agricultural Economics, 2025). Major crops include cassava, rice, and maize for animal feed. The Hin Kong (Hk) soil series, a sandy loam, is primarily used for cassava and other field crops but is limited by compaction and low fertility. The Chanthuk (Cu) soil series, a deep sandy soil, is also widely used for cassava and sugarcane (Department of Land Development, 2015), representing typical field crop soils in the region.

Farmers in this region largely rely on rainfed cultivation, and together with limited irrigation and coarse, saline soils, this results in low and highly variable crop yields (Lacombe *et al*., 2017; Khadka *et al*., 2024). Droughts, irregular rainfall, and occasional heavy downpours further create unfavourable conditions for crop growth. The low water-holding capacity of soils limits moisture availability for fertilizer nutrient dissolution, often leading farmers to perceive fertilizers as ineffective. In 2021, the region received an average annual rainfall of 1,464.3 mm, which was sufficient for the water requirements of field crops (Meteorological Department, 2022). Those conditions affect the dissolution and transformation of nitrogen fertilizers in the soil.

The release dynamics of nitrogen from compound fertilizers is therefore essential for improving nitrogen use efficiency. This study aimed to compare the release of ammonium, urea, nitrate, and available nitrogen from three compound fertilizer formulations in the Hin Kong and Chanthuk soil series using column leaching experiments.

Materials and methods

Soil sampling locations

A silty loam soil, Hin Kong (Hk) soil series, was collected from Ban Pa Kluai, Kut Nok Plao Subdistrict, Mueang Saraburi District, Saraburi Province (Figure 1), within a cassava cultivation area. A sandy loam soil, Chanthuk (Cu) soilseries, was collected from Ban Nong Sarai, Nong Sarai Subdistrict, Pak Chong District, Nakhon Ratchasima Province, within a grape cultivation area.

Soil sampling

Soil samples were collected using both disturbed and undisturbed techniques at two depths, 0–15 cm and 15–30 cm, corresponding to the crop root zone. Disturbed samples were obtained through complete random composite sampling, which were subsequently packed into soil columns and used for the analysis of soil properties prior to the experiment. Undisturbed samples were collected using a soil core to determine bulk density.

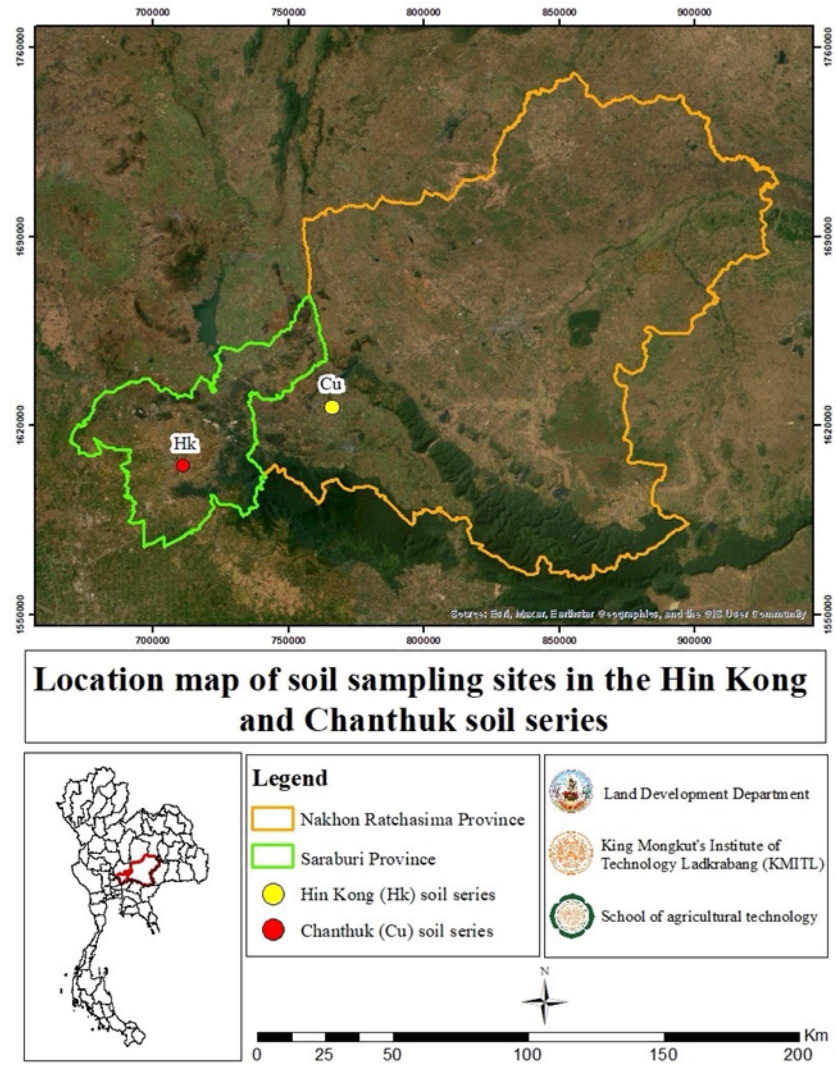

Figure 1. Location map of soil sampling sites in the Hin Kong and Chanthuk soil series.

Method of soil analysis

The initial soil properties of the experimental soil are summarized in Table 1. Soil pH was measured in a 1:1 soil-to-water suspension using a pH meter (FAO, 2021a). Electrical conductivity (EC) was determined in a 1:5 soil-to-water ratio using a Conductivity meter (FAO, 2021b). Soil organic matter was measured using the wet oxidation method (FAO, 2019). Available phosphorus was extracted using the Bray II method FAO (2021c). Exchangeable potassium

(K), exchangeable calcium (Ca), exchangeable magnesium (Mg) and exchangeable sodium (Na) were extracted by 1*M* ammonium acetate, pH 7 (FAO, 2022). Exchangeable cation were measured by the coupled plasma optical emission spectrometer (ICP-OES). Cation exchange capacity (CEC) was determined by extracting soils three times with 1*N* ammonium acetate (pH 7.0) (IITA, 1979). Bulk density was determined using the FAO (2023) and soil texture was analyzed using the pipette method (Gee and Bauder, 1986).

Table 1. Soil properties of Hin Kong (Hk) and Chanthuk (Cu) soil series

Parameter	**Hk soil series**		**Cu soil series**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**
Soil pH (1:1)	4.94	4.91	6.21	6.31
Electrical conductivity (1:5) (mS cm^{-1})	0.02	0.01	0.04	0.04
Soil organic matter (%)	1.46	1.39	2.41	1.99
Available phosphorus (mg kg^{-1})	2.38	2.92	320	281
Exchangeable potassium (mg kg-1)	62.7	52.9	124	110
Exchangeable sodium (mg kg^{-1})	11.8	11.5	10.7	5.67
Exchangeable calcium (mg kg^{-1})	457	407	1,321	1,214
Exchangeable magnesium (mg kg^{-1})	41.8	34.2	189	177
Cation exchange capacity (cmol(+) kg^{-1})	5.70	5.54	9.65	8.39
Bulk density (kg cm^{-3})	1.59	1.54	2.07	2.06
Sand (%)	23.5	25.8	73.2	73.3
Silt (%)	59.9	59.4	13.9	12.5
Clay (%)	16.3	14.8	12.9	14.2
Texture	silty loam	silty loam	sandy loam	sandy loam

Soil column leaching experiment

The experiment was arranged in a 2 × 4 factorial with two factors. Factor A, two soil series, including Hk (silty loam) and Cu (sandy soil), and factor B, fertilizer formulas, including no fertilizer, 15-5-20, 16-8-8, and 15-7-18. The experiment comprised eight treatments with two replications and was conducted over a 12 weeks.

Preparing soil columns

The columns were 40 cm in height and 7.62 cm in diameter, with a total volume of 1,360 cm^3 and were packed as ilustrator in Figure 2. The bottom of the column was covered with a synthetic fiber, white nylon net, and a sponge. Subsoil from the 15–30 cm depth was packed first, followed by the 0–15 cm topsoil layer. The soil was packed to match the bulk density measured in the field (Table 1). Fertilizer was incorporated at a depth of 3 cm in the topsoil layer, after which the column was covered with asponge. In each treatment, 1,000 mg N kg^{-1} of nitrogen was applied.

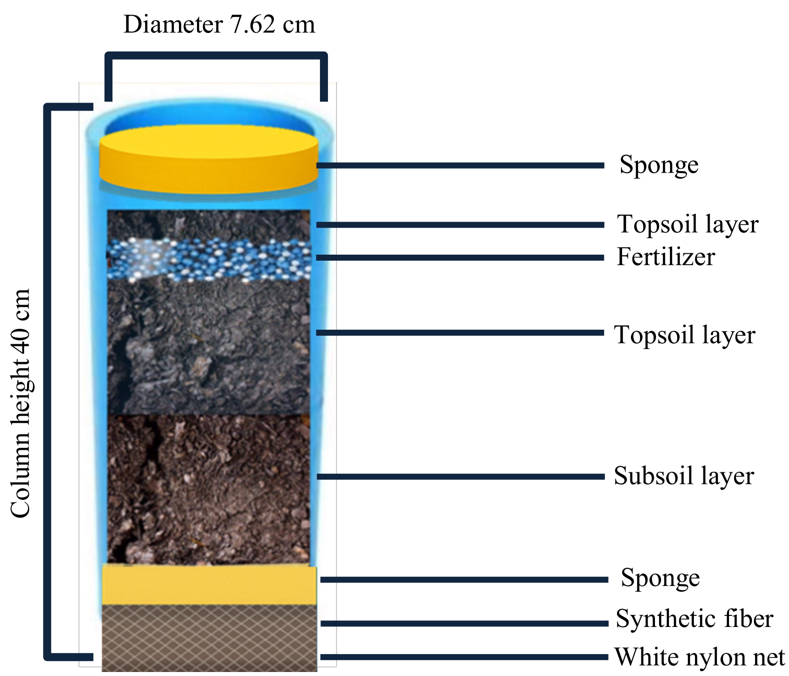

Figure 2. Soil column arrangement.

Leaching procedure

Each soil column was irrigated weekly with 278 mL of water, equivalent to the average annual rainfall in the Northeastern region, for a total of 12 applications. The amount of water applied was calculated using the following equation:

$$\text{Rainfall stimulation } (m^3) = \text{Area } (m^2) \times \text{Average rainfall } (m\ year^{-1})$$

where area (m^2) refers to the surface area of the soil column, and average rainfall represents the mean weekly rainfall in the Northeastern region (Meteorological Department, 2022). Leachate from each column was collected and subsequently analyzed in the laboratory to determine the amounts of ammonium-N, nitrate-N, and urea-N leached through the soil column.

Analysis of ammonium, nitrate, and urea

Urea-N concentration in leachate was determined using the colorimetric method, and absorbance was measured with a spectrophotometer at a wavelength of 520 nm (Langenfeld *et al*., 2021). Ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N) were determined by distillation method (FAO, 2021d). The accumulation of ammonium, nitrate, and urea was calculated as the cumulative release of these nitrogen forms from week 1 to week 12, whereas available nitrogen was calculated asthe sum of ammonium, nitrate, and urea released each week.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using statistical software. Mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at the 0.05 probability level ($P \leq 0.05$).

Results

Cumulative release of ammonium-N

Ammonium-N accumulation from week 1 to week 12 showed distinct differences between soil series and fertilizer formulations (Figure 3). In the Hk soil series, the 15-7-18 formulation resulted in the highest ammonium-N accumulation, followed by 16-8-8 and 15-5-20, respectively. All three formulations exhibited a rapid increase during weeks 1–4, after which accumulation tended to stabilize from weeks 5–12. In contrast, in the Cu soil series, the 15-5-20 formulation produced the greatest ammonium-N accumulation, followed by 15-7-18 and 16-8-8 (Figure 4). A sharp increase in ammonium-N was observed for the 15-5-20 and 15-7-18 formulations during weeks 1–4, whereas the 16-8-8 formulation showed only a slight increase before reaching stability. No ammonium-N accumulation was observed in the unfertilized treatments of either soil series.

Cumulative release of nitrate-N

The 15-5-20 fertilizer resulted in the highest nitrate-N accumulation in both the Hk and Cu soil series (Figure 5). In the Hk soil series, nitrate-N accumulation in the 15-7-18, 16-8-8, and unfertilized treatments increased gradually throughout weeks 1–12. By contrast, the 15-5-20 formulation exhibited a rapid increase during weeks 1–4, followed by a steady rise from weeks 5–12. In the Cu soil series, nitrate-N accumulation under the 15-5-20 treatment increased gradually from weeks 1–11 and then stabilized in the final week (Figure 6). This pattern was followed, in decreasing order, by the 15-7-18, 16-8-8, and unfertilized treatments.

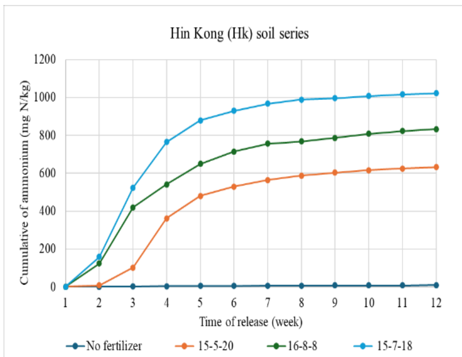

Figure 3. Ammonium-N accumulation in the Hk soil series

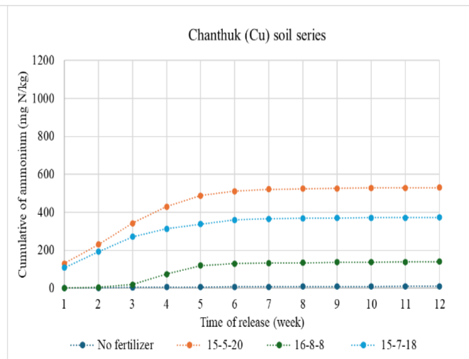

Figure 4. Ammonium-N accumulation in the Cu soil series

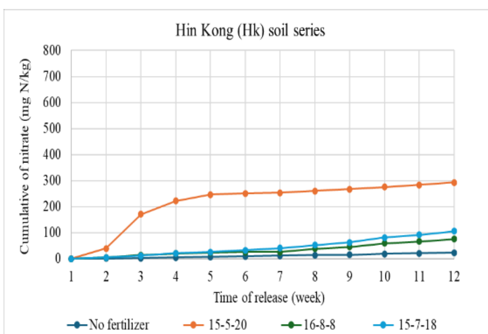

Figure 5. Nitrate-N accumulation in the Hk soil series over a 12-week

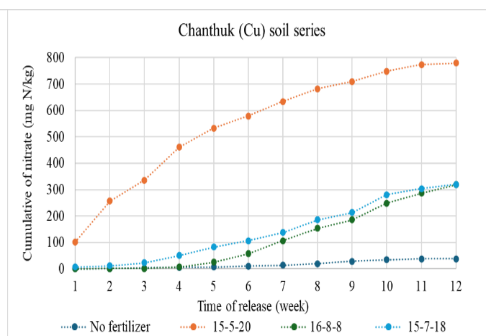

Figure 6. Nitrate-N accumulation in the Cu soil series over a 12-week

Cumulative release of urea-N

In the Hk soil series, urea-N accumulation began to increase after the fourth week and continued rising until the final week (Figure 7). Among the fertilizer treatments, the 15-7-18 formulation resulted in the highest urea-N accumulation, followed by 16-8-8, 15-5-20, and the no-fertilizer, respectively. In contrast, in the Cu soil series, urea-N accumulation gradually increased during weeks 1–4 and remained stable after week 5 (Figure 8). The highest urea-N accumulation was observed under the 15-5-20 treatment, followed by 15-7-18, 16-8-8, and the no-fertilizer, respectively.

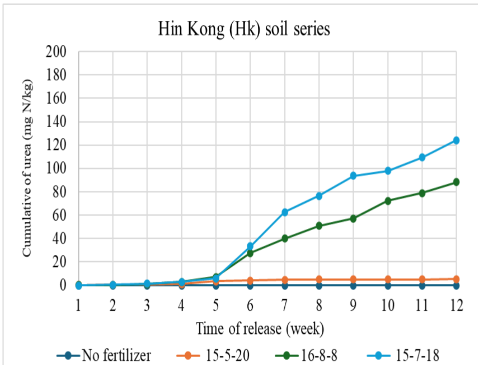

Figure 7. Urea-N accumulation in the Hk soil series over a 12-week

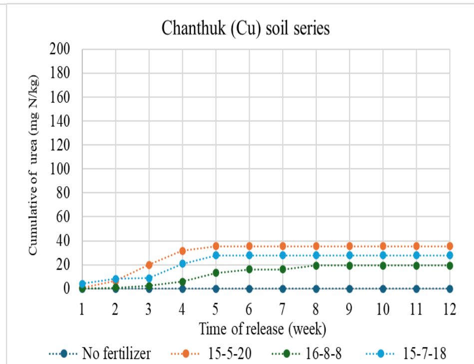

Figure 8. Urea-N accumulation in the Cu soil series over a 12-week

Cumulative release of available nitrogen (NH_4^+, NO_3^- and urea)

In the Hk soil series, available N increased rapidly from weeks 1 to 6 and then rose slightly thereafter (Figure 9). Among the fertilizer treatments, the 15-7-18 formulation resulted in the highest accumulation of available N, whereas the 16-8-8 and 15-5-20 formulations showed comparable levels, and the lowest values were observed in the no-fertilizer. In the Cu soil series, the 15-5-20 treatment recorded the highest available N (Figure 10), with a rapid increase during weeks 1–5 followed by a slight increase until week 12, while the 15-7-18, 16-8-8, and no-fertilizer, respectively.

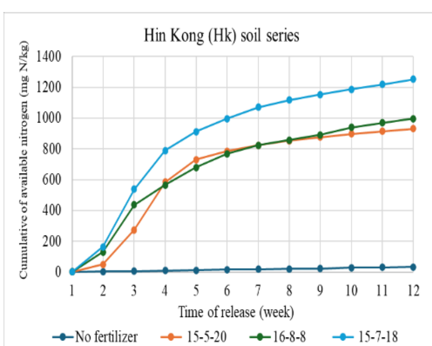

Figure 9. Available-N accumulation in the Hk soil series

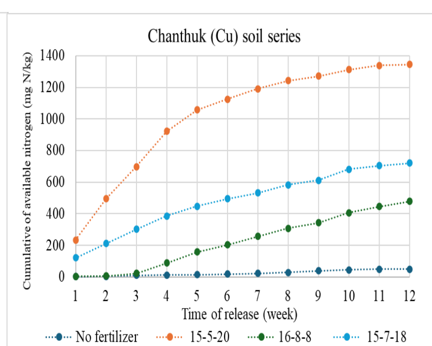

Figure 10. Available-N accumulation in the Cu soil series over a 12-week

At week 12, the Hk soil series exhibited significantly higher accumulations of NH_4^+ (624 mg N kg^{-1}) and urea (54.4 mg N kg^{-1}) compared with the Cu soil series (Table 2). In contrast, NO_3^- accumulation was significantly greater in the Cu soil series (364 mg N kg^{-1}) than in the Hk soil series. The available N content did not differ significantly between the two soil series; however, the Hk soil series tended to have slightly higher levels than the Cu soil series. Among the fertilizer treatments, the 15-7-18 formulation resulted in significantly greater accumulations of NH_4^+ and urea compared with the other treatments, although these values were not statistically different from those of the 15-5-20 formulation. In terms of NO_3^- and available N, the 15-5-20 treatment produced significantly higher accumulations than the other treatments, whereas available N in the 15-7-18 treatment did not differ significantly.

Table 2. Effects of cumulative ammonium-N, nitrate-N, urea-N and available nitrogen at week 12

Factor	**Cumulative at week 12 (mg N/kg)**			
	NH_4^+	**NO_3^-**	**Urea**	**Available N**
Soil series (S)				
Hk	624 A	125 B	54.4 A	804
Cu	264 B	364 A	20.7 B	649
Fertilizer formula (F)				
No fertilizer	9.92 c	31.3 c	-	41.3 c
15-5-20	582 ab	536 a	20.4 c	1,138 a
16-8-8	487 b	197 b	53.8 b	738 b
15-7-18	698 a	213 b	76.1 a	987 a
F-test				
S	**	**	**	ns
F	**	**	**	**
S x F	**	**	**	ns
CV (%)	37.11	30.82	37.87	30.07

** indicates a significant difference at $p \leq 0.01$, * indicates a significant difference at $p \leq 0.05$, ns indicates no significant difference at $p \leq 0.05$, and values followed by the same uppercase or lowercase letter within a column for each factor are not significantly different.

Discussion

The contrasting patterns of release nitrogen accumulation between the Hk and Cu soil series can be attributed primarily to differences in soil texture and organic matter content, rather than CEC alone. The Hk soil series, a silty loam with high silt content, exhibited a lower CEC than the Cu soil series, a sandy loam with high sand content but higher CEC. The greater CEC observed in the Cu soil is likely associated with its comparatively higher organic matter content. Due to its lower CEC, Hk accumulated greater release of ammonium-N during the early weeks , owing to its finer texture and higher silt content, which created smaller pores as well as limited oxygen diffusion that constrained nitrification rates and provided microsites favorable for NH_4^+ retention (Kabala *et al*., 2017; Brady and Weil, 2017; Havlin *et al*., 2014). The high accumulation of nitrate-N release in the Cu soil indicates that nitrification occurred, likely due to the high aeration of the sandy soil, and this corresponded to the continuous increase in nitrate release observed after week 4, whereas ammonium release had reached a steady state. The coarse texture of Cu soils (>70% sand) promoted higher porosity, rapid water movement, and oxygen diffusion, thereby accelerating nitrification and nitrate accumulation while reducing ammonium persistence (Zhao *et al*., 2022).

Furthermore, higher organic matter in Cu soil series likely enhanced microbial immobilization and protected ammonium against rapid transformation. In the Hk soil, urea first appeared in the leachate in week 5, whereas in the Cu soil, it was detected earlier, in week 3. This difference may be attributed to the coarser texture and greater aeration of the Cu soil, which likely facilitated faster urea dissolution and leaching. By contrast, the finer texture of the Hk soil may have delayed urea movement through the soil column by enhancing water retention and reducing percolation rates. Furthermore, urease activity is optimal at pH 5.5-8.5 (Motasim *et al*., 2024), whereas the pH of the Hk soil was 4.94, which may have slowed the hydrolysis of urea. Overall, nitrogen release was greater in the Hk soil than in the Cu soil, even though the latter is sandy in texture. This outcome suggests that factors other than soil texture, such as organic matter content, cation exchange capacity, or pH conditions influencing nitrogen transformations, may have contributed to the higher nitrogen release observed in the Hk soil.

The type of fertilizer applied further influenced nitrogen dynamics in both soils. The 15-7-18 formulation consistently promoted the highest ammonium release in the early stages, reflecting its relatively ammonium-based composition. By contrast, the 15-5-20 treatment favored rapid nitrate build-up in Cu soils, likely due to its high proportion of more soluble nitrogen forms, including urea, which was quickly hydrolyzed and nitrified under favorable soil pH conditions such as those the Cu soil. The 16-8-8 formulation exhibited a more gradual release pattern in both soils, maintaining available N at later stages which suggested reducing transformation rates and slower solubilization compared with the other treatments. These findings highlight that fertilizer composition interacts with soil properties to shape the timing and form of nitrogen availability (Norton and Ouyang, 2019; Wang *et al*., 2020).

Temporal patterns further illustrate the interaction between soil texture and fertilizer formulations. During weeks 1–4, rapid increases in nitrogen availability were observed, driven by fertilizer dissolution and active microbial nitrification (Kuzyakov and Blagodatskaya, 2015), especially in sandy Cu soils series. From weeks 5–12, nitrogen accumulation stabilized or continuous increased depending on soil type and fertilizer formula. In Hk soils series, finer pores and moderated aeration constrained nitrification, leading to steadier but lower nitrate accumulation. In Cu soils, fast mineralization and higher oxygen diffusion promoted higher nitrate levels. Notably, 15-7-18 initially produced the greatest available N in Hk soils series, but 16-8-8 surpassed it after week 7, reflecting a more balanced supply of ammonium forms and transformation reaction. In Cu soils series, early peaks under 15-7-18 gave way to more sustained availability under 16-8-8. Interestingly, unfertilized Cu soils series maintained relatively high available N in later weeks, likely due to accelerated mineralization of soil organic matter under sandy, well-aerated conditions (Compton *et al*., 2019; Swify *et al*., 2023; Motasim *et al*., 2024).

This study demonstrated that nitrogen accumulation in soils is strongly influenced by both intrinsic soil properties and fertilizer formulations. Soil texture, silt and sand content, organic matter and soil pH play key roles in regulating ammonium retention, nitrate formation and urea hydrolysis. Fertilizer composition further modulates nitrogen dynamics, with ammonium-based formulas promoting early NH_4^+ release, highly soluble formulations favouring rapid NO_3^- build-up, and balanced formulations providing more sustained N availability over time. Temporal analysis highlighted that initial rapid nitrogen release is followed by stabilization, reflecting interactions between soil physical structure, chemical properties, microbial activity, and fertilizer characteristics. These findings underscore the importance of integrating soil properties and fertilizer strategies to optimize nitrogen management in agricultural systems.

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Conflict of interest

The authors declare no conflict of interest.

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