J Bangladesh Agril Univ 23(3): 322–330, 2025 https://doi.org/10.3329/jbau.v23i3.84453

ISSN 1810-3030 (Print) 2408-8684 (Online)

Journal of Bangladesh Agricultural University

Journal home page: http://baures.bau.edu.bd/jbau

Research Article

Influence of Plant Spacing and Nitrogen Fertilizer on Growth, Yield and Yield Contributing Characters of Aus Rice Grown in the Coastal Region of Patuakhali in Bangladesh

Samsunnahar Pranto and Mohammad Asadul Haque✉

Department of Soil Science, Patuakhali Science and Technology University, Patuakhali 8602, Bangladesh

ARTICLE INFO

Article history
Received: 21 July 2025
Accepted: 18 September 2025
Published: 30 September 2025

Keywords
Aus rice,
Coastal ecosystem,
Grain yield,
Spacing,
Nitrogen rates

Correspondence
Mohammad Asadul Haque
✉: masadulh@pstu.ac.bd

OPEN ACCESS

Abstract

Rice is a principal crop cultivated across the coast of Bangladesh where plant spacing and nitrogen (N) level have distinct impingement on the rice production. But the favorable spacing along with appropriate N rate for this tidal coastal ecosystem has not decided yet. The study was escorted at Dumki upazila of Patuakhali district, Bangladesh during transplanted (T) Aus rice season of 2023 to find out optimum plant spacing and N fertilizer rates for rice in coastal ecosystem. Two factors Randomized complete Block Design was implemented in the study with three replications. The number of treatments was 12 which comprised of divergent levels of spacing (i.e. 20 cm ×15 cm, 25 cm ×15 cm, 20 cm ×20 cm, 30 cm ×15 cm, 25 cm × 20 cm, and 30 cm ×30 cm) and two different dosages of N (i.e. N rate of 50.4 kg ha^{-1} and 72 kg ha^{-1} that are equivalent to 70% and 100% of the recommended dosage of N, respectively). The findings of the study manifested that, although the yield assigning parameters like plant height, tillers hill^{-1}, grains panicle^{-1} etc. increased with the increase of spacing, grain yield (t ha^{-1}) was maximum (5.05 t ha^{-1}) at closer spacing (i.e. 20 × 15 cm) and 50.4 kg N ha^{-1}. At wider spacing, the number of tillers m^{-2} was quiet less compared to closer spacing which basically results in low yield of rice crop. The 50.4 kg N ha^{-1} combined with 20 cm×15 cm spacing was the best treatment for Aus rice in the tidal coastal region of Bangladesh.

Introduction

Rice (*Oryza sativa* L.) is the core cereals of greater part of the earth's inhabitants along with south and south-east Asia particularly in the offshore area of Bangladesh for its wide malleability to diversified ecosystem (Sume et al., 2023). Rice aligns third position in the world regarding production, with a gross yield of 502.98 million metric tons (Shahbandeh, 2023). It is the staple grain food for the citizens of Bangladesh. Rice production expanded to 56.9 from 15.1 million tons in 2021 from 1972 to meet up the need of Bangladeshi people (Knoema, 2023). But the entire rice growing area is dropping constantly for the reason of swift urbanization. In some cases, production become down word due to imbalance of nutrients and fertilizer application and inappropriate plant spacing (Khanam et al., 2000; Sultana et al., 2021; Haque et al., 2000; 2023a; 2025a). Recent change in climatic factors including frequent storm, surges and salinity was interacting on nutrient requirement of crops in the shoreside ecosphere (Jodder et al., 2016; Sikder et al., 2016; Shila et al., 2016; Haque et al., 2025b). Nutrient excavates by crops has been risen many folds considering current inflation in cropping intensity (Haque and Hoque, 2023; Haque et al., 2024ab; 2025c). But it should be swollen to further fold to expedient the requirement of the intensifying residents of the region (Kumar et al., 2018).

Nitrogen is a decisive element for maximizing rice grain yields in this coastal area. But if N fertilizer is abused, it would be cause of pollution of ground water (Pranto et al., 2023). Excess N fertilization also contributes soil acidification along with environmental pollution (Ma et al., 2021). At present, modernized fabricated yield comprises employing optimum fertilizer doses and

Cite This Article
Pranto, S. and Haque, M.A. 2025. Influence of Plant Spacing and Nitrogen Fertilizer on Growth, Yield and Yield Contributing Characters of Aus Rice grown in the Coastal Region of Patuakhali in Bangladesh. *Journal of Bangladesh Agricultural University*, 23(3): 322–330. https://doi.org/10.3329/jbau.v23i3.84453

application method to enhance outcomes for each area (Haque et al., 2023b). And the optimum rate is that rate at which farmers get highest economic yield. Over doses of N fertilizer enhance the vegetative expansion of rice absurdly that makes plants susceptible to lodging and pest incidence which ultimately decreases the yield of rice (Haque et al., 2015; 2018). It is very pivotal to ensure optimum N requirement for rice plant at the coastal area. Appropriate N fertilization could balance yield and quality of rice grain but excessive N fertilization is ruinous to grain quality and also decline taste (Haque et al., 2025d).

Plant spacing is also a very vital agronomic practice that should be maintained during transplanting of rice plant. As rice yield is a combined result of nutrient availability, soil water content, solar radiation, atmospheric condition and other growth input factors; a pertinent population of plants is essential for an optimum level of production (Baloch et al., 2002). Proper spacing increases leaf area index, light inceptions are adequate for photosynthesis at proper spacing which leads to enhance the yield of rice. It also ensures proper growth of both aboveground and belowground plant portions by efficient utilization of solar energy and available nutrients (Miah et al., 1990). When the spacing among plants is more, the number of plants as well as tillers m^{-2} is becoming less, and smaller number of tillers per m^2 eventually lowers the yield of rice. Optimum spacing can accelerate yield by 25 to 40% over irregular spacing. Plant spacing alters plant density, grain and straw weight, quantity of grains $panicle^{-1}$ and grain production etc. (Hasanuzzaman et al., 2009). At proper spacing, growth of individual plant is far better as optimum spacing ensure below contesting in the plant population for air, sunlight, nutrients and other inputs. And it also facilitates proper intercultural operations (Salahuddin et al., 2009). Researchers found that optimum nitrogen level and different spacing alter the growth and yield contributing characters including plant height, number of tillers, filled or unfilled grain, grain weight, grain outturn, straw production etc. (Abriham and Nazib, 2022). Maintaining favorable spacing is therefore very crucial for maximizing yield of rice.

In the coastal region, farmers generally use very wider plant spacing with excessive seedlings number $hill^{-1}$. From the traditional concept, farmers believe that wider plant spacing will produce plenty of tillers $hill^{-1}$ which will give greater yield than the closer one. However, researchers recommended closer plant spacing with limited quantity of seedlings $hill^{-1}$. For example, Bangladesh Rice Research Institute (BRRI) recommended plant spacing for BRRI dhan48 is 20 cm ×15 cm. So, there was a miss match of concepts among the farmers and researchers. However, the BRRI recommendation is for non-tidal water flooded region of the county; there was no such recommendation for tidal water flooded coastal ecosystem. This experiment was executed to identify the optimum plant distance and N fertilizer dose for Aus rice at coastal tidal water inundated areas of Bangladesh.

Materials and Methods

Location and soil

The field trail was carried out at eastern Gangetic coastal plains in 2023 at pre-monsoon season (May-August). The study was performed at farmer's field of Kartikpasha village of Dumki upazila, under Patuakhali district of Bangladesh which is typically coastal non-saline tidal water flooded area. The terrestrial location of the study site belongs between latitude 22.44355° and longitude 90.33682°. The experimental field surface soil (0-15 cm) was clay loam in texture. The field soil was non-saline and moderately acidic in nature with pH value 6.1 and electrical conductivity 1.12 dS m^{-1}. Total Kjeldahl nitrogen (N) of the experimental field soil was low (1.1 g kg^{-1}). Bray and Kurtz phosphorus was also low (7.1 mg kg^{-1}). NH_4OAC exchangeable potassium (K) was moderate (0.28 cmol kg^{-1} soil). The land type was moderately high.

Season and crop variety

Bangladesh Rice Research Institute (BRRI) developed rice variety named BRRI dhan48 was accustomed in this experiment that was declared in the year of 2008. It is a pre-monsoon (*Kharif-I*) Aus rice variety. Its standard height is 103-106 cm and life cycle is 110 days. The amount of protein in the rice is 8.5% and probable outturn is 5.5 t ha^{-1}. There are three cropping seasons in the experimental area. These are late *Rabi* season (January–March) which is very short duration season, *Kharif-I* prolongs long period (April to August), and late *Kharif-II* prolongs moderate period (August to December). Usually, fields endure uncultivated because of delayed depletion of soil moisture from the field in Rabi season. In *Kharif-I* (Aus) season BRRI dhan48 is cultivated by the farmers. During *Kharif-II*, farmers usually cultivate conventional photosensitive Aman rice varieties, although some high yielding rice varieties are also produced at the study location.

Treatments

The treatments comprised two factorial combinations of six inter-row spacing (i.e., 20 cm × 15 cm, 25 cm × 15 cm, 20 cm × 20 cm, 30 cm × 15 cm, 25 cm × 20 cm and 30 cm × 30 cm) and two N fertilizer rates (50.4 and 72 kg N ha^{-1}). The recommended rate of N for Aus rice was 72 kg N ha^{-1} (FRG, 2018). Hence, 50.4 and 72 kg N ha^{-1} was the 70 and 100 % of the recommended dose, respectively. All the treatments were replicated thrice following randomized complete block design. The measurement of each plot for every treatment was 4 × 3 m (12 m²).

Field management

The trail field was got ready by three ploughing using a rotary tiller and one after another leveling operations. The seeds were sown in seed bed on the 6 May, 2023 and 2-3 healthy seedlings comprising a hill were transplanted on the 02 June, 2023 in puddled condition of the field. For proper nourishment of the plants proper fertilizers were applied in the field. The N, P and K were put in the plots. The dosages of P and K were 10 and 40 kg ha^{-1}, respectively. The applied fertilizer rates were determined following the Fertilizer Recommendation Guide (2018). N was applied as urea at the rate of 50.4 kg ha^{-1} and 72 kg ha^{-1} at planting time as basal, 20 days after transplanting (DAT) and 35 DAT. P and K were applied in the form of triple super phosphate and Muriate of Potash, respectively after plot preparation as basal dose.

Intercultural operations

To minimize weed growth, herbicide was applied at 5 DAT. Manual weeding was also done during application of urea fertilizer. After 10 days of transplanting, Furadan was given in each plot to limit the infestation of rice stem borer. At 20 DAT, Virtaco insecticide was sprayed throughout the field. At ripening stage of crop rat trap was used to protect crops from rats. As, rice crop was cultivated under rain fed condition, there was no need to irrigate the field.

Data collection

The crops were harvested on the 19 August, 2023 at its 80% maturity. After threshing the grain and straw weight data were recorded separately. The grain and straw yield data were expressed at 14 % moisture content basis and sun-dry basis, respectively. The height of 5 plants was listed randomly then the listed data were calculated for average plant height. Using a centimeter scale plant height was recorded from ground level to top of the panicle. Amount of filled grains of 10 haphazardly chosen panicles were counted manually which is termed as number of grains per panicle. 1000-grains were also collected from each plot randomly and the weight was noted. The grain and straw weight of randomly selected 4 m² area were measured and converted the grain and straw yield into ton per hectare.

Statistical analysis

STAR (Statistical Tool for Agricultural Research) software version 2.0.1 was accustomed for doing statistical analysis for the study. The response of crops to spacing, amounts of N and their interactions on plant height, number of grains per panicle, tillers per hill, tillers m^{-2}, 1000-grain weight, grain yield and straw yield were resolved by applying a two-way analysis of variance (ANOVA) model. The Least Significant Difference test was employed to differentiate the means at 95% confidence level. The Pearson's correlation coefficients were calculated using same software.

Results

Plant height

Plant height of rice was greatly altered by different spacing but N rate had less impact on plant height. The topmost plant height of 125 cm was obtained from spacing of 30 cm ×30 cm (900 cm^2) and at 72 kg N ha^{-1} (Table 1). However, 30 cm ×30 cm (900 cm^2) spacing is statistically similar with 30 cm ×15 cm (450 cm^2) and 25 cm ×20 cm (500 cm^2) spacing. The lowest plant height (i.e.114 cm) was at 20 cm ×15 cm (300 cm^2). The interaction between spacing and N rate is not significant.

Tillers hill^{-1}

Spacing between rice plants had a significant effect on tillers number hill^{-1}. With the increase of spacing between rice plants, number of tillers hill^{-1} was progressively increased. It was maximum (18.4) at 30 cm ×30 cm spacing and at 50.4 kg N ha^{-1} (Table 1). With the same spacing, this tiller number was 18.0 at 72 kg N ha^{-1}. From the second highest spacing (i.e. 25 cm×20 cm), number of tillers hill^{-1} was similar with 25 cm ×25 cm, 20 cm ×20 cm and 30 cm ×15 cm spacing. But the difference between 50.4 kg N ha^{-1} and 72 kg N ha^{-1} on number of tillers hill^{-1} was not significant.

Tillers m^{-2}

Row spacing remarkably affected the number of effective tillers m^{-2}, but N application rate had no significant effect on effective tillers m^{-2}. However, 50.4 kg N ha^{-1} produced more effective tillers than 72 kg N ha^{-1} rate (Table 1). But spacing has the most obvious impact on effective tillers m^{-2}. When the spacing expanded the number of tillers m^{-2} was gradually reduced; the 20×15 cm (300 cm^2) spacing produced the highest tillers m^{-2} (271) which was statistically similar with 25 cm +×15 cm (375 cm^2), 20×20 cm (400cm^2) and 30×15 cm (450 cm^2).

Table 1. Growth parameters of rice as influenced by plant spacing in two N application rates at coastal region of Bangladesh

Plant spacing	N rates (kg ha^{-1})		Plant spacing mean
	50.4 kg N ha^{-1}	72 kg N ha^{-1}	
Plant height (cm)			
20 cm×15 cm (300 cm^2)	114	111	113 c
25 cm×15 cm (375 cm^2)	118	116	117 bc
20 cm×20 cm (400 cm^2)	118	117	117 bc
30 cm×15 cm (450 cm^2)	121	124	123 ab
25 cm×20 cm (500 cm^2)	120	124	122 ab
30 cm×30 cm (900 cm^2)	123	125	124 a
N rate mean	119	120	
Significance level	Significance level: N rate-ns, Spacing-**, Interaction-ns SE (±): N rate-1.65, Spacing-2.86, Interaction-4.05; CV (%)-4.16		
Tillers hill^{-1} (no.)			
20 cm×15 cm (300 cm^2)	8.1	7.1	7.6 c
25 cm×15 cm (375 cm^2)	9.9	9.9	9.9 b
20 cm×20 cm (400 cm^2)	9.5	10.1	9.8 b
30 cm×15 cm (450 cm^2)	10.9	10.4	10.6 b
25 cm×20 cm (500 cm^2)	10.9	11.3	11.1 b
30 cm×30 cm (900 cm^2)	18.4	18.0	18.2 a
N rate mean	11.3	11.1	
Significance level	Significance level: N rate-ns, Spacing-***, Interaction-ns SE (±): N rate-0.37, Spacing-0.65, Interaction-0.92; CV (%)-10.09		
Tillers m^{-2} (no.)			
20 cm×15 cm (300 cm^2)	271	261	266 a
25 cm×15 cm (375 cm^2)	271	258	265 a
20 cm×20 cm (400 cm^2)	237	253	245 ab
30 cm×15 cm (450 cm^2)	241	231	236 abc
25 cm×20 cm (500 cm^2)	217	227	222 bc
30 cm×30 cm (900 cm^2)	204	200	202 c
N rate mean	240	238	
Significance level	Significance level: N rate-ns, Spacing-***, Interaction-ns SE (±): N rate-6.69, Spacing-11.5, Interaction-16.3; CV (%)-8.38		

Note for all tables:

In plant spacing mean column similar small letter indicates no significant difference. In N rate mean row different capital letter indicates significant difference among the means.

*-Significant at 5% level, **-Significant at 1% level, ***-Significant at 0.1% level, SE-Standard error of means, CV-Coefficient of variation

Grains panicle^{-1}

Plant spacing also had an impact on number of grains panicle^{-1} but it was not significantly altered by N application rates (Table 2). Maximum number of grains panicle^{-1} (117.7) was generated at 72 kg N ha^{-1} with spacing of 30 cm×30 cm. Although increasing plant spacing increases the number of grains panicle^{-1}, however, only 20 cm×15 cm and 30×30 cm spacing was significantly different but other spacing was statistically similar.

1000-grain weight

The 1000-grain weight didn't vary significantly due to plant spacing, N rates and the interactions between them (Table 2). The utmost 1000-grain weight (25.4 g) was gained from 20 cm×20 cm spacing with 72 kg N ha^{-1} rate. The others also produced statistically similar grain weight.

Grain weight hill^{-1}

Grain weight hill^{-1} was markedly affected by different plant spacing and N rates. It was found that grain weight increased with the increase of row spacing (Table 3). Here, 50.4 kg N ha^{-1} produced more grain weight compared to 72 kg N ha^{-1}. Among the spacing, maximum grain weight (27.7 g hill^{-1}) was gained in case of 30 cm×30 cm spacing and while this spacing combined with 50.4 kg N ha^{-1}, the grain weight attained to maximum value of 29.2 g hill^{-1}.

Table 2. Yield contributing parameters of rice as influenced by plant spacing in two N application rates at coastal region of Bangladesh

Plant spacing	N rates (kg ha^{-1})		Plant spacing mean
	50.4 kg N ha^{-1}	72 kg N ha^{-1}	
Grains panicle^{-1} (no.)			
20 cm×15 cm (300 cm^2)	89.8	102.3	96.1 b
25 cm×15 cm (375 cm^2)	98.5	102.3	100.4 ab
20 cm×20 cm (400 cm^2)	101.4	100.7	101.1 ab
30 cm×15 cm (450 cm^2)	99.4	99.5	99.5 ab
25 cm×20 cm (500 cm^2)	104.4	100.1	102.3 ab
30 cm×30 cm (900 cm^2)	105.2	117.7	111.5 a
N rate mean	99.8	103.8	
Significance level	Significance level: N rate-ns, Spacing-*, Interaction-ns		
	SE (±): N rate-2.40, Spacing-4.16, Interaction-5.89; CV (%)-7.09		
1000-grain weight (g)			
20 cm×15 cm (300 cm^2)	24.3	24.7	24.5
25 cm×15 cm (375 cm^2)	24.1	23.3	23.7
20 cm×20 cm (400 cm^2)	24.4	25.4	24.9
30 cm×15 cm (450 cm^2)	23.3	24.4	23.9
25 cm×20 cm (500 cm^2)	24.4	23.3	23.9
30 cm×30 cm (900 cm^2)	23.2	23.2	23.2
N rate mean	23.9	24.1	
Significance level	Significance level: N rate-ns, Spacing-ns, Interaction-ns		
	SE (±): N rate-0.37, Spacing-0.64, Interaction-0.91; CV (%)-4.63		

Grain yield

The results evidenced that rice grain yield was remarkably altered by different spacing and N levels (Table 3). Among the N rates, 50.4 kg ha^{-1} had the topmost grain yield (4.50 t ha^{-1}). Nitrogen @ 72 kg ha^{-1} was found excess for growing BRRI dhan48 at coastal region of Bangladesh. There was an opposite relation of plant spacing to produce grain weight hill^{-1} and grain yield ha^{-1}. With the increasing of plant spacing, the grain yield gradually decreased. Maximum paddy yield was gained from the closest spacing of 20 cm×15 cm (5.04 t ha^{-1}). The plant spacing 25 cm ×15 cm, 20 cm×20 cm and 30 cm×15 cm had statistically similar grain yield. The undermost grain yield (3.54 t ha^{-1}) was at 30 cm ×30 cm spacing. The interaction of spacing and N rates was not significant on grain yield of rice.

Table 3. Grain yield of rice as influence by plant spacing in two N application rates at coastal region of Bangladesh

Plant spacing	N rates		Plant spacing mean
	50.4 kg N ha^{-1}	72 kg N ha^{-1}	
Grain weight (g hill^{-1})			
20 cm×15 cm (300 cm^2)	13.2	13.1	13.2 d
25 cm×15 cm (375 cm^2)	15.5	13.4	14.4 cd
20 cm×20 cm (400 cm^2)	16.5	15.3	15.9 bc
30 cm×15 cm (450 cm^2)	17.7	15.0	16.3 bc
25 cm×20 cm (500 cm^2)	18.2	16.2	17.2 b
30 cm×30 cm (900 cm^2)	29.2	26.2	27.7 a
N rate mean	18.4 A	16.5 B	
Significance level	Significance level: N rate-**, Spacing-***, Interaction-ns		
	SE (±): N rate-0.60, Spacing-1.03, Interaction-1.46; CV (%)-10.25		
Grain yield (t ha^{-1})			
20 cm×15 cm (300 cm^2)	5.05	5.03	5.04 a
25 cm×15 cm (375 cm^2)	4.76	4.24	4.50 b
20 cm×20 cm (400 cm^2)	4.75	4.39	4.57 ab
30 cm×15 cm (450 cm^2)	4.52	3.82	4.17 bc
25 cm×20 cm (500 cm^2)	4.18	3.73	3.95 cd
30 cm×30 cm (900 cm^2)	3.73	3.34	3.54 d
N rate mean	4.50 A	4.09 B	
Significance level	Significance level: N rate-**, Spacing-***, Interaction-ns		
	SE (±): N rate-0.14, Spacing-0.24, Interaction-0.34; CV (%)-9.80		

Straw weight hill^{-1}

Table 4 shows that spacing had a significant effect on the straw weight of rice plants hill^{-1}. The 50.4 and 72 kg N ha^{-1} recorded straw weight of 19.8 and 20.4 g hill^{-1}, respectively which were not statistically different from each other (Table 4). The increasing plant spacing progressively increased the straw weight of BRRI dhan48. Therefore, highest straw weight (33.9 g hill^{-1}) was achieved from 30 cm×30 cm spacing which was significantly higher than all other spacing. The lowest straw weight (13.3 g hill^{-1}) was found at 20 cm×15 cm spacing.

Straw yield

The nitrogen rates, plant spacing and interaction among them had no noteworthy impact on rice straw yield (Table 4). The highest straw yield of 5.10 t ha^{-1} was produced at closest spacing (i.e. 20 cm×15 cm) which was declined gradually with the extension of inter row spacing. The 30 cm×30 cm spacing had the nethermost straw yield (4.50 t ha^{-1}). Among the N rates, 72 kg ha^{-1} had higher outcome than 50.4 kg N ha^{-1}, which indicates that higher N rate favors straw production.

Harvest index

The data revealed that harvest index decreased with the expansion of spacing (Table 4). The topmost harvest index was achieved from 20 cm×15 cm spacing (49.8%). Interestingly, all the plant spacing except 30 cm×30 cm was statistically similar. This result indicated that wider spacing favors shoot production compared to grain. Among N rates, the 50.4 kg N ha^{-1} rate had significantly higher harvest index (48.4%) than 72 kg N ha^{-1} rate (45.8), which further indicates that higher N rate increases production of shoot than grain.

Table 4. Straw yield of rice as influence by plant spacing in two N application rates at coastal region of Bangladesh

Plant spacing	N rates (kg ha^{-1})		Plant spacing mean
	50.4 kg N ha^{-1}	72 kg N ha ha^{-1}	
Straw weight (g hill^{-1})			
20 cm×15 cm (300 cm^2)	13.5	13.1	13.3 d
25 cm×15 cm (375 cm^2)	16.5	16.8	16.7 c
20 cm×20 cm (400 cm^2)	16.8	16.5	16.6 c
30 cm×15 cm (450 cm^2)	16.0	18.6	17.3 c
25 cm×20 cm (500 cm^2)	23.2	22.7	22.9 b
30 cm×30 cm (900 cm^2)	32.9	34.9	33.9 a
N rate mean	19.8	20.4	
Significance level	Significance level: N rate-ns, Spacing-***, Interaction-ns		
	SE (±): N rate-0.86, Spacing-1.48, Interaction-2.10; CV (%)-12.7		
Straw yield (t ha^{-1})			
20 cm×15 cm (300 cm^2)	5.17	5.03	5.10
25 cm×15 cm (375 cm^2)	5.03	5.11	5.07
20 cm×20 cm (400 cm^2)	4.82	4.75	4.78
30 cm×15 cm (450 cm^2)	4.52	4.76	4.64
25 cm×20 cm (500 cm^2)	4.61	4.79	4.70
30 cm×30 cm (900 cm^2)	4.54	4.46	4.50
N rate mean	4.78	4.81	
Significance level	Significance level: N rate-ns, Spacing-ns, Interaction-ns		
	SE (±): N rate-0.15, Spacing-0.26, Interaction-0.37; CV (%)-9.35		
Harvest index (%)			
20 cm×15 cm (300 cm^2)	49.5	50.0	49.8 a
25 cm×15 cm (375 cm^2)	48.6	45.3	47.0 ab
20 cm×20 cm (400 cm^2)	49.8	48.1	48.9 a
30 cm×15 cm (450 cm^2)	49.9	44.7	47.3 ab
25 cm×20 cm (500 cm^2)	47.5	43.9	45.7 ab
30 cm×30 cm (900 cm^2)	45.1	42.8	43.9 b
N rate mean	48.4 A	45.8 B	
Significance level	Significance level: N rate-**, Spacing-**, Interaction-ns		
	SE (±): N rate-0.80, Spacing-1.39, Interaction-1.97; CV (%)-5.12		

Correlation matrix

In the experiment, improved grain yield was strongly correlated with improved number of tillers m^{-2} (P<0.01, Table 5). However, tillers per hill had a significant negative correlation with grain yield of rice. Straw yield had a significant positive correlation with grain yield of rice.

Table 5. Pearson's correlation coefficients among different plant parameters

	GY	GWH	SY	SWH	PH	TH	TM	GP	TGW
GWH	-0.35*								
SY	0.47**	-0.24ns							
SWH	-0.60***	0.86***	-0.12						
PH	-0.47**	0.41*	-0.01	0.56***					
TH	-0.66***	0.89***	-0.36*	0.88***	0.46**				
TM	0.49**	-0.66***	0.26ns	-0.70***	-0.50**	-0.53**			
GP	-0.23ns	0.58***	-0.11	0.51**	0.13ns	0.44**	-0.58***		
TGW	0.06ns	-0.35	-0.19	-0.35*	-0.26ns	-0.31ns	0.24ns	-0.31ns	
HI	0.75***	-0.23	-0.21	-0.60***	-0.53***	-0.47**	0.37*	-0.18ns	0.24ns

Note: GY- Grain yield, GWH-Grain weight $hill^{-1}$, SY-Straw yield, SWH-Straw weight $hill^{-1}$, PH-Plant height, TH-Tillers $hill^{-1}$, TM-Tillers m^{-2}, GP- Grains $panicle^{-1}$, TGW- Thousand grain weight, HI- Harvest index

Discussion

Plant growth and yield components of Aus rice (BRRI dhan48) were markedly influenced by plant spacing and nitrogen rates in the non-saline tidal coastal region of Bangladesh. Highest plant height and tillers $panicle^{-1}$ was acquired at a wider spacing; plant height and tillers per panicle decreased with the decrease of spacing. At wider spacing plants get air, water, sunlight, nutrients and other inputs in sufficient quantity. On the other hand, closer spacing limits these facilities which cause the stunted growth of plants (Qodliyati et al., 2018). If the spacing among the plants is optimum then the leaf growth enhances by getting proper sunlight and its efficient use. It also stimulates maximum root functioning through proper nutrient absorption. The 50.4 kg N ha^{-1} rate generated maximum tillers m^{-2} (271) compared to 72 kg N ha^{-1}. The reason is that in rainy season plants can absorb more soluble nitrogen from wetland, rain water, tidal water and suspended particles of the tidal water at this coastal tidal region (Haque, 2018). So, the requirement of N fertilizer is low in this area; thus production was the maximum at low fertilizer N supply (Pranto et al., 2023; Haque et al., 2023c).

Despite producing fewer tillers per hill, closer spacing (i.e. 20 cm×15 cm) provided more plants per unit area, thereby increasing the total number of effective tillers m^{-2} and ultimately improving yield. These findings are in agreement with Adhikari et al. (2022) and Dunn et al. (2020), who reported that high plant population density at optimal spacing enhances total biomass and yield in rice.

At closer spacing, the largest amount of plants m^{-2} indicates higher number of effective tillers per hectare which is the key indicator of increased yield (Awan et al., 2011). However, grains per panicle were utmost at 72 kg N ha^{-1} rate and 30 cm×30 cm spacing. This was probably because higher dose of N and maximum spacing may provide the plants with better N status at principle growth period. Using extensive spacing may result lower grain setting but higher weight of grains (Pandey et al., 2023). More N supply resulted in more chlorophyll content of leave that accelerates higher photosynthetic rates and more photosynthates become available during grain development (Haque et al., 2003; Pranto et al., 2023).

The experiment showed that although few parameters were positively responded to wider spacing but the grain yield was negatively responded to wider spacing, while grain yield was top-notch at closer spacing. Although grain yield is dictated by the outcome of different yield contributing features like tillers per plant, tillers per m^2, grains per panicle, thousand grain weight, environmental condition, nutrient and fertilizer applied, their management etc. but various spacing also affect grain yield remarkably. Superior grain yield (5.05 t ha^{-1}) was recorded at 20 cm ×15 cm spacing with 50.4 kg N ha^{-1} rate. Even though other yield contributing features were topmost at wider spacing, yield was minimal at wider spacing when compared with closer spacing. This might be because the gross consequence of other features affecting yield, like the number of plants per m^{-2}, as wider spacing between the plants will automatically restrict the total number of plants in a field or plot. Similar findings were also disclosed by some other researchers (Rajesh and Thanunathan, 2003; Akondo and Hossain, 2019). Besides when the plants were at closer and standard space, the number of primary and secondary tillers will be higher compared to tertiary tillers. More secondary tillers lead to more yield of rice. When there were more plants m^{-2} at closer spacing, there would also be more grain yield (Awan et al., 2011)

At 50.4 kg N ha^{-1} most of the yield influencing attributes i.e. number of grains $panicle^{-1}$, and grains m^{-2}, grain weight and grain yield were maximum. This may happen because Aus rice growing in tidal coastal areas get advantages of the supply of huge amount of nitrate N from tidal water and also rain water. This excess soluble N reduces the requirement of more N fertilizer supplements in soil of these areas (Haque et al., 2023c). This is the main reason of producing more grain yield at lower N rate (i.e., 50.4 kg N ha^{-1}).

Correlation study further supported these findings. Grain yield was strongly and positively correlated with tillers m^{-2}, but negatively with tillers per hill and straw weight per hill, indicating that optimal plant population density, rather than individual tillering capacity or biomass, is the main driver of yield improvement under the coastal ecosystem.

Overall, the findings underscore the need to revise current recommendations for N fertilizer and spacing in coastal rice farming. A closer spacing of 20 cm × 15 cm combined with 50.4 kg N ha^{-1} appears most suitable for maximizing yield of BRRI dhan48 in non-saline tidal coastal areas.

Conclusion

Being the most important serial crop; rice yield is frequently hampered by inappropriate fertilizer application and using unnecessary wider plant spacing in the coastal region of Bangladesh. The wider plant spacing facilitates to produce more tillers $hill^{-1}$; but in a certain area the tiller number is higher in densely transplanted crops. Therefore, the grain yield of BRRI dhan48 was higher in lowest plant spacing (20 cm×15 cm). On the other hand, current recommendation of N fertilizer for BRRI dhan48 in the coastal region is 72 kg ha^{-1} which was about 30% higher than the actual requirement. The dissolved N in tidal water, tidal water suspended particles and higher rainfall is the contributing factor for lower requirement of N fertilizer. Results of the study will assist farmers for judicious N fertilizer application and use of most suitable plant spacing. Similar research could be extended in the salt affected areas of the coastal regions using other traditional and improved rice genotypes.

Acknowledgements

The authors acknowledge the funding for the research through the project "Nutrient Management for Diversified Cropping in Bangladesh", which was funded by Australian Centre for International Agricultural Research, and Krishi Gobeshona Foundation, Bangladesh.

Conflict of interest

The authors declare that they have no financial or non-financial interests that are directly or indirectly related to the work.

References

Abriham, A., Nazib, N. 2022. Response of rice to nitrogen rate and inter-row spacing at Gurferda and Gojeb southwestern Ethiopia. *International Journal of Agricultural Extention,* 10(1):41-46. https://doi.org/10.33687/ijae.010.01.3682

Adhikari, M., Prajina, N., Bahadur, R.L., Raj, P.S., Santosh, M. 2022. Effect of plant spacing and genotype on growth, yield and yield related traits in rice (*Oryza sativa* L.). *Russian Journal of Agricultural and Socio-Economic Sciences*, 123(3):89-98. https://doi.org/10.18551/rjoas.2022-03.10

Akondo, M.R.I. Hossain, M.B. 2019. Effect of spacing on theperformance of newly developed aus rice var. Binadhan-19. *Agriculture Livestock and Fisheries,* 6(3):373-378. https://doi.org/10.3329/ralf.v6i3.44802

Awan, T.H., Ali, R.I., Manzoor, Z., Akhtar, M.A. 2011. Effect of different nitrogen levels and row spacing on the performance of newly evolved medium grain rice variety KSK-133. *The Jounal of Animal and Plant Sciences,* 2(21):231-234.

Baloch, A.W., Soomro, A.M., Javed, M.A., Ahmed, M., Bughio, H.R., Bughio, M.S. Mastoi, N.N. 2002. Optimum plant density for high yielding of rice (*Oryza sativa* L.). *Asian Journal of Plant Sciences,* 1(1):25-27. https://doi.org/10.3923/ajps.2002.114.116

Dunn, B.W., Dunn, T.S., Mitchell, J.H. Brinkhoff, J. 2020. Effects of plant population and row spacing on grain yield of aerial-sown and drill-sown rice. *Crop and Pasture Science,* 71(3):219-228.

FRG 2018. Fertilizer Recommendation Guide-2018. Bangladesh Agricultural Research Council. Farmgate, Dhaka 1215.

Haque, M.A. 2018. Variation in salinity through the soil profile in south coastal region of Bangladesh. *Journal of Bangladesh Academy of Science,* 42(1):11-23. http://dx.doi.org/10.3329/jbas.v42i1.37829

Haque, M.A., Bhuyan, M.I., Jahiruddin, M. 2025a. Impacts of plant spacing and nitrogen on wet season rice yield in the non-saline coast of Bangladesh. *International Journal of Plant Production*. 19:439-448 https://doi.org/10.1007/s42106-025-00345-3

Haque, M.A., Bhuyan, M.I., Jahiruddin, M., Bell, R.W. 2025d. High yielding maize produced negative nitrogen balance despite optimum rate of nitrogen fertilizer. Journal of Soil Science and Plant Nutrition 2025. https://doi.org/10.1007/s42729-025-02636-0

Haque, M.A., Hoque, M.F. 2023. Nitrogen fertilizer requirement and use efficiency in sunflower at Ganges delta coastal salt-affected soils*.* *Communications in Soil Science and Plant Analysis,* 54(16):2248-2262.

Haque, M.A., Hoque, M.F., Jahiruddin, M., Hossain, M.B., Satter, M.A., Haque, M.E. Bell, R.W. 2023a. Performance evaluation of different sources and rates of silicon in rice at eastern Gangetic coastal plains. *Journal of Soil Science and Plant Nutrition*. 23:5084-5096. https://doi.org/10.1007/s42729-023-01520-z

Haque, M.A., Husain, M.M., Jharna, D.E., Uddin, M.N., Iqbal Hussain, A.S.M. 2003. A comparative study of leaf color chart based and farmer's practice of nitrogen fertilizer application on rice under on-farm conditions of Bangladesh. *Pakistan Journal of Biological Sciences,* 6 (19):1685-1688.

Haque, M.A., Jahiruddin, M., Bell, R.W. 2025c. Early sowing of wheat with minimum tillage on wet soils increases yield potential and phosphorus fertilizer requirements on the coastal ecosystem. *Journal of Soil Science and Plant Nutrition,* 25:1047-1058. https://doi.org/10.1007/s42729-024-02183-0

Haque, M.A., Jahiruddin, M., Hoque, M.F., Hossain, M.B., Haque, M.E., Bell, R.W. 2025b. Enhancing sunflower yield by identifying phosphorus fertilizer requirements in the Eastern Ganges delta coastal ecosystem. *Journal of Plant Nutrition*, 48(13):2217-2237. https://doi.org/10.1080/01904167.2025.2470391

Haque, M.A., Jahiruddin, M., Hoque, M.F., Islam, M.S., Hossain, M.B., Satter, M.A., Haque, M.E., Bell, R.W. 2023b. Increasing the use efficiency of fertilizer phosphorus for maize in low-P Ganges delta soils*. Journal of Plant Nutrition.* 46(10):2257-2275. https://doi.org/10.1080/01904167.2022.2155544

Haque, M.A., Jahiruddin, M., Islam, M.R. 2000. Effect of sulphur and boron on seed yield of Mustard (*Brassica napus* L.). *Bangladesh Journal of Seed Science and Technology,* 4 (1&2):7-11.

Haque, M.A., Jahiruddin, M., Islam, M.S., Rahman, M.M., Saleque, M.A. 2018. Effect of bioslurry on the yield of wheat and rice in the wheat–rice cropping system. *Agricultural Research.* 7(4):432-442. https://doi.org/10.1007/s40003-018-0333-7

Haque, M.A., Jahiruddin, M., Rahman, M.M., Saleque, M.A. 2015. Usability of bioslurry to improve system productivity and economic return under potato-rice cropping system. *Research in Agriculture, Livestock and Fisheries.* 2(1):27-33. https://doi.org/10.3329/ralf.v2i1.23026

Haque, M.A., Kabir, M.E., Akhter, S., Hoque, M.F., Sarker, B.C., Anik, M.F.A., Ahmed, A., Pranto, S., Sima, A.S., Lima, F., Jahiruddin, M., Hossain, M.B., Haque, M.E., Satter, M.A., Bell, R.W. 2023c. Crop nutrient limitations in intensified cropping sequences on the Ganges delta coastal floodplains. *Journal of Soil Science and Plant Nutrition.* 23:1996-2006. https://doi.org/10.1007/s42729-023-01154-1

Haque, M.A., Mobaswera, A., Sume, M.A., Pranto, S., Jahiruddin, M., Hoque, M.F., Bell, R.W. 2024a. Silicon supplementation improves yield and silicon uptake + in maize at eastern Ganges delta coastal soils*. Journal of Plant Nutrition.* 47(2): 190-204. https://doi.org/10.1080/01904167.2023.2275066

Haque, M.A., Sima, A.S., Jahiruddin, M., Bell, R.W. 2024b. Minimizing phosphorus mining through optimum phosphorus fertilization in maize. *Journal of Soil Science and Plant Nutrition.* 24:5436-5448. https://doi.org/10.1007/s42729-024-01917-4

Hasanuzzaman, M., Nahar, K., Roy, T., Rahman, M., Hossian, M., Ahmed, J. 2009. Tiller dynamics and dry matter production of transplanted rice as affected by plant spacing and number of seedling per hill. *Academic Journal of Plant Sciences,* 2(3):162-168.

Jodder, R., Haque, M.A., Kumar, T., Jahiruddin, M., Rahman, M.Z., Clarke, D. 2016. Climate change effects and adaptation measures for crop production in South-West coast of Bangladesh. *Research in Agriculture Livestock and Fisheries,* 3(3):369-378. http://dx.doi.org/10.3329/ralf.v3i3.30727

Khanam, R., Arefin, M.S., Haque, M.A., Islam, M.R., Jahiruddin, M. 2000. Effects of magnesium, boron and molybdenum on growth, yield and protein content of chickpea and lentil. *Progressive Agriculture,* 11 (1 & 2):77-80.

Knoema. 2023. *Bangladesh-rice*. Retrieved from paddy production quantity: https://knoema.com/atlas/Bangladesh/topics/Agriculture/Crops-Production-Quantity-tonnes/Rice-paddy-production

Kumar, T., Haque, M.A., Islam, M.S., Hoque, M.F., Jodder, R. 2018. Effect of polythene mulch on growth and yield of sunflower (*Helianthus annuus*). *Achieves of Crop Science*, 2(1):38-46. https://doi.org/10.36959/718/600

Ma, P., Lan, Y., Lyu, T., Li, T.,Yang, Z., Sun, Y., Ma, J. 2021. Nitrogen: fate and efficiency of fertilizer application under a rapeseed-wrheat-rice rotation system in southwest China. *Agronomy,* 11(2):258.

Miah, M.N.H., Karim, M.A, Rahman, M.S., Islam, M.S. 1990. Performance of Nigersail mutants under different row spacing. *Bangladesh Journal of Training and Development,* 3(2):31-34.

Pandey, K.R., Joshi, Y.R., Pathak, A., Subedi, S. 2023. Effect of Different Spacing Practices on Yield and Yield Attributes of Spring Rice in Dhanusha,Nepal. *Journal of Agriculture, Food and Environment,* 4(2):1-7.

Pranto, S., Haque, M.A., Hoque, M.F. 2023. Requirement and use efficiency of nitrogen in transplanted Aman rice at Ganges tidal water flooded coatal ecosystem. *Journal of Bangladesh Academy of Sciences,* 47(2):169-180.

Qodliyati, M., Supriyono., Nyoto, S. 2018. Influence of spacing and depth of planting to growth andyield of arrowroot (*Marantha arundinacea*). *Conference Series: Earth and Environmental Science*, 142.

Rajesh, V., Thanunathan, K. 2003. Effect of seedling age and population management on growth yield of traditional Kambanchamba rice. *Journal of Ecobiology,* 15(2):99-102.

Salahuddin, K.M., Chowhdury, S.H., Munira, S. 2009. Response of nitrogen and plant spacing of transplanted Aman rice. *Bangladesh Journal of Agriciltural Research,* 34(2):279-285.

Shahbandeh, M. 2023. *Worldwide production of grain in 2022/23, by type (in million metric tons).* Retrieved from Statista: https://www.statista.com/statistics/263977/world-grain-production-by-type/

Shila, A., Haque, M.A., Ahmed, R., Howlader, M.H.K. 2016. Effect of different levels of salinity on germination and early seedling growth of sunflower. *World Research Journal of Agricultural Sciences,* 3(1):048-053.

Sikder, M.U., Haque, M.A., Jodder, R., Kumar, T., Mondal, D. 2016. Polythene mulch and irrigation for mitigation of salinity effects on maize (*Zea mays* L*). The Agriculturists,* 14(2):01-13. http://dx.doi.org/10.3329/agric.v14i2.31336.

Sultana, N., Haque, M.A., Hoque, M.F., Hossain, M.B., Satter, M.A., Jahiruddin, M. 2021. Effect of silicon application on growth and biomass yield of rice under salinity stress. *Journal of Bangladesh Agricultural University,* 19(4):429–436. https://doi.org/10.5455/JBAU.117294

Sume, M.A., Haque, M.A., Mobaswera, A., Hoque, M.F., Jahiruddin, M., Bell, R.W. 2023. Identifying varietal differences for silicon mediated improvement of leaf architecture and plant growth in rice. *Silicon,* 15:6299-6311. https://doi.org/10.1007/s12633-023-02514-3