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Enhancing Nitrogen Use Efficiency and Grain Yield in Dry Season Rice Through Optimized Fertilizer Management

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Abstract

Nitrogen (N) is one of the most critical nutrients limiting rice productivity, yet despite numerous management strategies, its use efficiency in *Oryza sativa L.* remains low, particularly in the dry season where effective application methods are still inadequate. A field study was carried out to explore how different nitrogen (N) application techniques influence the yield and nitrogen use efficiency (NUE) of dry season rice (BRRI dhan29). The experiment followed a randomized complete block design (RCBD) with three approaches to N fertilization-broadcasting, deep placement, and fortification-each tested across three replications. We observed that the deep placement method consistently produced the highest concentrations of both NH_4^+-N and NO_3^--N at soil depths of 0-15 cm and 15-25 cm, whereas broadcasting resulted in the lowest levels. Grain yield increased up to 9.68% in fortification and 17.74% in deep placement method as compared to broadcasting method. Deep placement method also reported the highest nutrient uptake (kg ha^{-1}) (N-115.6, P-32.4, K-94.2 and S-21.5), whereas broadcasting had the lowest values. Similarly, NUE was also found maximum in deep placement method and increased 7.72% in fortification and 12.88% in deep placement as compared to broadcasting method. From these results, applying nitrogen through deep placement appears to be the most effective approach for boosting both yield and nitrogen use efficiency in dry-season rice (BRRI dhan29).

Keywords: Broadcasting, Deep Placement, Fortification, NH_4^+-N and NO_3^--N Concentrations, N Use Efficiency, Grain Yield

Introduction

Rice is the lifeline of Bangladesh, not just as the main food on people's plates but also as a backbone of the rural economy. Among the different growing seasons, *Boro* rice-cultivated in the dry months from December/January to March/April-plays a vital role in ensuring the nation's rice supply (Habib *et al.* 2023) [18]. Despite efforts, productivity is still lagging, which may be linked to declining soil fertility, unbalanced fertilizer use, intensive cropping, continued reliance on traditional varieties, and limited knowledge among farmers about improved crop management practices (Halder *et al*. 2024; Baral *et al.* 2019) [19, 8].

For rice (*Oryza sativa* L.) to thrive, nitrogen fertilizer is essential in its cultivation yet its' insufficient imbalance use has long posed a challenge for sustainable agriculture especially during the dry season when water is limited and soil conditions are less forgiving (Imran *et al.* 2025; Mia *et al.* 2024) [24, 44]. In Bangladesh, farmers typically apply nitrogen (N) in the form of urea, yet in most crops, its efficiency rarely exceeds 50% (IFDC, 2013) [25]. Globally, nitrogen use efficiency (NUE) in lowland rice averages around 30% (Ladha *et al.* 2005) [38], and it drops even further during the dry season (Balasubramanian *et al.* 2004) [6]. This low efficiency is largely due to excessive fertilizer use without accounting for factors such as the soil's natural N supply, crop N uptake capacity, soil moisture levels (Islam *et al.* 2025) [26], and varying agro-climatic and management conditions (Halder *et al.* 2024) [20]. Nutrient use efficiency (NUE) can differ widely across regions and ecosystems because of varying weather conditions, crop types and varieties, management practices, and the timing and methods of fertilizer application (Rahman *et al.* 2021) [48]. In rice-growing areas, poor NUE is often caused by excessive nitrogen fertilization, incorrect timing, and broadcast application methods (Wang *et al.* 2018) [58]. For example, applying a single basal dose of urea can provide more nitrogen than the plant needs during early growth, leading to losses through volatilization and denitrification, which can account for roughly 16-20% and 0.75-1.0% of the applied nitrogen, respectively (Islam *et al.* 2024; Uddin *et al.* 2021; Jahangir *et al.* 2022) [28, 57, 32].

Due to numerous losses (volatilization, de-nitrification, runoff, seepage, and leaching), using N fertilizer effectively is very difficult. Since nitrogen from mineralization is quickly lost from the soil, crops frequently face N shortages during later growth, leading to lower nitrogen use efficiency, reduced grain production, and diminished profits (Sadik *et al*. 2025; Akter *et al*. 2022) [51, 2].

In Bangladesh, the success of dry season rice-a cornerstone of the country's food supply-depends heavily on optimizing nitrogen use. While broadcasting urea is common among local farmers, plants struggle to take up all the nutrients since they disperse too far from the roots. By maintaining time, rate and placement of N fertilizers, farmers can achieve crop performance even under water-stressed environment (Coggins *et al*. 2025; Islam *et al*. 2024) [9, 30]. Recent research highlights that adopting improved fertilization methods i.e., controlled release formulations, deep placement and split applications can substantially boost N uptake and utilization. For example, studies have demonstrated that methods like deep placement of urea contributes to reducing N wastage up to 30%, thereby enhancing grain yield while mitigating environmental impacts (Fiza *et al*. 2024; Mia and Salam, 2024) [11, 45]. Urea deep placement (UDP) is increasingly recognized as a better alternative to the traditional broadcast method. By placing nitrogen fertilizer deeper in the soil, it stays longer where oxygen is limited, reducing losses to the surface or floodwater (Li *et al*. 2015; Ke *et al*. 2018; Kapoor *et al*. 2008) [39, 35, 33]. This helps cut nitrogen losses from ammonia volatilization, runoff, and denitrification, while also lowering nitrous oxide (N_2O) emissions (Siddika *et al*. 2024; Rochette *et al*. 2013) [54, 50]. Studies show that deep placement not only improves nitrogen use efficiency but also boosts grain yields compared with broadcasting (Salam *et al*. 2022; Huda *et al*. 2016) [52, 23]. This situation highlights the need for further research to understand how different N fertilization methods affect both NUE and yield in dry season rice. Despite its importance, the potential of various N management strategies to enhance NUE in dry season rice has not been thoroughly evaluated. We therefore hypothesize that UDP may offer better results under these conditions. The main objective of this study was to identify an effective N fertilization method that can boost both grain yield and NUE in dry season rice.

Materials and Methods

Site of the experiment

Located in Agro-ecological zone-17 (Old Brahmaputra Floodplain), the experimental site features non-calcareous dark grey floodplain soil at 24.75° N latitude and 90.5° E longitude, with an elevation of 18 m above sea level (FAO and UNDP, 1988) [10]. Experiments were performed in typical silt loam soil at the SS Field Laboratory, BAU.

Acronyms and abbreviation

To avoid redundancy with other research, we adopt unique acronyms and abbreviations, such as UDP: Urea deep placement, NUE=Nitrogen use efficiency, SS=Soil Science, BAU=Bangladesh Agricultural University, RCBD= randomized complete block design, BRRI= Bangladesh Rice Research Institute, PH= Plant height, TT= Total tiller hill^{-1}, ET= Number of effective tillers hill^{-1}, FG= Number of filled grain, UFG= Number of unfilled grains, TGW= 1000-grain weight, GY= Grain yield, SY= Straw yield, DMRT=Duncan's multiple range test, PCA=Principal component analysis, T_1= Broadcasting, T_2= Deep placement, T_3= Fortification.

Treatments and experimental setup

The experiment was conducted using RCBD, with the field divided into three blocks to account for soil variability. Three nitrogen fertilization methods-broadcasting, deep placement, and fortification-were tested, each replicated three times. The treatments were randomly assigned to plots within each block, resulting in a total of nine experimental plot.

Fertilizer management

Nitrogenous fertilizer: Urea (178 kg N ha^{-1}) splitted into the following three equal applications:

Basal application: Applied at transplanting.

Mid-tillering stage: Approximately at 20-25 days after transplanting (DAT).

Panicle initiation stage: Approximately at 40-50 DAT.

Application methods

Broadcasting: Fertilizer was scattered across the soil.

Deep placement: Fertilizer was placed in the root zone (7-10 cm depth).

Fortification: Fertilizer was mixed with micronutrients before application.

Test cultivar

For this experiment, BRRI dhan29 rice was chosen due to its high yield potential. Developed by the BRRI, this variety matures in approximately 160 days and offers an average yield of 6.2 t ha^{-1}, with sturdy stems that reduce lodging risks.

Measurement of yield and yield contributing parameters

At full crop maturity, growth parameters i.e., PH, TT, ET, FG, UFG were measured. The harvested samples from each treatment were used to determine the yield attributes i.e., TGW, GY, SY. We measured the SY as it was, while the GY was adjusted to a standard 14% moisture.

Determination of soil NH_4^+-N and NO_3^--N

To start, we collected soil samples and checked how much ammonium NH_4^+) and nitrate (NO_3^-) they contained, looking at two soil layers: the top 0-15 cm and the layer below, 15-25 cm. The initial soil samples were evaluated for chemical components such as NO_3^--N and NH_4^+-N using the method recommended by Keeney and Nelson (1987) [36].

Nutrient uptake

Nutrient uptake (N, P, K, and S in kg ha^{-1}) was assessed according to Islam *et al.* (2021) [27], applying the equation presented here:

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Grain yield} \times \text{Grain N content} + \text{Straw yield} \times \text{Straw N content}}{100}$$

Determination of NUE (%)

We calculated (NUE for each treatment, taking into account agronomic efficiency, nitrogen uptake per unit of N applied, and grain produced per unit of N supplied. The NUE was calculated using the equation below-

$$\text{N use efficiency (NUE (\%)} = \frac{N\ uptake\ (kg/ha))}{Total\ N\ input\ (kg/ha)} \times 100$$

Statistical methods

A complete randomized design served to measure the analyses of variance (ANOVA) for various crop characteristics, yields, N concentration and uptake, and NUE. We compared the treatment means using DMRT at a 5% significance level, following the method of Gomez and Gomez (1984) [17], with analyses conducted in Statistix 10.

Results

Mineral (NH_4^+ and NO_3^-)-N in soil

The way NH4+-N was released in the soil differed significantly across the various N fertilizer methods applied to dry season rice (BRRI dhan29) at both 0-15 cm and 15-25 cm soil depth (Fig. 1A). At 0-15 cm depth the amount of available NH_4^+-N in soil found maximum (34.7 mg kg^{-1}) in deep placement method though that numerically dissimilar but statistically resembled to fortification (32.1 mg kg^{-1}) method, whereas the minimum NH_4^+-N (28.5 mg kg^{-1}) was observed in broadcasting method. NH_4^+-N concentration increased 12.63% to 21.75% as compared to broadcasting at 0-15 cm soil depth. With the increase of depth NH_4^+-N concentration trend to decrease and like NH_4^+-N at 0-15 cm depth, similar trend was also obtained in case of 15-25 cm depth where, the highest (27.8 mg kg^{-1}) NH_4^+-N was observed in deep placement followed by fortification (25.6) and the lowest (22.4 mg kg^{-1}) was recorded in broadcasting. Concentration of NH_4^+-N increased 14.29% to 24.11% compared to broadcasting at 15-25 cm soil depth.

NO_3^--N levels at both depths showed a comparable trend, changing significantly with different N fertilization approaches (Fig. 1B). At 0-15 cm soil depth, NO_3^--N was recorded maximum (18.2 mg kg^{-1}) in deep placement followed by fortification (15.4 mg kg^{-1}) whereas, the minimum (12.3 mg kg^{-1}) was observed in broadcasting. NO_3^--N concentration increased 25.20% to 47.97% compared to broadcasting at 0-15 soil depth. A decreasing trend with increasing soil depth was also observed in case of NO_3^--N. At 15-25 cm soil depth, the highest NO_3^--N was obtained in deep placement method that was statistically resembled to fortification method (13.3), whereas the lowest (10.1 mg kg^{-1}) was found in broadcasting. NO_3^--N concentration in soil was increased 31.68% to 45.54% compared to broadcasting at 15-25 cm soil depth.

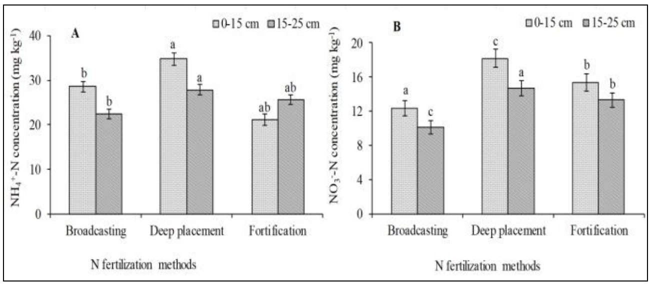

Fig 1: NH_4^+-N (mg kg^{-1}) and NO_3^--N (mg kg^{-1}) concentrations in soil at 0-15 cm and 15-25 cm depth under different N fertilization methods in dry season rice (BRRI dhan29)

Yield attributes

The analytical data of Table 1 shows the response of different yield attributes of dry season rice (BRRI dhan29) under different N fertilization methods. It sketched a clear picture that all yield attributes were significantly altered by different urea application methods. All the parameters mentioned was found maximum in deep placement method and though those were numerically dissimilar but statistically resembled to fortification, whereas the minimum result was observed in broadcasting method. PH was increased 3.57% to 7.56%; TT 3.13% to 13.28%; ET 5.71% to 18.10%, and FG 3.86% to 8.29% respectively, whereas UFG decreased to 16.03% to 42.06% as compared to broadcasting.

Table 1: Yield contributing parameters under different N fertilization methods in dry season rice (BRRI dhan29)

Treatments	Plant height (cm)	No. of tillers hill^{-1}	No. of effective tillers hill^{-1}	No. of filled grains panicle^{-1}	No. of unfilled grains panicle^{-1}
Broadcasting	95.3±2.1b	12.8±0.7b	10.5±0.8b	85.6±3.2b	15.2±1.1a
Deep placement	102.5±1.8a	14.5±0.6a	12.4±0.7a	92.7±3.5a	10.7±0.9c
Fortification	98.7±2.0ab	13.2±0.5ab	11.1±0.6ab	88.9±3.0ab	13.1±1.0b

Figures in a column having common letters do not differ significantly at 5% level of significance

GY and SY

As demonstrated in Table 2, TGW, GY and SY of dry season rice (BRRI dhan29) boosted significantly under different N fertilization methods. The TGW was highest (22.8 g) in deep placement method followed by fortification (22.1 g) method, whereas the lowest value (21.4 g) was recorded in broadcasting method. It was observed 3.27% to 6.54% increase in TGW compared to broadcasting. Similar trend also observed in case of GY and SY. The maximum GY (7.3 t ha^{-1}) and SY (8.2 t ha^{-1}) was found in deep placement method followed by fortification (6.8 and 7.8 t ha^{-1}), whereas the minimum GY (6.2 t ha^{-1}) and SY (7.5 t ha^{-1}) was obtained in broadcasting method. GY increased 9.68% to 17.74% and SY increased 4% to 9.33% as compared to broadcasting method.

Table 2: Grain yield and straw yield under different N fertilization methods in dry season rice (BRRI dhan29)

Treatments	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Broadcasting	21.4±0.6b	6.2±0.4b	7.5±0.5b
Deep placement	22.8±0.5a	7.3±0.3a	8.2±0.4a
Fortification	22.1±0.7ab	6.8±0.3ab	7.8±0.4ab

Figures in a column having common letters do not differ significantly at 5% level of significance

Nutrient uptake

The dry season rice (BRRI dhan29) significantly boosted their nutrient uptake under different N fertilization approaches (Fig 2). Nitrogen uptake was highest with deep placement (115.6 kg ha^{-1}), closely followed by fortification (110.3 kg ha^{-1}), while broadcasting resulted in the lowest uptake (102.4 kg ha^{-1}). A similar trend was also noticed in case of P, K and S where the maximum P (32.4 kg ha^{-1}), K (94.2 kg ha^{-1}) and S (21.5 kg ha^{-1}) was obtained in deep placement method and the minimum P (28.7 kg ha^{-1}), K (86.5 kg ha^{-1}) and S (18.4 kg ha^{-1}) was noted in broadcasting method. The increase in N was noted 7.71% to 12.89%, P 6.27% to 12.89%, K 3.7% to 8.9% and S was 16.85% over broadcasting method.

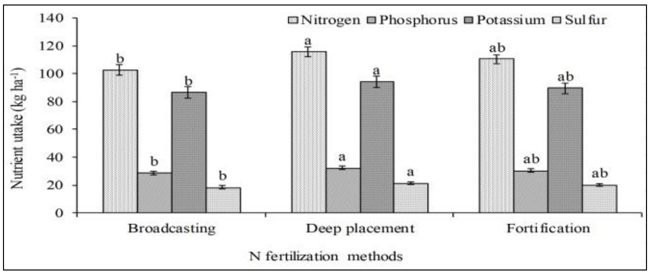

Fig 2: N, P, K and S uptake of dry season rice (BRRI dhan29) under different N fertilization methods in dry season rice (BRRI dhan29)

N Use Efficiency (NUE)

When N fertilization was done through deep placement method, the highest (64.94%) NUE was identified, followed by fortification method (61.97%), whereas the lowest (57.53%) value was observed in broadcasting method (Table 3). The increase of NUE was noted 7.72% in fortification to 12.88% in deep placement over broadcasting method.

Table 3: N use efficiency of dry season rice (BRRI dhan29) under different N fertilization methods

Treatments	N applied (kg ha^{-1})	NUE (%)
Broadcasting	178	57.53
Deep placement	178	64.94
Fortification	178	61.97

NUE (%) = N use efficiency

Multivariate analysis

PCA was used to determine the improving nitrogen use efficiency through strategic fertilizer application in dry season rice (Fig 3). On the graph, the x-axis represents PC1, which accounts for 53.5% of the variation in the data, and the y-axis represents PC2, explaining 20.8% of the variation. PC1 is closely linked to FG, SY, PH, TGW, ET, and UFG, showing strong positive correlations. TT is more aligned with PC2. The GY and ET are closer to origin. A clear positive link exists among FG, SY, PH, TGW, and GY. Treatment 2 stands out because it is strongly shaped by PC1, while Treatment 3 is clearly guided by PC2, setting both apart from the other observations. In contrast, Treatment 1 lies near the origin, reflecting more average values across the principal components.

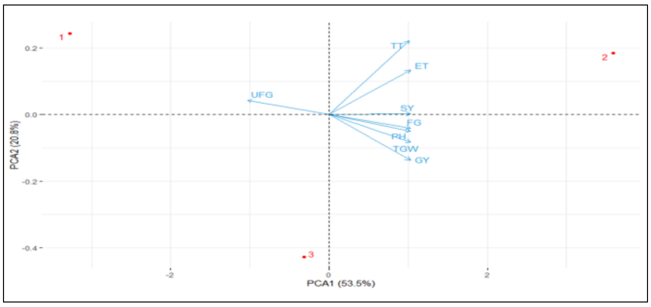

Fig 3: Bi-plot of principal component analysis (PCA) showing the first two principal components (PC 1 and PC 2)

For PCA, data on nitrogen use efficiency through strategic fertilizer application in dry season rice. The red dots are indicating five residue treatments, like 1 = Broadcasting, 2 = Deep placement, 3 = Fortification. Where PH= Plant height (cm), TT= Total tiller $hill^{-1}$, ET= Number of effective tillers $hill^{-1}$, FG= Number of filled grain, UFG= Number of unfilled grains, TGW= 1000-grain weight (g), GY= Grain yield (t ha^{-1}), SY= Straw yield (t ha^{-1}).

A correlation analysis was conducted to explore how strategic fertilizer application could improve NUE across three treatments (Fig 4). The results showed that PH was moderately and positively correlated with FG ($P < 0.01$). TGW and SY also exhibited positive correlations with both PH and FG ($P < 0.05$). In contrast, UFG were negatively correlated with all measured variables.

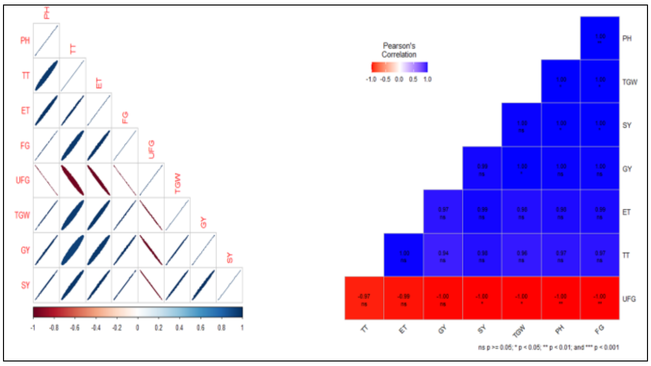

Fig 4: Pearson correlation analysis of nitrogen use efficiency through strategic fertilizer application in dry season rice

***, **, * and NS (Not Significant) represent probability of ≤0.001, ≤0.01, ≤0.05 and >0.05, respectively. Others details are same as shown in Fig 3.

A heat map was created to explore which traits most effectively reflect improved NUE in dry-season rice under strategic fertilizer management. In the map, the x-axis shows the different variables, and the y-axis represents the various treatments (Fig 5). Traits like TT, FT, GY, SY, TGW, FG, and PH showed a strong positive response to deep fertilizer placement, while their contribution was lowest under broadcasting. The other treatments exhibited mostly light to moderate effects, showing neutral to moderate relationships across the measured parameters.

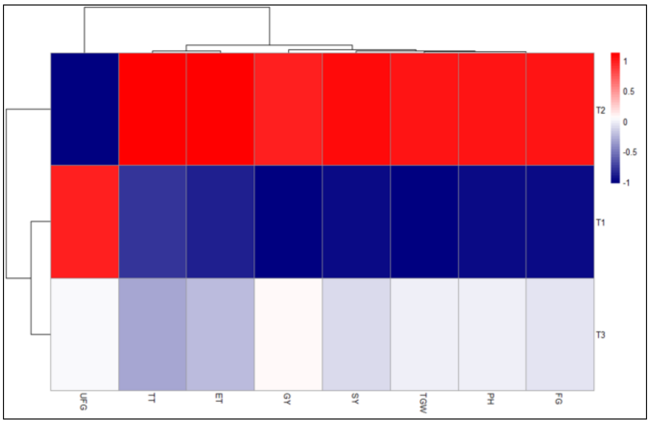

Fig 5: Heat map analysis of improving nitrogen use efficiency through strategic fertilizer application in dry season rice

T_1= Broadcasting, T_2= Deep placement, T_3= Fortification. Others details are same as shown in Fig 3

Discussion

Our research showed that the yield characteristics and NUE of dry season rice (BRRI dhan29) had been substantially improved by various N fertilization techniques. When nitrogen fertilizer was applied deeply, as opposed to broadcasting, the study found that soil $NH4^+$-N concentrations were much higher, especially at depths of 0–15 cm and 15–25 cm. Nitrogen availability was increased by 12–24% using this approach, which probably decreased losses from leaching and volatilization. Additionally, the fortification technique retained larger amounts of $NH4^+$-N than broadcasting, suggesting that it could enhance nitrogen retention in dry season rice production (Zhou *et al*. 2022; Liu *et al*. 2019) [61, 41]. By increasing nitrate availability by 25–48%, deep nitrogen fertilizer placement significantly increased soil NO_3^--N concentrations when compared to broadcasting at both depths. Additionally, the fortification strategy greatly enhanced NO_3^--N and demonstrated efficiency comparable to deep placement, especially at depths of 15 to 25 cm (Reddy *et al*. 2025; Liu *et al*. 2015) [49, 40]. In comparison to broadcasting, deep placement of nitrogen continuously enhanced growth and yield components, greatly boosting PH, TT, ET, and full grains per panicle. It also significantly decreased UFG by as much as 42%, demonstrating how effective it is at raising rice output (Mia *et al*. 2023; Giri *et al*. 2022; Wang *et al*. 2016) [43, 16, 59]. These findings closely match those of earlier research carried out in an irrigated rice system (Alam *et al*. 2013; Bandaogo *et al*. 2015) [3, 7]. Because there were more ET and more grains per panicle, the deep placement approach produced a larger GY. Similar to our findings, Wu *et al*. (2017) [60] found that applying N fertilizer in a deep location resulted in more panicles. GY were higher in our study because the deep placement approach considerably accelerated crop growth and the buildup of dry matter at various growth stages. The increased crop growth rate, yield components, and yields with the deep-placement approach are probably due to a continuous supply of N as per the plant's demand. The deep placement method of N fertilization retains more N at a depth of 50 to 150 mm than the broadcasting method, which increases plant N absorption and yields. This assures a constant supply of N throughout the crop growth period (Siddique *et al*. 2019) [55]. The higher effectiveness of these placement strategies in optimizing rice productivity was confirmed by the fortification method's notable performance over broadcasting (Hossain *et al*. 2024; Li *et al*. 2024) [22, 39].

Furthermore, deep placement of nitrogen fertilizers effectively reduces floodwater ammonium-nitrogen concentration, a key factor in mitigating nitrogen losses and enhancing overall nitrogen use efficiency in rice paddies (Afroz *et al*. 2015) [1]. This strategy not only benefits crop productivity but also mitigates harmful nitrogen emissions, such as nitrous oxide and nitric oxide, which are significant contributors to atmospheric pollution and global warming (Gaihre *et al*. 2020; Islam *et al*. 2018) [13, 31]. Deep placement ensures that nitrogen is directly accessible to plant roots, leading to more robust plant growth and development, which ultimately translates to higher crop yields and better economic returns for farmers (Gaihre *et al*. 2017; Alam *et al*. 2023) [14, 4].

In comparison to broadcasting, deep placement of nitrogen fertilizer significantly enhanced nutrient uptake, boosting N, P, K, and S accumulation by up to 16.85%. This demonstrates how well it works to improve overall nutrient efficiency in rice production as well as nitrogen consumption (Sharifi *et al*. 2023) [53]. NUE was greatly increased by deep placement; the maximum value, 64.94%, was 12.88% higher than broadcasting. In comparison to broadcasting, fortification also increased NUE, highlighting the advantages of better fertilizer distribution techniques for effective nitrogen use (Pandit *et al*. 2022; Khalofah *et al*. 2021) [47, 37].

Deep placement of nitrogen fertilizers ensures effective nutrient availability at later growth stages, directly contributing to enhanced nitrogen use efficiency by tailoring nitrogen application to meet crop demands more precisely (Hassan *et al*. 2022) [21]. This method not only improves crop productivity but also mitigates the negative environmental impacts associated with excessive nitrogen fertilization, such as nitrous oxide (N_2O) emissions and nitrate leaching (Islam *et al*. 2018) [31]. Conversely, optimizing nitrogen use efficiency through techniques like deep placement can significantly reduce the total amount of nitrogen fertilizer required, leading to substantial cost savings for farmers while simultaneously bolstering crop yields by supporting crucial plant processes like photosynthesis and protein synthesis (Ali *et al*. 2025) [5]. Moreover, the strategic placement of nitrogen within the root zone minimizes gaseous losses, such as ammonia volatilization, and reduces denitrification in anaerobic soil layers, further enhancing nitrogen availability and uptake (Ma & Ruan, 2021) [42]. This is particularly evident in flooded rice fields where urea deep placement has been shown to minimize nitrogen losses by protecting ammonium from nitrification and denitrification (Gaihre *et al*. 2017) [14]. This targeted delivery ensures that nitrogen remains in a plant-available form for extended periods, directly correlating with improved agronomic efficiency and apparent nitrogen recovery efficiency compared to surface applications (Gaihre *et al*. 2023; Steusloff *et al*. 2019) [12, 56]. Deep placement strategies have also been observed to significantly reduce nitrous oxide (N_2O) emissions, a potent greenhouse gas, compared to conventional broadcast methods, thus offering an environmental co-benefit (Hassan *et al*. 2022) [21]. This reduction is crucial, considering that inappropriate nitrogen management practices contribute to a significant portion of anthropogenic nitrous oxide and nitric oxide emissions (Gaihre *et al*. 2015) [15]. Therefore, advanced nitrogen fertilizer management approaches, including precise placement, are essential for improving crop productivity, optimizing nitrogen use efficiency, and mitigating the associated environmental risks of nitrogen losses (Mirzaee & Nafchi, 2025; Kazlauskas *et al*. 2021) [46, 34].

Several issues may contribute to the poorer performance of the broadcasting approach, such as the soil's inability to properly cover the urea owing to dry soil that makes it difficult to open and close the furrow. For instance, studies indicate that conventional broadcasting can result in nitrogen recovery rates as low as 30–45%, with over 50% of applied nitrogen lost through various mechanisms (Gaihre *et al*. 2015) [15].

With the deep-placement method, a larger surface area might have been in contact with the soil than with the broadcasting and fortification methods. This could increase the likelihood of N leaking to surface soils by NH_3 volatilization if it is not adequately covered. Furthermore, urea exposure to oxygen may intensify nitrification, which is followed by denitrification with precipitation. Consequently, in comparison to the deep-placement strategy, it did not raise NUE or GY. Therefore, the best way to increase NUE is to apply urea deeply.

Conclusions

It is difficult to handle N fertilizer during dry season cultivation because farmers may not be able to maintain the right time, rate, and positioning of N topdressing because of prolonged drought or floods (extra rainfall) caused on by irregular precipitation. The majority of farmers apply urea using the broadcasting method, but because of the lack of coverage, fertilizers cannot be adequately absorbed by plant roots through broadcasting, which results in significant loss through volatilization. One of the best methods for raising crop production and raising the NUE in rice farming in recent years has been the urea deep implantation technique. Deep urea placement reduces environmental N loss and increases farmers' net economic return by saving a substantial amount of N fertilizer and time spent on follow-on split treatments. Thus, we tested various methods of N fertilizer application in dry season rice cultivation, ranging from broadcasting to deep placement method, to improve NUE and crop productivity. This study suggests that deep placement of urea is a solution to increase GY and NUE in dry season rice cultivation. Additionally, it has favorable effects on government subsidy programs, which include fertilizer subsidies, especially in developing nations like ours. Overall, the results demonstrated that the urea deep implantation strategy outperformed the other approaches in terms of NUE and crop yields. For a more comprehensive recommendation, more on-farm field research should be carried out in a variety of agro-ecologies and management scenarios.

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