Bangladesh Rice J. 19(2): 65-70, 2015

Rice Response to Nitrogen in Tidal Flooded Non-saline Soil

S M M Islam[1,*], A Khatun[2], F Rahman[1], A T M S Hossain[1], U A Naher[1] and M A Saleque[3]

ABSTRACT

Cultivation of modern varieties (MV) of rice in the coastal non-saline soils of the Asian countries is increasing. Nitrogen (N) deficiency is one of the most nutritional disorders for lowland rice production in Bangladesh. N management recommendation for MV rice in the coastal non-saline soils deserves special attention. A field experiment was conducted for consecutive two years aimed to determine the effect of different nitrogen levels on the yield and nitrogen nutrition of MV rice in coastal non-saline soils of Bangladesh. The field experiment involved five nitrogen levels- 50, 100, 150, 200 and 250 kg ha^{-1} including one N-control in randomized complete block design. The application of 150 kg N ha^{-1} gave the highest yield of 6.76 t ha^{-1} in 2009 and 6.49 t ha^{-1} in 2010, respectively. Total nitrogen uptake at 150 kg N ha^{-1} showed 112 and 116 kg ha^{-1} in 2009 and 2010, respectively. Results averaged over two years showed agronomic use efficiency and physiological use efficiency of 22 and 47 kg kg^{-1} with the application of 150 kg N ha^{-1}. The apparent recovery efficiency of applied nitrogen (150 kg N ha^{-1}) had 44 and 50% in 2009 and 2010, respectively.

Key words: Rice yield, tidal flooded soil, nitrogen use efficiency, nitrogen rate

INTRODUCTION

Coastal and offshore soils occupies about 2.85 million ha in Bangladesh and about 0.73 million ha of the coastal cultivable land has salinity of more than 4.0 dS/m (Saleque *et al*., 2010). The coastal non-saline soils are suitable for growing modern rice in winter season. Nitrogen is the most limiting nutrient for rice in tropical Asian soils and almost every farmer has to apply the costly N fertilizer to get a desirable yield of rice (Fageria *et al*., 2007). The nitrogen fertilizer requirement in a particular area would not be the same for all type of soils, although their yields would be similar in well-fertilized fields. Modern rice varieties need chemical N fertilizer application to achieve higher yield. Tropical rice-growing soils have a capacity to supply about 40-60 kg N from its inherent reserve of organic matter and from the biological fixation during rice growth, which is sufficient to produce rice yield of 2-3 t ha^{-1} (Saleque e*t al*., 2004). A modern rice variety may yield up to 8 t ha^{-1} in the coastal non-saline soils, but it must be supplied with the proper dose of N fertilizer (BRRI, 2008).

However, limited researches has been done so far in Bangladesh to recommend optimum N dose for modern rice in coastal soils of Bangladesh. There are several information on the optimum N rate of rice production in different countries. Manzoor *et al*. (2006) reported the most favorable nitrogen rate of 175 kg ha^{-1} over three years in clay loam soils of Pakistan. Peng *et al*. (2006) reported the optimum nitrogen rates of 150-250 kg ha^{-1} in soils of China. Kumar *et al*. (2010) reported most advantageous nitrogen rate of 122 kg ha^{-1} for Gangetic soil of India. Fageria and Baligar (2001) reported the optimum nitrogen rates of 78-120 kg ha^{-1} in three consecutive years in Inceptisols of Brazil. Saha *et al*. (2012) reported that 30-60 kg N ha^{-1} is sufficient to obtain rice yield (5.0 t ha^{-1}) of some promising lines of T. Aman season in Bangladesh. The nitrogen use efficiency and recovery efficiency of N fertilizer in rice production are rather low. Only 30-40% of applied N is used by the crop, however, due to losses through volatilization, denitrification, leaching and run off (De Datta and Buresh, 1989). Increase in fertilizer nutrient input, especially N fertilizer, has contributed significantly to the improvement of the crop yields in the world (Cassman *et al*., 2003).

[1]Soil Science Division, [2]Rice Farming Systems Division and [3]Coordinator for Advanced Studies and Research, Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh, *Corresponding author's email: mislambrri@gmail.com

Most of the farmers in Bangladesh use N fertilizer for rice production and the dose of N are being increased year after year to sustain the crop yield. Because of using more fertilizer with benefit in yield, the efficiency and recovery of N fertilizer are threatened further. Over application of N fertilizer may actually decrease grain yield by increasing susceptibility to lodging (Pham *et al*., 2004) and damage from pests and diseases (Cu *et al*., 1996). Judicious use of N fertilizer in rice requires synchronizing N fertilizer applications with plant needs. The application of nitrogen fertilizer either in access or less than optimum rate affects both yield and quality of rice to remarkable extent, hence, proper management of crop nutrition is of immense importance. An increase in nitrogen supply increased dry matter and straw yield and N, P and K uptake (Hussain *et al*., 1989; Mahabari *et al*., 1996; Nawaz, 1999; Meena *et al*., 2003).

Salinity level in many coastal soils of the Asian countries (Bangladesh, India, Myanmar, Thailand and Vietnam) is not necessarily high enough to prevent modern rice cultivation. Non-saline coastal lands represent an excellent niche for modern rice production, however, received scant attention in nutrient management option, particularly nitrogen management. Because of tidal sedimentation in every year, coastal non-saline soils possess a good inherent fertility level and nourish the local rice varieties for centuries without any yield reduction. With continuous increasing demand of rice production, MV rice varieties need to be grown in non-saline coastal soils. Our recent studies showed that the tidal flooded coastal soil had no response of rice to applied phosphorus or potassium, but omission of nitrogen greatly limits its yield (BRRI, 2007). However, limited literatures focused on the nitrogen management for coastal non-saline soils. Therefore, the present investigation aimed to compare the yield and nitrogen nutrition of MV rice in tidal non-saline soils under varying levels of nitrogen application.

MATERIALS AND METHODS

The experiment was conducted at the experimental farm of the Bangladesh Rice Research Institute Regional Station, Barisal, Bangladesh in Boro season during 2009 and 2010 located at 22°43′ N latitude and 90°27′ E longitude. The average annual rainfall is 200 mm with more than 80% of it occurring from mid-June to the end of September. Mean temperature is the lowest (15°C) in January and the highest (30°C) in May.

The soil of the experimental field is clay loam in texture. Initial properties of the surface soil (0-15 cm depth) were as follows: pH 6.08, organic carbon 1.2%, available phosphorus (P) 8.7 mg kg^{-1} (0.5 M $NaCO_3$ extracted) and exchangeable potassium (K) 0.26 meq/100 g soil (Neutral 1.0 N NH_4OAc extracted). Treatments consisted of six nitrogen rates: 0, 50, 100, 150, 200 and 250 kg ha^{-1} were applied as urea. A flat dose of P, K and S @ 15-50-10 kg ha^{-1} was applied as soil test basis (STB), respectively. The experiment was laid out in randomized complete block design (RCBD) with three replications. Urea was applied in three equal splits i.e. one-third N at basal, one-third N at active tillering stage and one-third N at 5 to7 days before panicle initiation stage of BRRI dhan29. Phosphorous, K and S fertilizers were applied at final land preparation. The unit plot size was 6 m × 3 m. Fifty-four-day-old seedlings using 2-3 seedlings $hill^{-1}$ were transplanted at 20 cm × 20 cm spacing. All intercultural operations were done as and when required. At maturity, the crop was harvested at 5 m^2 areas at the centre of each plot for straw and grain yield. The grain yield was adjusted to 14% moisture content and straw yield as oven dry basis (Yoshida *et al*., 1976). Nitrogen content from plant samples (grain and straw) was determined by micro Kjeldahl method (Yoshida *et al*., 1976). Means for the treatment effect and coefficient of variance were analyzed using CropStat7.2 software (IRRI, 2007).

RESULTS AND DISCUSSIONS

Grain and straw yield

Nitrogen control plot showed grain yield of 3.41 t ha^{-1} in 2009 and 3.22 t ha^{-1} in 2010. Receiving 50 kg N ha^{-1}, the grain yield increased to 5.19 t ha^{-1} in 2009 and 4.44 t ha^{-1} in 2010 (Table 1). Rice grain yield increased progressively with the increase of nitrogen rate and reached to a maximum (6.76 t ha^{-1} in 2009 and 6.49 t ha^{-1} in 2010) with 150 kg N ha^{-1}. Literatures suggested higher paddy yield at higher nitrogen rates (Marazi *et al*., 1993; Daniel and Wahab, 1994; Bali *et al*., 1995; Nawaz, 1999; and Meena *et al*., 2003). Fageria *et al*. (2011) also reported the highest grain yield was found by nitrogen application of 150 kg ha^{-1} and 250 kg ha^{-1}, respectively. Another study revealed that maximum average grain yield of 20 lowland rice genotypes was obtained at 150 to 200 kg N ha^{-1} (Singh *et al*., 1998). Similarly, Dobermann *et al.* (2000) obtained maximum average grain yield in the dry season at IRRI, Philippines with 120 to 150 kg N ha^{-1}. Singh *et al.* (2007) observed 120 kg N ha^{-1} as an optimum dose for a yield level of 7.45 and 6.80 t ha^{-1} in two consecutive years for direct wet season rice in Indo-Gangetic plain of Ludhiana, India.

Table 1. Effect of N fertilizer rates on grain and straw yields of BRRI dhan29 in BRRI RS farm, Barisal, Boro 2009-10

N rate (kg ha^{-1})	Panicle m^{-2}		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	2009	2010	2009	2010	2009	2010
N_0	183	141	3.41	3.22	3.20	2.33
N_{50}	238	194	5.19	4.44	4.07	3.20
N_{100}	304	196	5.82	5.40	6.78	4.25
N_{150}	332	236	6.76	6.49	6.64	5.18
N_{200}	368	227	6.66	6.48	6.57	5.04
N_{250}	404	271	4.91	6.31	7.57	4.97
$LSD_{0.05}$	34	13	0.70	0.46	2.31	0.39

Nitrogen application at the rate of 200 and 250 kg ha^{-1} declined rice yield compared to that of 150 kg N ha^{-1}. Rice grain yield showed quadratic response with the rates of nitrogen application in both 2009 and 2010 (Figure 1). Response equation ($Y = 3.31 + 0.044\,N - 0.00015\,N^2$, $R^2 = 0.94$ in 2009 and $Y = 3.13 + 0.032N - 0.00008N^2$, $R^2 = 0.99$ in 2010) explained the quadratic relationship between applied N and grain yield. Differentiating the quadratic equation of yield response with respect to applied N doses, the economic optimum dose appeared as 145 kg ha^{-1} in 2009 and 200 kg ha^{-1} in 2010, respectively.

Data points in Figure 1 showed insignificant yield difference between 150 kg N ha^{-1} and 200 kg N ha^{-1} both in 2009 and 2010. But the quadratic equation significantly explained the relationship between applied N and grain yield (R^2=0.94 in 2009 and 0.99 in 2010). The predicted optimum N dose appeared to be an overestimation in 2010.

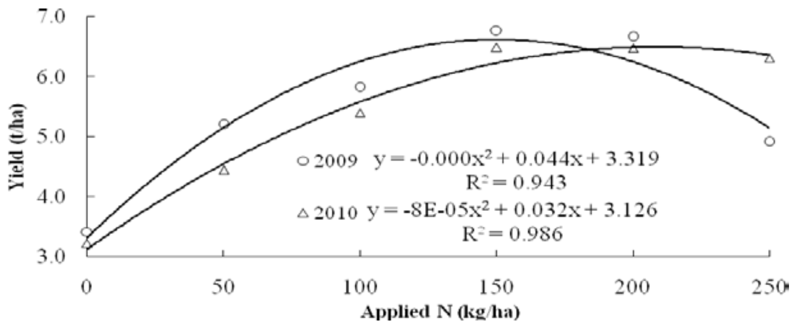

Fig. 1. Quadratic relationship between applied nitrogen and grain yield of rice in 2009 and 2010 under tidal flooded ecosystem

The experimental field soil had a potential nitrogen supplying capacity of 94 kg ha^{-1} and capable of supporting 8.50 t ha^{-1} yield of MV rice according to QUEFTS model (Janssen *et al*., 1990). The calculated dose of N appeared for the estimated yield level was 152 kg ha^{-1}, which agrees the predicted optimum dose of N from the response trial. The observed yields in both the years were about 2 t ha^{-1} lower than the predicted achievable yield. The lower yield might be attributed to the aged seedlings in 2009 and insect (stem borer) infestation in both the years. The application of N increased straw yield significantly in both the years, except the N_{50} treatment in 2009 (Table 1). The variation of straw yield between N control and N_{50} treatment was insignificant in 2009. Other N treatments showed insignificant straw yield in 2009. In 2010, straw yield increased with the increase of N rate up to 150 kg N ha^{-1} then decreased insignificantly. These might be associated with higher nitrogen fertilizer application and tiller or panicle production.

Nitrogen nutrition and uptake

The N concentration in grain varied significantly among the treatments (Table 2). The grain N concentration in N-control plot observed 0.87%, which increased to 1.06% in 2009 and 1.03% in 2010 receiving 50 kg N ha^{-1}. The grain N concentration increased progressively with the increase of N rates. The highest seed N concentration was obtained from 200 kg N ha^{-1} in 2009 (1.18%) and 250 kg N ha^{-1} in 2010 (1.42%). The straw N concentration varied from 0.50 to 0.60% in 2009 and from 0.52 to 0.78% in 2010; however, the values were statistically similar (Table 2).

Grain N uptake in the N control plots had 29.71 and 28.20 kg ha^{-1} in 2009 and 2010, respectively (Table 3). The application of N increased grain N uptake significantly in both the years. Increasing the N rates increased grain N uptake progressively and reached maximum to 78.62 kg ha^{-1} in 2009 and 89.87 kg ha^{-1} in 2010. Straw N uptake varied from 16.95 to 40.87 kg ha^{-1} in 2009 and from 12.35 to 38.74 kg ha^{-1} in 2010, respectively. In both the years,

Table 2. Concentration of N in grain and straw of BRRI dhan29 in BRRI RS farm, Barisal, Boro 2009-10

N rate (kg ha^{-1})	Grain N (%)		Straw N (%)	
	2009	2010	2009	2010
N_0	0.87	0.87	0.53	0.52
N_{50}	1.06	1.03	0.61	0.53
N_{100}	1.11	1.27	0.50	0.58
N_{150}	1.12	1.30	0.56	0.62
N_{200}	1.18	1.36	0.57	0.67
N_{250}	1.13	1.42	0.55	0.78
$LSD_{0.05}$	0.06	0.20	ns	ns

the N-control plots had the lowest N uptake and the plots that received the highest dose of N gave the highest N uptake in rice straw. Total N uptake varied from 46.66 to 115.69 kg ha^{-1} in 2009 and from 40.55 to 128.61 kg ha^{-1} in 2010. The predicted N supplying capacity of 94 kg ha^{-1} from the QUEFTS model corroborated the magnitude of N uptake (46.66 kg ha^{-1} in 2009 and 40.55 kg ha^{-1} in 2010) in the N-control plots assuming about 50% of N recovery of the soil N by lowland rice. The requirement of rice for N fertilizer can, however, vary greatly from location to location, season to season, and year to year because of high variability among fields, seasons, and years in N-supplying capacity of soil (Cassman *et al*., 1996; Dobermann *et al*., 2003). The predicted N supplying capacity from the QUEFTS model supported the extent of N uptake 50% and 43% in the N-control plots.

Nitrogen use efficiency

Agronomic use efficiency (AUE) of N varied from 6.0 to 35.7 kg kg^{-1} in 2009 and from 12.36 to 24.40 kg kg^{-1} in 2010 (Table 4). The AUE was the highest at 50 kg N ha^{-1} and then decreased progressively with the increase of N rates in both the years. The 150 kg N ha^{-1}, which was the desired level of N application for tidal soils, had AUE of 22.3 and 21.8 kg kg^{-1} in 2009 and 2010, respectively. Fageria and Baligar (2001) reported that AUE was 23 kg grain produced per kg of N applied across N rates. Yoshida (1981) reported agronomic efficiency in lowland rice in the tropics in the range of 15 to

Table 3. Nitrogen uptake in BRRI dhan29 as influenced by different nitrogen fertilizer rates in BRRI farm Barisal, Boro 2009-10.

N rate (kg ha^{-1})	Grain N uptake (kg ha^{-1})		Straw N uptake (kg ha^{-1})		Total N uptake (kg ha^{-1})	
	2009	2010	2009	2010	2009	2010
N_0	29.71	28.20	16.95	12.35	46.66	40.55
N_{50}	55.11	46.24	24.79	17.02	79.90	63.26
N_{100}	64.26	69.11	35.46	24.91	99.73	94.02
N_{150}	75.75	84.03	36.40	32.12	112.15	116.15
N_{200}	78.62	88.41	37.07	33.77	115.69	122.18
N_{250}	55.42	89.87	40.87	38.74	96.29	128.61
$LSD_{0.05}$	7.58	13.27	15.00	4.97	20.11	15.43

25 kg grain produced per kg of applied N. Physiological N use efficiency (PUE) varied from 30.2 to 53.7 kg kg^{-1} in 2009 and 38.6 to 53.7 kg kg^{-1} in 2010. As a rule, physiological N use efficiency decreased with the increasing N rates.

Reciprocal of internal N use efficiency (kg N required to produce 1 t of grain) varied from 13.67 to 19.60 kg t^{-1} in 2009 and from 12.59 to 20.38 kg t^{-1} in 2010 (Table 4). Reciprocal of internal N use efficiency (RIUE) showed the lowest in N-control and the highest with the highest rate of N. The RIUE at 150 kg N ha^{-1} had 16.59 and 17.90 kg t^{-1} in 2009 and 2010, respectively. Buresh *et al*. (2010) reported mean RIUE of 16.4 kg t^{-1} with full fertilization and 12.8 kg t^{-1} in-N plots.

Apparent recovery efficiency of N varied from 19.9 to 66.5% in 2009 and 35.22 to 53.47% in 2010 (Table 4). The apparent recovery efficiency (ARE) was higher at 50 kg N ha^{-1} compared to the other higher doses of N and the highest N dose showed the lowest N recovery. The 150 kg N ha^{-1} treatment showed 43.7 and 50.40% N recovery in 2009 and 2010, respectively. For lowland rice in the tropics ARE is 30-50% of applied N depending on season, yield level, the rate and timing of N application (Yoshida, 1981; De Datta, 1986). Fageria and Baligar (2001) also reported that ARE was 39% across N rates in flooded rice cultivar Metica 1.

Table 4. Agronomic use efficiency, physiological efficiency, internal efficiency and recovery of N by BRRI dhan29 in BRRI RS farm, Barisal, Boro 2009-10

N rate (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})		Physiological efficiency (kg kg^{-1})		Reciprocal internal use efficiency (kg kg^{-1})		Apparent recovery efficiency (%)	
	2009	2010	2009	2010	2009	2010	2009	2010
N_0	-	-	-	-	13.67	12.59	-	-
N_{50}	35.7	24.40	53.7	53.72	15.37	14.24	66.5	45.42
N_{100}	24.1	21.80	45.4	40.77	17.12	17.41	53.1	53.47
N_{150}	22.3	21.80	51.1	43.25	16.59	17.90	43.7	50.40
N_{200}	16.2	16.30	47.1	39.94	17.37	18.85	34.5	40.81
N_{250}	6.0	12.36	30.2	38.60	19.60	20.38	19.9	35.22

CONCLUSIONS

Nitrogen management is essential to reduce N losses, improve N use efficiency and obtain higher rice yield. The optimum N dose for tidal soils in Boro season might be 150 kg ha^{-1} for rice. The application of 150 kg N ha^{-1} showed AUE, PUE and RIUE for N as 22.3 and 21.8 kg kg^{-1}, 51.1 and 43.25 kg kg^{-1}, 16.59 and 17.90 kg kg^{-1} in 2009 and 2010, respectively. However, the economic optimum rate of N for BRRI dhan29 appeared as about 173 kg N ha^{-1} averaged over two years. Thus, sufficient N application is one of the strategies to boost straw yield and consequently grain yield in tidal flooded non-saline soil.

REFERENCES

BRRI (Bangladesh Rice Research Institute). 2007. Annual Report for 2006-2007. BRRI, Gazipur 1701. 177-178.

BRRI (Bangladesh Rice Research Institute). 2008. Annual Report for 2007-2008. BRRI, Gazipur 1701.

Buresh, R J, M F Pampolino and C Witt. 2010. Field-specific potassium and phosphorus balances and fertilizer requirements for irrigated rice-based cropping systems. Plant Soil 335: 35-64.

Cassman, K G, A Dobermann, D T Walters and H S Yang. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. Ann. Rev. Environ. Resour. 28: 315-358.

Cassman, K G, A Dobermann, P C S Cruz, G C Gines M I Samson, J P Descalsota, J M Alcantara M A Dizon and D C Olk. 1996. Soil organic matter and the indigenous nitrogen supply of intensive irrigated rice systems in the tropics. Plant Soil 182: 267-278.

Cu, R M, T W Mew, K G Cassman and P S Teng. 1996. Effect of sheath blight on yield in tropical, intensive rice production system. Plant Disease 80:1103-1108.

De Datta, S K. 1986. Improving nitrogen fertilizer efficiency in lowland rice in Tropical Asia.Fert. Res. 9: 171-186.

De Datta, S K and R J Buresh. 1989. Integrated nitrogen management in irrigated rice. Adv. Soil Sci. 10:143-169.

Dobermann, A, C Witt, S Abdulrachman, H C Gines, R Nagarajan, T T Son, P S Tan, G H Wang, N V Chien, V T K Thoa, C V Phung, P Stalin, P Muthakrishnan, V Ravi, M Babu, G C Simbahan and M A AAdviento. 2003. Soil fertility and indigenous nutrient supply in irrigated rice domains of Asia. Agron. J. 95: 913– 923.

Dobermann, A, D Dawe, R P Roetter and K G Cassman. 2000. Reversal of rice yields decline in a long term continuous cropping experiment. Agron. J. 92: 633-643.

Fageria, N K and V C Baligar. 2001. Lowland rice response to nitrogen fertilization.Comm. Soil Sci. Plant Anal. 32: 405-1429.

Fageria, N K and A B Santos and V C Baligar. 1997. Phosphorus soil test calibration for lowland rice on an Inceptisol, Agron. J.89: 737-742.

Fageria, N K, A Moreira and A M Coelho. 2011. Yield and yield components of upland rice as influenced by nitrogen sources. J. Plant Nut. 34: 361–370.

Hussain, T, G Jilani and A Ghaffar. 1989. Influence of rate and time of nitrogen application on growth and yield of rice in Pakistan. Inter. Rice. Res. Newsletter. 18p.

International Rice Research Institute (IRRI), "CropStat for Windows 7.2," Dapo, Metro Manila. 2007.

Janssen, B H, F C T Guiking, D van der Eijk, E M A Smaling, J Wolf and H van Reuler. 1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS).Geoderma 46: 299-318.

Kumar, D, C Devakumar, R Kumar, P A Das, P Panneerselvam and Y S Shivay. 2010. Effect of *neem*-oil coated prilled urea with varying thickness of neem-oil coating and nitrogen rates on productivity and nitrogen-use efficiency of lowland irrigated rice under Indo-Gangetic plains. J. Plant Nut. 33: 1939-1959.

Mahabari, M B, D S Patil and S D Kalke. 1996. Yield and uptake of nutrients as influenced by the method and time of application of nitrogen fertilizer under flood prone rice. Soils and Crops 6: 27–30.

Manzoor, Z, T H Awan, M A Zahid and F A Faiz. 2006. Response of rice crop (super basmoti) to different nitrogen levels. J. Anim. Pl. Sci. 16: 52–55.

Meena, S L, S Surendra, Y S Shivay and S Singh. 2003. Response of hybrid rice (*Oryza sativa*) to nitrogen and potassium application in sandy clay loam soils. Indian J. Agric. Sci. 73: 8–11.

Nawaz, H M A. 1999. Effect of various levels and methods of nitrogen application on nitrogen use efficiency in rice Super Basmati. MSc Thesis Deptt.Agron, Univ. Agric., Faisalabad.

Peng, S, R J Buresh, J Huang, J Yang, Y Zou, X Zhong, G Wang and F Zhang. 2006. Strategies for overcoming low agronomic nitrogen use efficiency in irrigated rice systems in China. Field Crops Res. 96: 37-47.

Pham, Q D, A Abe, M S Hirano Sagawa and E Kuroda. 2004. Analysis of lodging-resistant characteristics of different rice genotypes grown under the standard and nitrogen-free basal dressing accompanied with sparse planting density practices. Plant Prod. Sci. 7: 243–251.

Saha, P K, S M M Islam, M Akter and S K Zaman. 2012. Nitrogen response behaviour of developed promising lines of T. Aman rice. Bangladesh J. Agril. Res. 37: 207-213.

Saleque, M A, U A Naher, N NChoudhury and A T M S Hossain. 2004.Variety-specific nitrogen fertilizer recommendation for lowland rice. Comm. Soil Sci. Plant Anal. 35: 1891–1903.

Saleque, M A, M K Uddin, M A Salam, A M Ismail and S M Haefele. 2010. Soil characteristics of saline and non-saline deltas of Bangladesh. pp (144-153). *In*. Hoanh, C T, B W Szuster, K Suvan-Pheng, A M Ismail and A W Noble. (Eds.) *Tropical deltas and costal zones*. CABI, UK.

Singh, U, J K Ladha, E G Castillo, G Punjalan, A Tirol-Padre, M Duqueza. 1998. Genotypic variation in nitrogen use efficiency in medium and long duration rice. Field Crop Res. 58: 35-53.

Singh, Y, R K Gupta, B Singh and S Gupta. 2007. Efficient management of fertilizer nitrogen in wet direct-seeded rice (*Oryza sativa*) in northwest India. Indian J. Agri. Sci. 77: 56-564.

Yoshida, S, D A Forno, J H Cock and K A Gomez. 1976. *Laboratory Manual for physiological Studies of Rice*. 3rd ed. International Rice research Institute. Manila, Philippines.

Yoshida, S. 1981. *Fundamentals of Rice crop science*, IRRI, Los Banos, Philippines. 269-270.