Source and rate of nitrogen as influenced its mineralization during the growth stages of rice in a wheat-mungbean-rice cropping system

M.M.H. Bhuiyan[1], G.K.M.M. Rahman[2], A.J.M.S. Karim[2], S. Islam[2], M. Haque[3], A. Gaber[4], M. Rahman[5] and A. Hossain[5,*]

[1] Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Cumilla 3500, Bangladesh
[2] Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur 1706, Bangladesh
[3] Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur 1706, Bangladesh
[4] Department of Biology, College of Science, Taif University, Taif 21944, Saudi Arabia
[5] Division of Soil Science, Bangladesh Wheat and Maize Research Institute, Dinajpur 5200, Bangladesh
* Corresponding author: akbarhossainwrc@gmail.com
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ABSTRACT

Background and Objectives: The crops' mineralization and uptake of nitrogen (N) are important during the crop growth stage, leading to improved crop productivity. However, the source and dose of N are also important since these are linked to the N use efficiency under field conditions. Considering the important aspect, a field-based incubation study was conducted in a wheat-mungbean-transplanted Aman (T. Aman) rice cropping system to determine the effects of sources and doses of N on N mineralization in wetland rice cultivation systems.

Methodology: The experiment was piloted in a split-plot design, where four sources of N, such as urea, neem-coated urea (NCU), di-ammonium phosphate (DAP), and urea super granule (USG), were assigned in the main plots, and four levels of nitrogen, i.e., 0, 30, 60, and 90 kg ha^{-1} were assigned in the subplots replicated three times.

Main Results: The highest NH_4^+-N concentration was recorded in USG at the harvesting time of T. Aman rice, followed by NCU, urea, and DAP. NO_3^--N concentration was the highest in DAP, followed by urea, NCU, and USG. However, the NH_4^+-N and NO_3^--N concentrations progressively increased with the dose of N and the highest concentration was noted in 90 kg N ha^{-1} for all N fertilizer sources.

Conclusions: The information from the current study will be helpful for proper N management in the intensive rice-wheat and rice-maize cropping systems in South Asia.

Keywords: Nitrogen, mineralization, neem-coated urea, DAP, NH_4^+-N, NO_3^--N

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INTRODUCTION

Rice (*Oryza sativa*) is the staple food for nearly half of the world's population and around 150 million people in Bangladesh (BBS, 2018). Bangladesh has three rice-growing seasons, and Aman rice, following Boro rice in total production, dominates area coverage as the main crop. Aman rice, comprising 49.1% of three rice crops, maintains a stable area (BBS, 2016). Nutrient management is crucial for its high-yield cultivation.

Nitrogen (N) is a key element for plant growth. Optimizing crop yield requires effective N management, especially in multiple cropping systems like wheat-mungbean-rice rotations. The relationships between N availability, sources, and plant growth stages in rice cultivation within a wheat-mungbean-rice cropping system require careful investigation. Previous studies have studied the effect of N on rice yields, considering features such as slow-release fertilizer usage, varied N sources in crop rotations, and N mineralization in flooded soil are unusual. The study conducted by Noellsch *et al*. (2009) found that treatments involving slow-released anhydrous ammonia and polymer-coated urea resulted in higher N uptake, N recovery efficiency, and grain yield. However, information on the precise effects of different N sources and rates on mineralization in the stages of rice growth at different phases in a wheat-mungbean-rice cropping system is still lacking.

Nitrogen mineralization is a vital process within the soil N cycle, where mineralization and immobilization occur simultaneously. Several factors influence nutrient mineralization from applied fertilizers, including temperature, soil moisture, attributes, manure qualities, and microbial activity (Liu *et al*., 2015). In Bangladesh agriculture, urea is the major nitrogenous fertilizer, undergoing hydrolysis in water to release available N for plant uptake. Nitrate (NO_3^--N) and ammonium (NH_4^+-N) are the available forms of nitrogen for plants, with both being essential for crop development (Shan *et al.*, 2015; Hanly *et al*., 2017), although NO_3^--N is susceptible to leaching losses due to its high mobility in soil.

Slow-release nitrogenous fertilizers may offer enhanced efficiency in N management, ensuring a sustained N supply throughout the crop's growth. Zareabyaneh and Bayatvarkeshi (2015) investigated nitrate leaching from various slow-release fertilizers. Results indicated that nano-nitrate chelate, sulfur-coated nano-nitrogen chelate, and sulfur-coated urea reduced leaching by 35.72, 41.56, and 9.94%, respectively, compared to urea application.

Nitrogen mineralization in wetland soil differs significantly from dryland soil behavior, with organic matter decomposition requiring less N under anaerobic conditions in wet soils (Savant and De Datta, 1982). Anggria *et al*. (2012) experimented with varied organic matter, examining N mineralization in flooded soil. They observed maximum N mineralization, ranging from 4.33 to 7.61 mg NO_3^--N kg^{-1}, on day 8. Studies on N mineralization in sub-tropical wetland rice soils are limited (Manguiat *et al*., 1996), emphasizing the need for further research in this area. The diverse properties of available inorganic nitrogenous fertilizers play a role in N mineralization, highlighting the importance of considering fertilizer characteristics for effective N management (Suganya *et al*., 2009).

In order to fill this knowledge gap, this study evaluates the intricate interactions between N sources, rates of application, and the subsequent mineralization processes in submerged rice throughout its growth stages. Through this approach, this research intends to find various points of view that could help improve N management strategies in the specific conditions of the wheat, mungbean, and rice cropping systems. The effect of N fertilizer management with different N sources and doses on mineralization on rice grown under wheat-mungbean-T. Aman cropping system in field conditions has not been reported systemically. Therefore, such studies under the stated cropping system are crucial because N availability to plants departs with N sources for their mobility system in the soil solution. Considering this, the present study was designed to determine the effects of different fertilizer N sources and doses on N mineralization in wetland T. Aman rice grown under wheat-mungbean-T. Aman cropping system.

MATERIALS AND METHODS

Study Area and Soil Characteristics

The field experiment was conducted at the experimental field of the Department of Soil Science of Bangabandhu Shiekh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh. The site is located at 24°02'16.3" N latitude and 90°23'52.6" E longitude with an elevation of 8.2 m from sea level. The study area was under the agroecological zone of the Madhupur Tract (AEZ 28). The soil of the experimental site belongs to the Salna series. It had been classified as Shallow Red Brown Terrace soil in Bangladesh under the soil classification system. It was acidic and was characterized by heavy clay within 50 cm from the surface. Selected characteristics of the soils are presented in Table 1. The soils were sampled from a 0–20 cm depth, air-dried, sieved through a 2 mm mesh, and analyzed before the initiation of the experiment. Initial soil analysis results revealed that the physical properties of the soil were poor because it had low organic matter content (0.52 to 0.62%) with high bulk density (1.42 g cm^{-3}).

Table 1 Physicochemical properties of experimental soils

Properties	Value	Analytical methods
Soil texture	Clay loam	Hydrometer method (Bouyoucos,1962)
pH	5.26	Soil : water = 1 : 2.5
Organic carbon (%)	0.61	Walkley and Black’s wet oxidation method (Jackson, 1973)
Total N (%)	0.115	Kjeldhal method (Bremner, 1960)
Available		
EC (mS)	0.036	Soil : water = 1 : 5
CEC (meq/100 g soil)	8.6	Ammonium acetate extraction method (Baker and Suhr, 1982)
Available P (µg g^{-1})	6.9	Bray and Kurtz (1945) method
Exchangeable K (cmol kg^{-1} soil)	1.67	Ammonium acetate extraction method (Baker and Suhr, 1982)
Available Ca (cmol kg^{-1})	0.0135	N NH_4OAc extraction method (Pleysier and Juo,1980)
Available Mg (cmol kg^{-1})	0.0122	N NH_4OAc extraction method (Pleysier and Juo,1980)
Available S (µg g^{-1})	29.9	Calcium dihydrogen phosphate extraction method (Karltun,1994)
Available Cu (µg g^{-1})	0.09	DTPA extraction method (Lindsay and Norvell, 1978)
Available Mn (µg g^{-1})	0.47	DTPA extraction method (Lindsay and Norvell, 1978)
Available Zn (µg g^{-1})	3.8	DTPA extraction method (Lindsay and Norvell, 1978)

Note: EC = electrical conductivity, CEC = cation exchange capacity.

Experiment Setup, Treatments, and Design

The experiment was conducted between July 2018 and November 2018 in the T. Aman rice season, and the variety BRRI dhan-75 was used as a test crop variety. A sufficient amount of rainfall occurred during the experimentation, but after October 2018, rainfall was scattered and distributed. The average temperature ranged from 25 to 33°C. Before initiation of the experiment, previous crop residue (mungbean residue) was incorporated throughout the plot and kept for 20 days for decomposition. The experiment was laid out in a split-plot design with two factors, taking N sources as the main plot factor and N doses as the subplot factor. The experiment comprised 16 treatments with 3 replications. The main plot treatments were urea, neem-coated urea (NCU), di-ammonium phosphate (DAP), and urea super granule (USG), and subplot treatments were 0, 30, 60, and 90 kg N ha^{-1}. The land was prepared using a power tiller after 20 days of incorporation of mungbean residue—twenty-five days old

T. Aman rice seedlings were transplanted in the main field on 25 July 2018. A 20 cm × 15 cm spacing was maintained for good management practices. On each hill, two to three healthy seedlings were transplanted. Intercultural operations and irrigation water application management were done properly.

Soil Sampling and Analysis

Collected soil samples from 0 to 15 cm depth at harvest were taken into the laboratory and prepared for N (total N, NH_4^+-N, and NO_3^--N) analysis. The micro-Kjeldahl digestion method analyzed total soil N content (Jones and Bradshaw, 1989). Digestion was done first in this process, followed by distillation and titration. Representative soil samples were taken in a digestion tube and digested in a block digester. Then, digested samples were distilled in a Kjeldahl distillation unit (Model No UDK 129, VELP Scientifica, Germany), and the distillate was titrated against 0.02 N H_2SO_4 as described by Bremner and Mulvaney (1982). The concentration of total N in soil was calculated and expressed in a percentage. Ammonium (NH_4^+-N) and nitrate (NO_3^--N) nitrogen were extracted using 1.0 M potassium chloride (Maynard and Kalra, 1993), followed by analysis through the Berthelot and Griess reaction methods. Color intensity was measured spectrophotometrically to determine concentrations.

Statistical Analysis

Differences in active N (NH_4^+-N and NO_3^--N) due to N fertilization were analyzed using the ANOVA procedure of "R" a statistical software using the Agricole package (R Core Team, 2018). Duncan's multiple range test was used to separate significant differences in response parameters due to different N fertilization where appropriate (Steel and Torrie, 1980) at a 5% probability level. Graphs were prepared by using Microsoft Excel Office 2016.

RESULTS AND DISCUSSION

Different soil, crop, and management approaches impact how much N is mineralized in the soil. The following chart illustrates how different N sources and dosages affect N mineralization in wetland rice cultivation.

Ammonium and Nitrate N Content of Soil

Mineralization of N is the key process for the availability of N in the plant. Ammonification is the first step of the mineralization process. Data from Figure 1 showed the effect of N sources on NH_4^+-N concentrations in wetland rice soil at harvest time. The variable amount of N significantly ($P < 0.01$) influenced soil NH_4^+-N and NO_3^--N at the harvest time of rice. Initial NH_4^+-N and NO_3^--N concentrations before establishing the experiment were 3.64 and 2.36, respectively, due to the contribution of inherent soil organic matter and N contents.

The NH_4^+-N increased progressively in soils because of the different amounts of N applied in the soil. The range of NH_4^+-N concentration was 4.63 to 13.39 mg kg^{-1}. The highest amount of NH_4^+-N (13.39 mg kg^{-1}) in soils was found with the application of 90 kg N $ha^{-1,}$ followed by 60 kg N ha^{-1} (10.47 mg kg^{-1}), whereas the lowest NH_4^+-N concentration (4.63 mg kg^{-1}) was noted in no N fertilizer plot. The NH_4^+-N content in wetland rice soil increased with an increasing N amount. Meanwhile, the influence of different N sources also exhibited a significant ($P < 0.001$) effect on NH_4^+-N concentration in wetland rice soil (Figure 1). The maximum NH_4^+-N concentration was 10.35 mg kg^{-1} for the application of USG, followed by NCU and urea, while the minimum (6.86 mg kg^{-1}) NH_4^+-N was noted in DAP. There were no significant differences between urea and NCU regarding NH_4^+-N concentration due to N sources. The higher NH_4^+-N concentration in USG may be due to deep placement and the slow-releasing tendency of the fertilizer. Craswell *et al*. (1985) reported that deep placement of USG significantly decreased N losses through immobilization by up to 21% in the rainy season, and the effect of deep placement of urea is essentially the same as in the dry season.

Figure 2 shows that NO_3^--N concentration ($P < 0.001$) increased with increasing the doses of N in soils at harvesting time of T. Aman rice soil, but the increased amount was less as compared to

NH_4^+-N. Conversely, different N sources significantly ($P < 0.001$) influenced NO_3^--N concentration in the soil of T. Aman rice. Significantly higher amounts of soil NO_3^--N (5.97 mg kg^{-1}) was recorded with DAP as compared to USG, NCU, and urea.

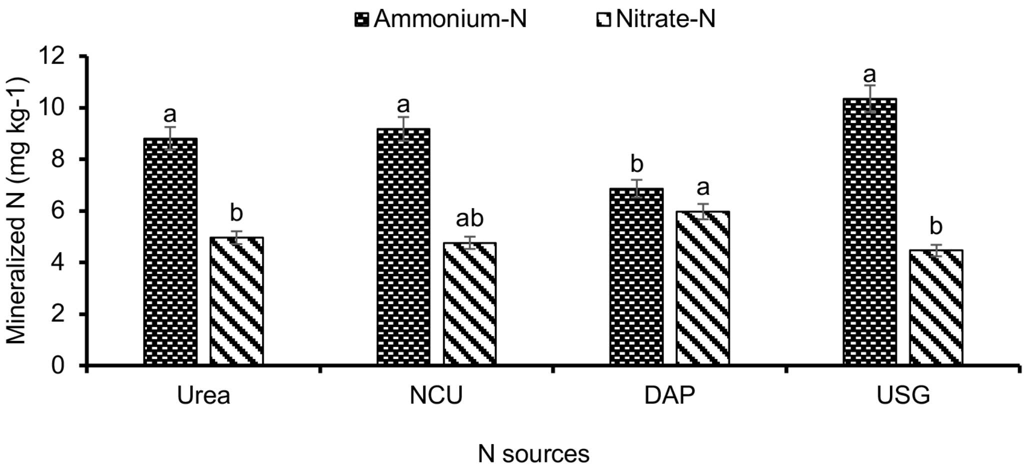

Figure 1 Effect of N sources on the release of NH_4^+-N and NO_3^--N in the soil at the harvesting time of T. Aman rice. Mean ± standard deviation in each bar was estimated from three replications for each treatment. Bars within the same group labeled with the same letters are not significantly different at a 5% probability level. NCU = neem-coated urea, DAP = di-ammonium phosphate, USG = urea super granule.

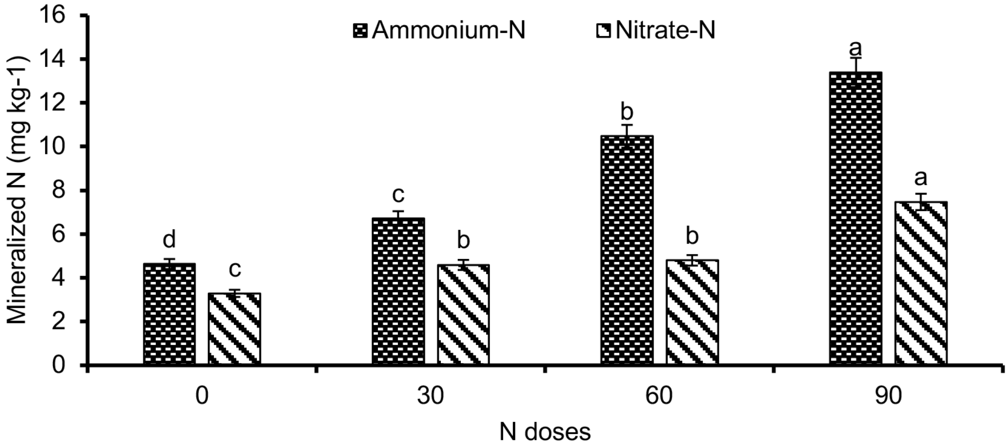

Figure 2 Effect of N doses for all sources on the release of mean NH_4^+-N and NO_3^--N in the soil at the harvesting time of T. Aman rice. Mean ± standard deviation in each bar was estimated from three replications for each treatment. Bars within the same group labeled with the same letters are not significantly different at a 5% probability level.

However, a lower amount of NO_3^--N was noted in USG (4.46 mg kg^{-1}), which was statistically similar to urea and NCU. In all cases, the amount of NH_4^+-N concentration was comparatively higher than NO_3^--N, which may be due to the predominant nature of the flooded soil. Buresh *et al.* (2008) reported that NH_4^+-N is the dominant form of mineralized N in submerged soil, while NO_3^--N is comparatively higher in aerated soil. In submerged soil, due to lack of oxygen, the formation of NO_3^--N is very low. Sahrawat (2010) noted that wetland paddy soil deficient in oxygen declines the production of NH_4^+-N in aerobic or anaerobic conditions. On the other hand, the interaction effect of N sources and N doses on the dynamics of NH_4^+-N and NO_3^--N was found to be significant (Table 2). The maximum NH_4^+-N (15.89 mg kg^{-1}) was mineralized from USG with the highest dose of N (90 kg N ha^{-1}), but it was statistically similar to NCU. On the contrary, the lowest amount of NH_4^+-N (4.23 mg kg^{-1}) was recorded where no fertilizer was used, which was statistically similar to other sources at the same N level. In soil, mineralized NH_4^+-N progressively increased at the same style as all N sources. In the case of NO_3^--N, a similar mineralization trend was observed at the different levels of N with N sources. Nonetheless, USG at 90 kg N ha^{-1} produced the highest amount of NO_3^--N (7.60 mg kg^{-1}), which was statistically identical to urea at the same N level. The lowest NO_3^--N was attributed to all N sources where no fertilizer was used. In all cases, the concentration of NH_4^+-N was relatively higher than NO_3^--N in wetland rice soil.

Table 2 Influence of N sources and doses on dynamics of NH_4^+-N and NO_3^--N at harvest time of T. Aman rice

N sources	N dose (kg ha^{-1})	Mineralized N (mg kg^{-1})	
		NH_4^+-N	NO_3^--N
Urea	0	5.63 ± 1.00^{fg}	3.45 ± 0.50^{fgh}
	30	5.29 ± 2.79^{g}	3.97 ± 0.25^{efg}
	60	10.81 ± 1.18^{c}	3.95 ± 1.00^{efg}
	90	13.53 ± 1.54^{b}	7.14 ± 2.63^{a}
NCU	0	4.91 ± 1.73^{g}	2.73 ± 0.55^{gh}
	30	7.47 ± 0.20^{ef}	4.82 ± 1.00^{de}
	60	10.29 ± 0.62^{cd}	4.41 ± 0.41^{def}
	90	14.04 ± 2.19^{ab}	7.07 ± 0.43^{b}
DAP	0	4.23 ± 0.14^{g}	4.55 ± 0.27^{def}
	30	5.51 ± 0.58^{g}	5.66 ± 0.17^{cd}
	60	7.59 ± 0.50^{e}	6.96 ± 1.11^{bc}
	90	10.23 ± 0.45^{cd}	6.73 ± 0.09^{bc}
USG	0	3.75 ± 0.89^{g}	2.44 ± 0.49^{h}
	30	8.58 ± 0.00^{de}	3.91 ± 0.18^{efg}
	60	13.20 ± 0.57^{b}	3.89 ± 1.17^{efg}
	90	15.89 ± 0.00^{a}	7.60 ± 1.16^{ab}
P-value		0.002	0.003
CV (%)		13.1	19.8
LSD (0.05)		1.94	1.34

Note: Means followed by the same letter in the same column are not significantly different at a 5% probability level. NCU = neem-coated urea, DAP = di-ammonium phosphate, USG = urea super granule.

Nitrogenous fertilizer was applied in three splits during rice cultivation, but USG was deeply placed at the first split of other N fertilizers. The different amounts of N fertilizers have different potentialities to mineralize NH_4^+-N and NO_3^--N concentrations. Hence, the highest amount of N showed the maximum mineralized N in the soil, significantly higher than the other doses for all cases. Besides, different N sources showed inconsistent results regarding N mineralization in wetland rice soil. It was observed that the application of different N sources in the T. Aman rice field contributed about 2 times higher NH_4^+-N than NO_3^--N in soils (Figures 1–2 and Table 2). Mineralization of NH_4^+-N and NO_3^--N from different N sources also inconsistently varies due to the potentiality of N sources. Cabrera *et al*. (2005) reported that the mineralization of N fertilizers in the soil is governed by the composition or quality of added organic matter, soil temperature and water content, drying-rewetting events, soil biota, and soil characteristics. The result showed that N sources combined with higher doses of N considerably contributed to soil NH_4^+-N and NO_3^--Navailability. Two forms of mineralized N exist in soil depending on their moisture condition. Highly water-soluble NO_3^--N is negatively charged and repulsed by negatively charged soil particles. That is why it has a great chance to move downward by leaching and loss from soil. Positively charged NH_4^+-N has a high affinity to negatively charged clay and humus, hence preventing its downward movement from soil systems (Rahman, 2014). Urea coated with neem oil has also slowed release and N nitrification inhibition properties. Hence, NO_3^--N production is comparatively lower in NCU than in other N sources. Nitrogen release can be prolonged up to 10 days in NCU compared to prilled urea, and the lowest NO_3^--N was produced by NCU (Suganya *et al.,* 2009). Thus, using NCU can extend the N availability for crop growth, thereby minimizing the losses of N and enhancing the N use efficiency.

CONCLUSIONS

In conclusion, the study looked at how different N sources and doses affect the concentrations of NH_4^+-N and NO_3^--N in wetland rice soil during T. Aman rice at harvest. The findings revealed that applying different quantities of N significantly affected the concentrations of both NH_4^+-N and NO_3^--N in the soil, with NH_4^+-N constantly showing greater levels than NO_3^--N. The mineralization patterns were also significantly influenced by the choice of N source, with USG showing the greatest NH_4^+-N concentration due to its deep placement and slow-releasing properties. In contrast, DAP substantially contributed to the levels of NO_3^--N in the soil. The dynamics of NH_4^+-N and NO_3^--N were greatly impacted by the interaction of N sources and doses, emphasizing the need to take both into consideration when developing fertilization techniques. Because there was insufficient oxygen for the synthesis of NO_3^--N, NH_4^+-N dominated in submerged soil. Neem-coated urea, which has a slow release and neem oil coating, has shown the potential to increase N use efficiency by extending N availability and minimizing losses. In summary, optimizing fertilization procedures in wetland rice cultivation is essential for sustainable nutrient management and crop production. It involves a knowledge of the intricate relationships between N sources, doses, and soil conditions. The findings provide valuable insights for agricultural practices aiming to improve N utilization efficiency while minimizing environmental impact.

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