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Research Article

Requirement and use efficiency of nitrogen in transplanted Aman rice at Ganges tidal water flooded coastal ecosystem

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ABSTRACT

Transplanted (T) Aman rice covers most of the arable land in the south coastal region of Bangladesh, where nitrogen fertilizer requirement in the Ganges tidal water flooded ecosystem yet not determined. The on-farm experiment was conducted at Dumki Upazila, Patuakhali district of Bangladesh, during T. Aman rice season 2020. The three replicated randomized complete block design was used in the experiment. There were eight treatments with different rates of nitrogen, e.g., control (no nitrogen fertilizer), 18, 36, 54, 72, 90, 108, and 126 kg N ha^{-1}, which was equivalent to 0, 20, 40, 60, 80, 100, 120 and 140% of the current recommended rate, respectively. The test variety of rice was BR23. An increase in nitrogen rates progressively increased the grain yield of rice. The highest yield of 5.04 t ha^{-1} was found in 54 kg N ha^{-1} rate. However, using a quadratic equation, the most optimum rate was 75 kg N ha^{-1}, 17% lower than the current recommendation. Nitrogen amendment could increase T. Aman rice grain yield by only 35% over control under tidal water flooded conditions. The agronomic efficiency, recovery efficiency, and physiological efficiency of nitrogen were higher in lower rates of N and gradually decreased with the increase of the rate of N application. The present study recommends 75 kg N ha^{-1} for cultivating T. Aman rice (BR23) in tidal water flooded the south coastal ecosystem of Bangladesh.

Introduction

Rice is the staple food for approximately 163 million people in Bangladesh (BBS, 2019). Almost 16.5 million farm families (48% rural employment) cultivate rice (Akter et al., 2019). Especially in the south coastal region, most of the arable lands are occupied by T. Aman rice in the wet season (Kharif II). Although a big coverage, the yield potentiality of the traditionally grown T. Aman rice crop is very low.

While agronomic research has appeared to neglect cropping systems in environmentally challenging coastal areas, increasing T. Aman rice productivity is critical in efforts to improve food security. The location of farmers' fields in relation to the landscape is a key factor determining T. Aman's productivity in those areas. Increasing macro and micronutrients may be the most common technique for enhancing crop yields (Howlader et al., 2013; Hania et al., 2013; Begum et al., 2015). Nitrogen is the most limiting element, but the ecosystem usually loses more than half of the applied nitrogen (Haque et al., 2023a). In flooded rice, water depth may fluctuate during the growing season due to tidal water submergence; improving nitrogen performance is especially problematic (Ladha et al., 2005). Rice has

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recorded the low efficiency of nitrogen recovery by above-ground biomass (Haque and Jharna, 2008). Denitrification and volatilization, which impact farmers' water and crop management practices, may also induce fewer efficiencies under some circumstances due to leaching, seepage, and/or runoff (Choudhury and Kennedy, 2005).

To achieve optimal lowland rice grain yields, nitrogen is usually a crucial component. Among the mineral nutrient elements, nitrogen is the highest required element, which considerably improves the yield and quality of rice (Peng et al., 2021). However, if it is misused, it will pollute groundwater. Farmers generally apply excess nitrogen fertilizer, which is an optimum requirement for rice's rapid and vigorous growth. The over-application of nitrogen fertilizer in the soil causes underground water and environmental pollution and promotes soil acidification (Ma et al., 2021).

Modern crop production technology includes using appropriate fertilizer rates and fertilizer application methods to improve crop yield per unit area (Haque et al., 2023b). The optimal rate of nitrogen fertilization has traditionally been the rate that yields the highest economic yield. The required optimum nitrogen rate varies depending on soil type, cultivar yield potential, phosphorus and potassium levels, water management methods, disease, pest, and weed strength. In Bangladesh, fertilizer recommendations are made based on the agro-ecological zones with high heterogeneity in land type and soil fertility (FRG, 2018). Moreover, soil fertility status decreases daily due to increasing cropping intensity and introduction of high-yielding crops and crop varieties in the coastal cropping systems (Haque, 2020). The reduced fertility status signifies the update of nitrogen fertilizer recommendations. An updated recommendation is therefore needed for growing rice, especially in coastal tidal water-flooded ecosystems. Using an acceptable nitrogen rate is critical for maximizing economic returns and reducing emissions of chlorofluorocarbon gas (Fageria and Baligar, 2003).

Improved nitrogen use efficiency to achieve both high yield and grain quality needs close consideration of the rate of nitrogen fertilizer applications (Haque and Hoque, 2023). The current research work, therefore, is undertaken to determine the optimum nitrogen rate for T. Aman rice cultivation at the south coastal Ganges tidal water flooded ecosystem.

Materials and Methods

Experimental site and soil

The experiment was conducted at the farmers' field of Dumki upazila of Patuakhali district, Bangladesh, in the Kharif-II season 2020. Geographically, the experimental sites were located at 22.46328° north latitude and 90.39665° east longitude, typical of a non-saline Ganges tidal water flooded coastal ecosystem. Texturally, the soil (0-15 cm) was silt loam (80 sand:755 silt:165 clay, g kg^{-1}) with pH (water) 6.6, EC (dS/m) 0.92, Walkley & Black organic carbon 5.6 g kg^{-1}, total N (Kjeldahl N) 0.45 g kg^{-1}, Olsen P 5.75 mg kg^{-1}, NH_4OAc exchangeable K 0.33cmol (+) kg^{-1} and $CaCl_2$ extractable S 17.5 mg kg^{-1}. Soil physical and chemical analysis was done according to the methods described by Page et al. (1982).

Treatments and design

There were eight treatments with different rates of nitrogen, e.g., control (no nitrogen fertilizer), 18, 36, 54, 72, 90, 108, and 126 kg N ha^{-1}, which was equivalent to 0, 20, 40, 60, 80, 100, 120 and 140% of the current agro-ecological zone (AEZ) based recommended rate of nitrogen (FRG 2018), respectively. The statistical design of the study was a single randomized complete block design, having been replicated thrice. In each block, the treatments were randomly distributed to the plots.

Crop and Variety

The tested crop was rice, and the variety was BR23. The rice variety was developed by the Bangladesh Rice Research Institute for the Kharif-II season. This is a late variety for the T. Aman season and is very popular in coastal regions. This variety can be transplanted up to the last week of September.

Raising seedling

Healthy seeds of BR23 were immersed in water for 24 hours. The seeds were then taken into a gunny bag. The bag was covered with a polythene sheet to improve the temperature inside the gunny bag. By 48 hours, the seeds started to sprout. After 72 hours, most of the seeds were fully germinated. A seedbed was prepared on high land for raising seedlings. The sprouted seeds of BR23 were sown on 3rd August 2020 in the seed bed.

Field preparation

The main field was tilled with a tractor one week prior to transplanting. Three plowing and cross plowing followed by laddering were done to make optimum puddled condition and to level the field. Individual small plots were prepared according to the layout and design of the experiment. Each plot had a size of 4m × 3m, and the unit plots were surrounded by 30 cm wide and 10 cm high earthen embankment. In between two blocks, a one-meter space was kept free of crops.

Fertilizer application

Every plot received equal P and K fertilizers (15 and 50 kg ha^{-1} P and K, respectively). Sulfur, zinc, or other nutrients were not applied in the field because, in our earlier experiments, we found no response to those elements in rice (Haque et al., 2023a). Urea, triple super phosphate, and muriate of potash were the sources of N, P, and K, respectively. One-third of urea and full TSP and MoP were broadcasted during tilling. The rest of the urea was top-dressed at 20 and 35 days after transplanting.

Uprooting and transplanting of seedlings

A light irrigation was made in the seedbed before the uprooting of the seedlings. Seedlings were then uprooted carefully so that no injury occurred in the seedlings. The seedling age was thirty days during transplanting, and plant-to-plant and row-to-distance was 20 cm × 20 cm. Each hill is comprised of 3-4 healthy seedlings. Transplanting of seedlings was done on 2nd September 2020.

Intercultural operations

Crops were grown under rainfed conditions; therefore, no irrigation was done. Rice plants enjoyed tidal water flooding during their growth period. However, there are fifteen days of spring tide and fifteen days of neap tide. During the neap tide period, water drains out from the field, and fields are inundated with water during the spring tide. Urea fertilizers were top-dressed during the neap tide period, a common practice in the coastal region. The experimental plots were weeded three times. A popular insecticide named Virtako was sprayed to control rice stem borer infestation.

Harvesting and data collection

The rice crop was harvested separately on 25th December 2020 in every unit plot. The grain was separated from the straw by threshing immediately after harvesting, and the fresh weight of each plot's grain was collected at the time of harvest. During weighing grain, moisture content was determined using a moisture meter. Grain yield was expressed on a 14% moisture content basis, whereas straw yield was expressed on a sundry basis. Growth and yield contributing data were recorded from five randomly selected plants. The grain and straw yield data were recorded by harvesting crops from 4 m^2 area. The harvest index and nitrogen use efficiencies were calculated using the following formula:

Harvest index (%)

The Harvest index was calculated by the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain Yield}}{\text{Grain Yield + Straw Yield}} \times 100$$

Agronomic efficiency of N (AEN)

The agronomic efficiency of nitrogen was calculated as follows:

$$AEN = \frac{Y_{NA} - Y_{NO}}{R_N}$$

Where, AEN= Agronomic efficiency of nitrogen

Y_{NA}= Yield (kg ha^{-1}) due to N addition

Y_{NO}= Yield (kg ha^{-1}) due to N omission

R_N= Rate of N addition (kg ha^{-1})

Recovery efficiency of N (REN)

Recovery efficiency can be calculated as follows:

$$\text{Recovery efficiency} = \frac{NU_{NA} - NU_{NO}}{R_N}$$

Where,

NU_{NA}: Nutrient uptake (kg ha^{-1}) due to nutrient addition

NU_{NO}: Nutrient uptake (kg ha^{-1}) due to nutrient omission

R_N: Rate of nutrient addition (kg ha^{-1})

Physiological efficiency of N (PEN)

Physiological efficiency was calculated as follows:

$$\text{Physiological efficiency} = \frac{Y_{NA} - Y_{NO}}{NU_{NA} - NU_{NO}}$$

Where,

Y_{NA}: Yield (kg ha^{-1}) due to nutrient addition

Y_{NO}: Yield (kg ha^{-1}) due to nutrient omission

NU_{NA}: Nutrient uptake (kg ha^{-1}) due to nutrient addition

NU_{NO}: Nutrient uptake (kg ha^{-1}) due to nutrient omission

Plant sample analysis

The micro-Kjeldahl method determined the total N content in grain and straw samples (Page et al., 1982). The top third leaf was used to determine chlorophyll concentration following the method described by Coombs et al. (1985).

Statistical analysis

Data recorded on plant parameters were analyzed through the computer-based statistical program STAR (Statistical Tool for Agricultural Research). The significant effect of treatments was determined by analysis of variance (ANOVA) using a one-way randomized complete block design model. The treatment means were compared at a 5% significance level by Duncan's Multiple Range Test (DMRT).

Results and Discussion

Growth and yield attributing characters

The plant height of the T. Aman rice varied significantly due to different nitrogen doses (Table 1). The plant height was greatly affected by the application of different doses of N, and plant height increased with increasing rate of N. Plant height varied from 127.3 to 144.1 cm. The tallest plant was found both in 108 kg N ha^{-1} (120% recommended rate) and 126 kg N ha^{-1} (140% recommended rate) rate, which was statistically similar to 90 kg N ha^{-1} (100% recommended rate) rate (143.5 cm). The shortest plant of 127.3 cm was found in the control treatment. The 18 kg N ha^{-1} recorded statistically similar plant height of the control treatment. However, in the experiment, the increased rate of N progressively increased the plant height of T. Aman rice up to 90 kg N ha^{-1}. Thereafter, plant height attained a plateau. Increased plant height with the nitrogen treatments in sufficient amounts for the rice plant throughout the life cycle might have favored increased cell division and cell enlargement, which ultimately contributed to higher plant height and the number of effective tillers $hill^{-1}$ of rice (Jahan et al., 2020).

Table 1. Effects of different rates of nitrogen application on growth and yield contributing characters of T. Aman rice (BR23)

Treatments	Plant height (cm)	Effective tillers hill^{-1} (no.)	No. of filled grains panicle^{-1}	1000-grain wt. (g)
T_1: N control	127.3 c	4.9 c	78.9 c	24.1
T_2: 18 kg N ha^{-1}	132.0 c	5.9 bc	110.5 b	24.4
T_3: 36 kg N ha^{-1}	137.3 b	6.7 abc	131.6 ab	25.1
T_4: 54 kg N ha^{-1}	137.9 b	7.3 ab	135.3 ab	25.4
T_5: 72 kg N ha^{-1}	140.2 ab	7.7 ab	137.1 ab	25.4
T_6: 90 kg N ha^{-1}*	143.5 a	8.2 ab	142.1 a	25.1
T_7: 108 kg N ha^{-1}	144.1 a	8.0 ab	128.1 ab	25.6
T_8: 126 kg N ha^{-1}	144.1 a	9.0 a	126.7 ab	25.5
% CV	1.29	11.36	8.76	7.31
Pr (> F)	0.0000	0.0005	0.0001	0.9550

Means with the same letter are not significantly different at the 5% level by DMRT; * indicate recommended rate (FRG, 2018)

Different nitrogen doses significantly influenced the number of effective tillers per hill (Table 1). Results showed that 126 kg N ha^{-1}(140% recommended rate) produced the highest number of tillers per hill (9.0). The lowest number of tillers per hill, 4.9, was recorded in T_1, which was statistically similar to the treatments T_2 and T_3. Table 1 shows that an increased level of N progressively increased the tiller production of T. Aman rice, although a higher rate of N had no significant improvement. The improved efficiency in tillers hill^{-1} observed in those treatments was attributed to positive root development and increased nitrogen mobility in soil solution and plant root absorption. The results conform with those of Tripathi and Jaishwal (2006).

Different nitrogen doses significantly affected the number of filled grains per panicle (Table 1). The highest number of grains per panicle (142.1) was obtained from 90 kg N ha^{-1}(100% recommended rate). The results clearly showed that with theincrease in the nitrogen dose, the number of grainsper panicle progressively increased to a certain level. After that, it sharply decreased. It indicates that excess N reduced rice fertility, which ultimately negativelyimpacted achieving higherrice yields (Zhao et al., 2022). It was found that 90 kg N ha^{-1}(100% recommended rate) treatment had 80% higher grain production over control. This might be because of the interaction between the source and sink, indicating that the maximum N source percentage is used per panicle and grain filling to create maximum spikelets (Ghoneim et al., 2018).

Thousand-grain weight of T. Aman rice did not vary significantly due to different N doses (Table 1). It probably happened due to the genetic characteristics of rice because rice coleoptile size did not vary to a greater extent by any management practices.

Yield parameters

Different nitrogen doses significantly affected the grain yield of T. Aman rice (Table 2). The lowest grain yield of 3.74 t ha^{-1} was recorded in the control treatment. The grain yield was progressively increased up to 54 kg N ha^{-1} with the increase of the rate of N application, and the highest yield of 5.04 t ha^{-1} was found at 54 kg N ha^{-1}rate, and yield decreased with increasing N rate. From the crop response curve, grain yield attained a static level up to 72 kg N ha^{-1}, and after that, grain yield decreased with increasing N rates under tidal flooded conditions. All the grain yield data were fitted into a quadratic equation of crop response curve to find out the optimum rate of N for growing T. Aman rice. It was found from Fig. 1 that 75 kg N ha^{-1} was the optimum rate of N for growing T. Aman rice (BR23) under tidal water flooded conditions of the coastal region of Bangladesh. This rate is 83% of the current recommended rate. Therefore, there is a scope to reduce the N rate by about 17% from the AEZ-based recommendation made by the Fertilizer Recommendation Guide (FRG, 2018). Improved root and canopy functions and a morecoordinated source-sink relationship increased yield associated with yield-contributing characters (Ju et al., 2021). The less severe effects of N deficiency for T. Aman rice may be related tolower yield and, therefore decreased demand and to The supplementary supply of N from tidal water inundation (Rahman et al. 2013). Tidal water contains a huge amount of suspended silt and clay particles, which contribute to the N nutrition of the plant (Haque et al. 2008; Haque 2010, 2012). In the experiment, the initial soil contained only 0.45 g kg^{-1} N and 5.6 g kg^{-1} organic carbon, indicating a very low level of N. However, crop response was not obtained in higher N doses because of dissolved N in tidal water. According to Rahman et al. (2013), a 10 cm depth of tidal water can supply 0.05 to 0.46 kg ha^{-1} nitrate, 0.02 to 0.38 kg ha^{-1} ammonium, and 0.05 to 0.42 kg phosphate ha^{-1} daily.

Table 2. Effects of different rates of nitrogen application on yield of T. Aman rice (BR23)

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_1: N control	3.74 ^{b}	4.48 ^{b}	45.6 ^{ab}
T_2: 18 kg N ha^{-1}	4.48 ^{ab}	4.97 ^{ab}	47.3 ^{ab}
T_3: 36 kg N ha^{-1}	4.99 ^{a}	5.17 ^{ab}	49.4 ^{a}
T_4: 54 kg N ha^{-1}	5.04 ^{a}	5.07 ^{ab}	49.6 ^{a}
T_5: 72 kg N ha^{-1}	4.76 ^{a}	5.13 ^{ab}	48.2 ^{ab}
T_6: 90 kg N ha^{-1}*	4.55 ^{ab}	5.46 ^{a}	45.3 ^{ab}
T_7: 108 kg N ha^{-1}	4.36 ^{ab}	5.57 ^{a}	43.9 ^{ab}
T_8: 126 kg N ha^{-1}	4.30 ^{ab}	5.73 ^{a}	42.9 ^{b}
% CV	7.50	6.07	4.47
Pr (> F)	0.0075	0.0068	0.0095

Means with the same letter are not significantly different at the 5% level by DMRT;*indicate recommended rate (FRG, 2018)

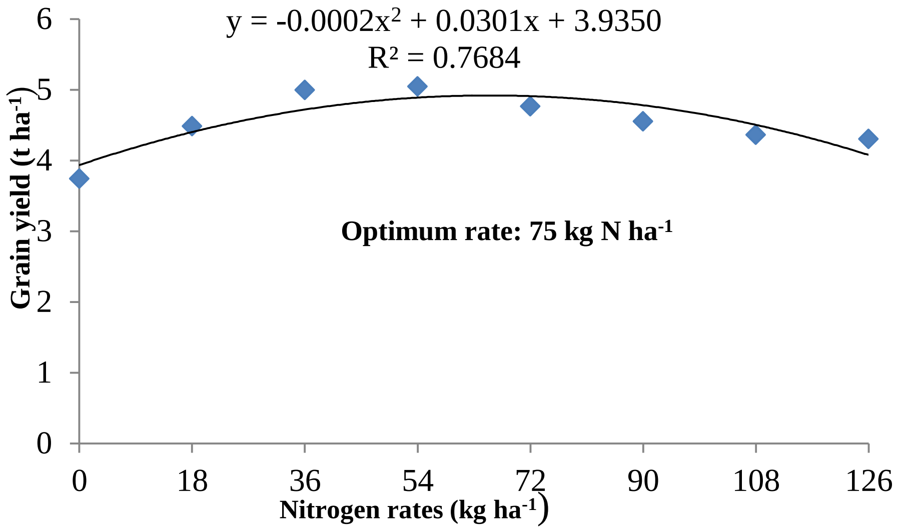

Fig. 1. Crop response curve to identify the optimum rate of N for growing T. Aman rice (BR23) at Ganges tidal water flooded the ecosystem

Optimum N rate = $\frac{-b}{2c} = \frac{-0.0301}{2 \times (-0.0002)}$ = 75 kg ha^{-1}

The straw yield varied significantly due to the application of different doses of nitrogen (Table 2). Results showed that increasing the N dose progressively increased the straw yield of rice; the highest (5.73 t ha^{-1}) was found in 126 kg N ha^{-1}(140% recommended rate), which was statistically similar to 90 and 108 kg N ha^{-1} with the value of 5.46 t ha^{-1} and 5.57 t ha^{-1}, respectively. The lowest straw yield (4.48 t ha^{-1}) was obviously achieved from the control treatment. The results found in grain yield were quite different from straw yield data. Increasing the N rate proportionately increases the vegetative growth of rice; interestingly, excessive vegetative growth does not favor a higher yield; rather, grain yield decreases due to an increase in the sterility of rice. Higher availability of nitrogen in the field at the vegetative growth stage when the primary, secondary, and tertiary tillers are initiated, and the accumulation of dry matter is probably favored to produce the higher straw yield. The results showed that the higher dose of nitrogen influenced vegetative growth in terms of plant height and total tillers per hill, resulting in differences in straw yield (Haque et al., 2003).

The different nitrogen doses significantly influenced the harvest index (HI) (Table 2). No N fertilizer was added in the control treatment, and HI was 45.6. The HI value progressively increased with the increase in the rate of N up to 54 kg N ha^{-1} (49.6 %); after that, it gradually decreased with increasing rate of applied N. The lower HI was found in higher rates of N due to higher straw yield in these treatments. Similar findings also found that the harvest index increased with increasing doses of N fertilizer, but after a certain level, it decreased (Siddique et al., 2014).

Grain and straw N contents

Different nitrogen doses had remarkable effects on the grain N content of T. Aman rice, though the effects on grain N contents were not significantly different (Table 3). Grain N content varied from 1.13 to 1.49 % over the treatments, with the highest value found in 126 kg N ha^{-1} rate and the lowest in the control treatment. It is observed from Table 3 that increasing the applied N rate proportionately increases the grain N content. Unfortunately, a higher rate of N in grain could not contribute to achieving a higher grain yield of rice. It means that rather than excess, a certain level of N in grain is required to attain the maximum rice yield. Various nitrogen doses significantly affect straw nitrogen content (Table 3). Like grain, the straw N content also progressively increased with the increased rate of applied N. The Highest nitrogen content (1.33%) was obtained from the T_8 (126 kg N ha^{-1}) treatment, and the lowest straw nitrogen content (0.95%) was found in the control treatment. However, there was found no significant difference in straw N contents in all the N doses except control.

Table 3. Effects of different rates of nitrogen application on N content and uptake of T. Aman rice (BR23)

Treatments	Grain N content (%)	Straw N content (%)	Grain N uptake (kg ha^{-1})	Straw N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})
T_1: N control	1.13	0.95^b	42.14^b	42.84^d	84.89^b
T_2: 18 kg N ha^{-1}	1.39	1.18^a	62.40^a	58.38^c	120.78^a
T_3: 36 kg N ha^{-1}	1.44	1.21^a	72.32^a	62.49^{bc}	134.81^a
T_4: 54 kg N ha^{-1}	1.41	1.22^a	70.20^a	61.69^{bc}	131.89^a
T_5: 72 kg N ha^{-1}	1.43	1.25^a	67.97^a	63.85^{abc}	131.82^a
T_6: 90 kg N ha^{-1}*	1.46	1.23^a	66.56^a	67.35^{abc}	133.91^a
T_7: 108 kg N ha^{-1}	1.48	1.31^a	64.70^a	72.98^{ab}	137.68^a
T_8: 126 kg N ha^{-1}	1.49	1.33^a	64.11^a	76.21^a	140.32^a
% CV	10.36	6.14	10.56	6.88	7.08
Pr (> F)	0.1375	0.0008	0.0023	0.000	0.0001

Means with the same letter are not significantly different at the 5% level by DMRT; * indicate recommended rate (FRG, 2018).

Nitrogen uptake

Grain nitrogen uptake varied significantly with different nitrogen doses (Table 3). It varies from 42.14 kg ha^{-1} to 64.11 kg ha^{-1} over the treatments. Different nitrogen doses also significantly influenced straw nitrogen uptake (Table 3). The highest straw nitrogen uptake (76.21 kg ha^{-1}) takes place in the T_8 (126 kg N ha^{-1}) treatment, and the lowest straw nitrogen uptake (42.84 kg ha^{-1}) takes place in the T_1 (no nitrogen) treatment. Total nitrogen uptake also varied due to different N doses (Table 3). It varies from 84.89 kg ha^{-1} to 140.32 kg ha^{-1}. The highest was found in T_8 (126 kg N ha^{-1}), and the lowest was in T_1 (no nitrogen) treatment.

Agronomic use efficiency of N

Nitrogen doses had a tremendous effect on agronomic efficiency of N (AEN; Fig. 2). The AEN varied from 4.5 to 41.1 kg grain per kg added N. In lower N application doses, agronomic efficiency was found to be higher, and agronomic efficiency was found to be lower in higher N application doses. Haque and Hoque (2023) reported that the progressively increased rate of N application increased both grain yield and N concentration in plants following quadratic model, therefore, at a lower rate of N application, the N use efficiency parameters were higher, and at a higher rate, the N use efficiency was lower. At low doses of N fertilizer application, Saleque et al. (2005) also indicated that AEN generally is higher.

Recovery efficiency of N (REN)

Nitrogen doses greatly affected recovery efficiency (Fig. 3). The REN varied from 0.174 to 1.125 kg grain per kg added N. In lower N application doses, the recovery efficiency was higher, and similarly, in higher N application doses, the recovery efficiency was lower.

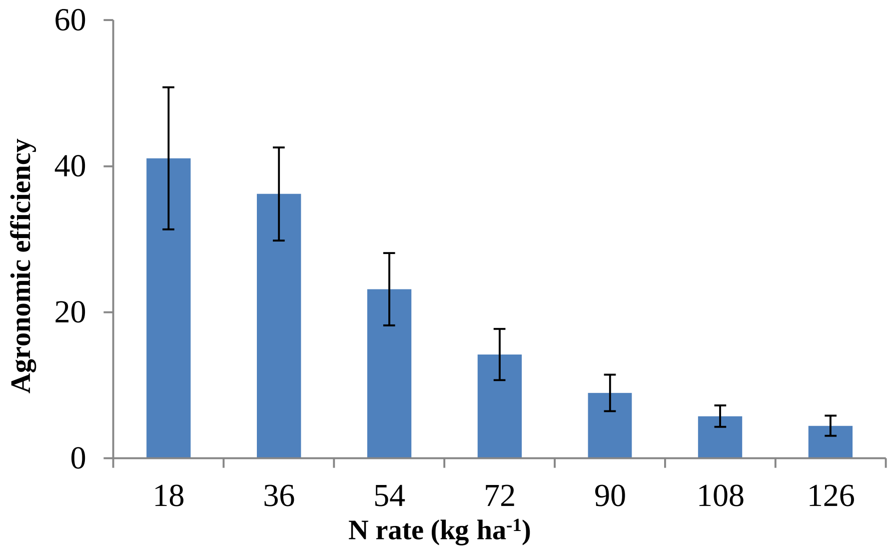

Fig. 2. Agronomic efficiency (kg grain kg^{-1}N) of nitrogen for growing T. Aman rice (BR23) at Ganges tidal water flooded coastal ecosystem of Bangladesh; vertical lines in bars indicate standard error of the mean.

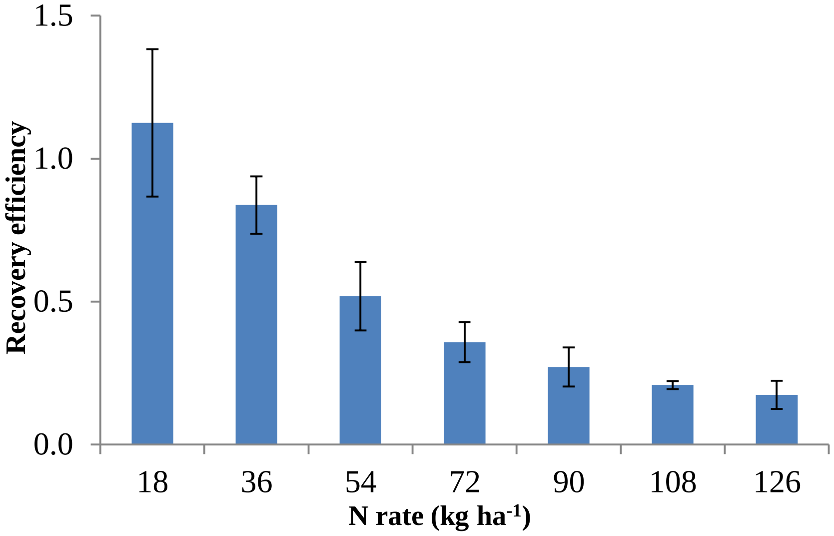

Fig. 3. Recovery efficiency (kg N uptake kg^{-1} added N) of nitrogen for growing T. Aman rice (BR23) at Ganges tidal water flooded coastal ecosystem of Bangladesh; vertical lines in bars indicate standard error of the mean.

Physiological efficiency of N (PEN)

Nitrogen doses had an interesting effect on the physiological efficiency of N (Fig. 4). The PEN varied from 27.5 to 44.5 kg grain per kg N uptake. Firstly, in lower N application doses, the PEN was found to be lower; similarly, in higher N application doses, the PEN was higher. Physiological efficiency was found to be highest at a 54 kg N ha^{-1} rate but gradually decreased after an increase in nitrogen rate.

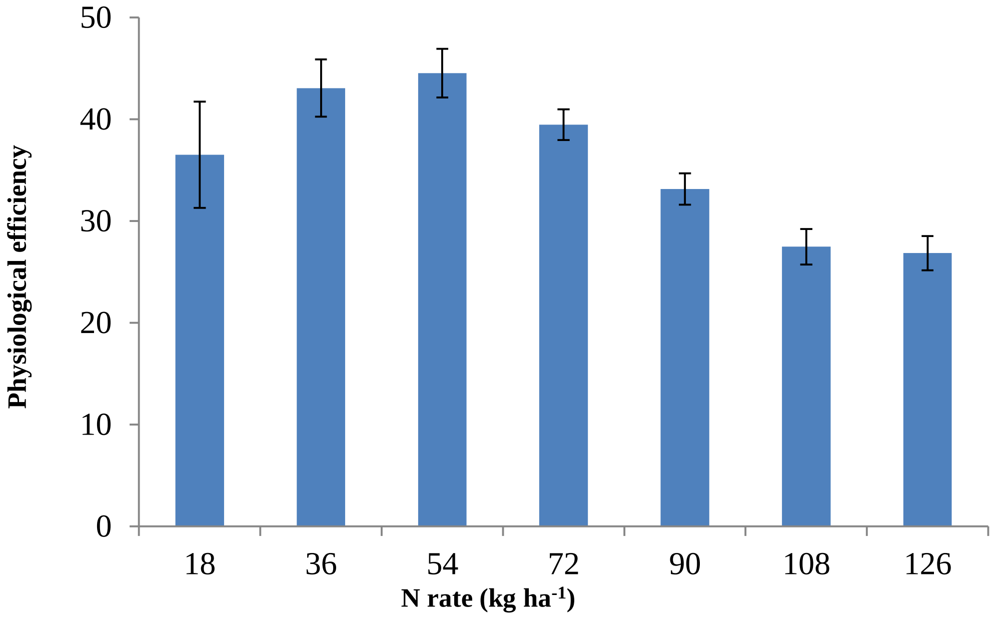

Fig. 4. Physiological efficiency (kg grain kg^{-1} N uptake) of nitrogen for growing T. Aman rice (BR23) at Ganges tidal water flooded coastal ecosystem of Bangladesh; vertical lines in bars indicate standard error of the mean.

Chlorophyll content of leaf

Chlorophyll-a, chlorophyll-b, and total chlorophyll content varied significantly with different nitrogen doses (Table 4). Increased N levels progressively increased the chlorophyll content of the leaf. Over the treatments, chlorophyll-a, chlorophyll-b, and totalchlorophyll content varied from 2.48 to 3.36, 0.52 to 0.77 and 3.01 to 4.13 mg g^{-1} fresh leaf, respectively. Overall results indicated that the application of N increases the chlorophyll contentof rice, and it was progressively increased with the increase of the rate of N. The use of nitrogen immediately increased the content of chlorophyll and leaf surface, leading to higher photosynthesis (Verma et al., 2004). The findings of this study revealed that a suitable nitrogen rate may increase photosynthesis, but excess nitrogen was not favorable for photosynthesis. Nitrogen is one of the major nutrients in chlorophyll biosynthesis (Razaq et al., 2017).

Conclusion

Increasing nitrogen levels caused an increase in plant growth and development up to a certain level of nitrogen application; after that, crop growth decreased. One of the essential factors to enhance N efficiency in rice cultivars is the application of an adequate quantity of N fertilizers. Optimum N application rate enhances the efficiency of N usage. It was found that 75 kg N ha^{-1} is an optimal N rate for producing a higher grain yield of T. Aman rice. This optimum rate is 83% of the current recommended rate for T. Aman rice in the study area. Therefore, there is a scope to reduce the N rate by about 17% from the Fertilizer Recommendation Guide (FRG-2018) recommend-dation. Further study is suggested to validate the findings by including more areas and other rice varieties.

Table 4. Effects of different rates of nitrogen application on chlorophyll content of leaf of T. Aman rice (BR23)

Treatments	Chlorophyll-a (mg g^{-1} fresh leaf)	Chlorophyll-b (mg g^{-1} fresh leaf)	Total chlorophyll (mg g^{-1} fresh leaf)
T_1: N control	2.48^{b}	0.52^{b}	3.01^{b}
T_2: 18 kg N ha^{-1}	2.82^{ab}	0.63^{ab}	3.45^{ab}
T_3: 36 kg N ha^{-1}	2.86^{ab}	0.64^{ab}	3.5^{ab}
T_4: 54 kg N ha^{-1}	2.88^{ab}	0.66^{ab}	3.53^{ab}
T_5: 72 kg N ha^{-1}	3.08^{ab}	0.69^{ab}	3.77^{ab}
T_6: 90 kg N ha^{-1}*	$3.21a^{b}$	0.75^{a}	3.96^{ab}
T_7: 108 kg N ha^{-1}	3.36^{a}	0.77^{a}	4.13^{a}
T_8: 126 kg N ha^{-1}	3.27^{ab}	0.77^{a}	4.04^{a}
% CV	9.25	11.23	9.33
Pr (> F)	0.0277	0.0173	0.0202

Means with the same letter are not significantly different at the 5% level by DMRT; *indicate recommended rate (FRG, 2018)

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Author contributions

Samsunnahar Pranto experimented and wrote the first draft of the manuscript. Mohammad Asadul Haque planned and supervised the research work, edited, improved, and submitted the manuscript. Md Fazlul Hoque helped in the chemical analysis of soil and plant samples.

Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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