

## Review

# Nitrogen Fertilizer Management Strategies for Rice Production in Bangladesh

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**Abstract.** Various ways of increasing nitrogen (N) fertilizer use efficiency in rice culture has been evaluated by conducting field experiments at Bangladesh Rice Research Institute (BRRI). Nitrogen fertilizer use efficiency in rice culture can be increased by root-zone application of modified forms of urea like urea large granule (ULG) and urea super granule (USG). The efficiency of urea-N can be increased to some extent even by injection of the conventional prilled urea (PU) into the root-zone of the rice plant by the instrument "Pneumatic Urea Injector". Application of sulphur (S) along with N increases N use efficiency in rice culture in S deficient soils. Modern rice varieties having relatively taller plant stature can exploit more soil N for grain production compared to short statured varieties. Different varieties require different amounts of N for maximum grain yield and it is important to note it to avoid indiscriminate application of a single N rate for all the varieties.

**Keywords:** nitrogen fertilizer, rice production, environmental pollution control

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Rice is the major cereal crop in Bangladesh. With increase in population, the demand for rice is increasing over the years. With intensive research rice yield per unit area has increased gradually over the years (Table 1). Consequently fertilizer consumption especially N fertilizer has also been increased gradually (Table 2). Nitrogen (N) is a primary nutrient for all crops. Rice crop requires large amount of N for its growth, development and grain production (Sahrawat, 2000). Generally rice plant removes around 14-20 kg N to produce one tonne of rough rice including straw (Table 3). Most of the rice soils of the world are deficient in N, and biological nitrogen fixation by Cyanobacteria and diazotrophic bacteria can only meet a fraction of the N requirement (Sattar *et al.*, 2008; Hashem, 2001; Baldani *et al.*, 2000). Thus, fertilizer N application is essential to meet the crop requirement. But, the efficiency of added fertilizer N in rice culture depends on N sources, application method, rate of N as well as management practices as evidenced by the <sup>15</sup>N tracer studies (Wang *et al.*, 2011; Chen *et al.*, 2010; Wang *et al.*, 2008). Prilled urea (PU) is applied as N source for rice but the efficiency of added N from PU is very low, generally it is around 30-45% and in many cases even much lower as determined by the <sup>15</sup>N tracer technique (Table 4).

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This low N use efficiency in rice culture is attributed mainly to denitrification, ammonia volatilisation and leaching losses (Hakeem *et al.*, 2011; Mai *et al.*, 2010; Zhao *et al.*, 2010; Choudhury and Kennedy, 2005). Ammonia volatilisation and denitrification cause atmospheric pollution through the production of greenhouse gases like nitrous oxide, nitric oxide and ammonia (Choudhury and Kennedy, 2005; Reeves *et al.*, 2002). Nitrous oxide absorbs infrared radiation and depletes the stratospheric ozone layer. Nitric oxide causes acid deposition by forming nitric acid. Leaching causes nitrate toxicity in the groundwater. High nitrate toxicity in the groundwater causes human health problems (Shrestha and Ladha, 1998). These problems are of great concern to the agronomists, soil and environmental scientists and policy makers around the world. Appropriate strategies should be taken to reduce N losses and thereby minimize these environmental problems. In this regard, research has been conducted around the world in several research organizations including Bangladesh Rice Research Institute (BRRI). This paper reviews some salient findings of BRRI already published in different journals to accumulate the information altogether indicating N fertilizer management strategies for sustainable rice production and control of environmental pollution problems.

**Table 1.** Population, rice cropped area, rice production and yield in Bangladesh over the years since 1960

Year	Population (million)	Rice cropped area (000 ha)	Paddy production (000 tonnes)	Paddy yield		Rice production (kg/person)	Rice available excluding import (g/person/day)
				t/ha	kg/person		
1960	51.585	8857	14522	1.64	282	197	540
1970	66.671	9912	16731	1.69	251	176	481
1980	88.219	10309	20844	2.02	236	165	453
1990	109.820	10435	26781	2.57	244	171	468
2000	129.194	10887	37633	3.46	291	204	559
2010	153.437	11800	48455	4.11	316	221	606

The population data was collected from the website <http://www.populstat.info/Asia/bangladesh.htm>. The data on rice cropped area and paddy (un-milled rice) production have been collected from the USDA database available in the IRRI website (IRRI, 2011). Paddy yield per person was converted to rice (milled rice) yield considering 70% milling outturn which is average of varieties (BRRI, 2000).

**Table 2.** Consumption of fertilizer N, P and K in Bangladesh over the years since 1961

Year	Fertilizer consumption (000 tonnes)		
	N	P	K
1961	20.0	DNA	1.5
1970	99.2	34.0	10.4
1980	266.2	118.4	28.7
1990	609.2	231.8	90.0
2000	995.8	250.3	143.0
2010	1275.0	420.0	220.3

Source: IFA, 2011; DNA = data not available.

**Table 3.** N, P, K and S removal of four rice varieties

Rice variety	Grain yield (t/ha)	Total amount of nutrients (kg) removed by grain and straw per tonne of grain production				Reference
		N	P	K	S	
BR1	4.2	19.76	3.10	21.43	1.90	Choudhury <i>et al.</i> , 1992
BR3	5.6	13.93	3.39	20.89	2.14	Choudhury <i>et al.</i> , 1994c
BR11	5.2	17.69	3.08	22.31	1.92	Choudhury <i>et al.</i> , 1994c
BR22	4.6	15.65	2.83	19.13	1.96	Choudhury <i>et al.</i> , 1992

**Sources and forms of nitrogen fertilizer.** Now-a-days different sources and forms of N fertilizer are available in the market for commercial use. The most commonly used N fertilizer for rice crop is prilled urea (PU). Urea super granule (USG) is a modified form of urea having an average diameter of 11.5 mm. It has been developed

**Table 4.** Fertilizer N uptake and recovery of MR185 rice in different soils as determined by the <sup>15</sup>N tracer technique

Soil series	Fertilizer N applied (kg/ha)	N uptake (kg/ha) by whole plant (grain and straw)		Fertilizer N recovery (%)
		Total N uptake	Fertilizer N uptake	
Guar	40	96.53	6.40	16
	80	133.21	18.49	23
	120	151.68	28.50	24
Hutan	40	54.39	8.02	20
	80	54.94	13.94	17
	120	47.66	14.22	12
Idris	60	67.82	23.74	40
	120	90.37	48.62	41
	180	116.75	74.44	41
Tebengau	60	53.31	23.72	40
	120	79.46	50.40	42
	180	93.02	68.63	38

Source: Choudhury (2000).

at the International Fertilizer Development Centre (IFDC), United States of America. The superiority of USG over PU in rice culture has been found in many investigations (Roy, 1988; Craswell *et al.*, 1985). Urea large granule (ULG), another modified form of urea having an average diameter of 7 mm, has been developed in the Netherlands. This modified form of urea, because of its larger granule size than PU, may go deep into the mud simply by force throwing, and thus may be expected to be more efficient than PU. Azollon, a slow release nitrogen fertilizer, has been developed in Germany. It is a urea-formaldehyde condensation product containing

38% N. A field experiment was conducted on a clay loam soil at BIRRI to evaluate the relative performances of PU, ULG, USG and azollon in wetland rice culture (Choudhury *et al.*, 1994a). Considering grain yield, USG was significantly superior to PU and azollon; whereas, ULG had a slight edge over PU, but statistically not significantly different (Table 5). Total N uptake increased significantly in ULG and USG treated plots compared to the conventional PU treated plots. Agronomic efficiency and apparent recovery of added N were considerably higher with USG and ULG as compared to PU. Azollon was inferior to PU.

The increase in fertilizer N use efficiency due to the use of modified forms of urea will reduce environmental pollution problems like eutrophication (over enrichment in nutrients), production of greenhouse gases like nitrous oxide and nitrate toxicity in the ground water. However, these modified forms of urea are not commonly used by farmers. Farmers' awareness of environmental benefits of these practices should be created at farm level in order to use USG and ULG for rice production.

**Methods of nitrogen fertilizer application.** Generally, urea is applied as surface broadcasting which causes losses of urea by different mechanisms, and thereby N use efficiency becomes low. Sub-surface placement of N fertilizer into the anaerobic soil zone has been proposed by many investigators as a possible mean of increasing N use efficiency (Reddy and Mitra, 1985). Pneumatic urea injector, an instrument for deep placement of prilled urea, has been developed in the Netherlands. Prilled urea (PU) can be placed through injection by this instrument with necessary calibration into a depth of 8-10 cm. A field experiment was conducted on a clay loam soil at BIRRI to evaluate the relative performance of PU surface broadcasting and PU injection for N use efficiency in wetland rice culture

(Choudhury and Bhuiyan, 1994). In the surface broadcasting method, PU was applied in three equal splits (1/3 immediately after seedling establishment + 1/3 at active tillering stage + 1/3 at 5-7 days before panicle initiation); while in the injection method, PU was applied at a time immediately after seedling establishment. Three rates of N (29, 58 and 87 kg N/ha) were used in both methods of N application. A nitrogen control treatment was also used in the trial. The injection method gave higher grain yield over the surface broadcasting method at all the rates of applied N, however, the difference was significant only at 87 kg N/ha (Table 6). Straw yield and total N uptake were significantly higher with the injection method over the surface broadcasting method at all the rates of added N. Agronomic efficiency and apparent recovery of added N were considerably higher with the injection method.

Although deep place of PU is time consuming and laborious, this will reduce environmental problems by minimizing N fertilizer losses by volatilisation and denitrification in addition to increase in rice yield. Adoption of this technique at farm level by proper demonstration is necessary.

**Nitrogen and sulphur interactions.** Sulphur (S) is a secondary nutrient for all crops. The metabolism of N and S in plants is closely interrelated. As a result plant cannot utilize N properly in S deficient soils and conversely S utilization of plant is being adversely affected by N deficiency in soils (Shah *et al.*, 1996). A field experiment was conducted on a silty clay soil at BIRRI to study the synergistic effects of N and S on growth and yield of wetland rice (Choudhury *et al.*, 1994b). A strong synergistic effect between N and S was observed (Table 7). At 0 kg N/ha, S application at 20 kg/ha increased grain yield by only 0.3 t/ha, while the same S rate increased grain yield by 0.9 t/ha at

**Table 5.** Effects of forms and sources of nitrogen fertilizer on grain yield of BR3 rice, total N uptake, agronomic efficiency and apparent recovery of added N

N rate (kg/ha)	N fertilizer form/source	Grain yield (tonnes/ha)	Total N uptake (kg/ha)	Agronomic efficiency (kg grain/kg added N)	Apparent recovery of added N (%)
0	-	2.9 <sup>d</sup>	36.7 <sup>e</sup>	-	-
87	Prilled urea	4.0 <sup>b</sup>	62.6 <sup>c</sup>	12.6	29.8
87	Urea large granule	4.4 <sup>ab</sup>	70.3 <sup>b</sup>	17.2	38.6
87	Urea super granule	4.6 <sup>a</sup>	91.0 <sup>a</sup>	19.5	62.4
87	Azollon	3.6 <sup>c</sup>	53.0 <sup>d</sup>	8.1	18.7

Values followed by different letters within a column are significantly different at 5% level by Duncan's Multiple Range Test (DMRT); source: Choudhury *et al.* (1994a).

**Table 6.** Effects of rates and methods of nitrogen fertilizer application on grain and straw yields of BR3 rice, total N uptake, agronomic efficiency and apparent recovery of added N

N rate (kg/ha)	Method of application*	Grain yield (t/ha)	Straw yield (t/ha)	Total N uptake (kg/ha)	Agronomic efficiency (kg grain/kg added N)	Apparent recovery of added N (%)
0	-	2.7	1.8	35.9	-	-
29	SB	3.3	2.0	44.3	20.7	29
58	SB	3.6	2.3	49.8	15.5	24
87	SB	4.0	2.6	55.9	14.9	23
29	I	3.7	2.5	51.4	34.5	53
58	I	4.0	2.8	59.2	22.4	40
87	I	4.6	3.4	69.9	21.8	39
<b>LSD (0.05)</b>		0.42	0.41	3.3	-	-

\*SB = surface broadcasting; I = injection; source: Choudhury and Bhuiyan (1994).

**Table 7.** Effects of nitrogen and sulphur on grain yield of BR3 rice and agronomic efficiency of added N

N rate (kg/ha)	Sulphur rate (kg/ha)			Mean
	0	20	40	
Grain yield (tonnes/ha)				
0	2.9	3.2	3.2	3.1 c
60	4.0	4.1	4.2	4.1 b
120	4.1	5.0	5.2	4.8 a
Mean	3.7 b	4.1 a	4.2 a	
Agronomic efficiency of N <sup>1</sup>				
60	18.3	20.0	21.7	20.0
120	10.0	17.5	19.2	15.6
Mean	14.2	18.8	20.5	

Kg grain per kg added N compared to the plots those received neither N nor S; in a row/column, values followed by different letters are significantly different at 5% level by DMRT; source: Choudhury *et al.* (1994b).

120 kg N/ha. Similarly at 0 kg S/ha, N application at 120 kg/ha increased grain yield by 1.2 t/ha, while the same N rate increased grain yield by 1.8 t/ha at 20 kg S/ha. Agronomic efficiency of added N increased gradually with increasing S rates up to 40 kg S/ha.

In S deficient soils, combined application of N and S is necessary to optimize grain yield. Investigations in India showed that combined application of N and S increased N and S uptakes by rice significantly (Srivastava and Singh, 2007). This implies that interactions between N and S have large effects on N and S transfers to rice plants for increasing grain production. Generally farmers are not using S fertilizer for rice. Awareness should be grown at farm level for

the benefit S fertilisation in S deficient soils for increasing N use efficiency in rice production.

**Varietal difference in nitrogen response.** The magnitude of N response may vary from variety to variety depending upon their agronomic traits like plant height and growth duration in addition to N fertility status of the soil. Therefore, variety and soil specific N fertilizer recommendation is necessary to get optimum yield (Saleque *et al.*, 2004). Agronomic efficiency (kg grain/kg added N) varies among rice varieties (Table 8). Nitrogen fertilizer requirement for maximum grain yield varies among varieties (Choudhury *et al.*, 2002). Nitrogen rate for the maximum yield of a rice variety can be estimated from the regression equation  $Y = a + bx - cx^2$  as follows (Gomez and Gomez, 1984):

$$N_y = b/2c$$

where,  $N_y$  = N rate (kg/ha) for maximum yield. Determination of N rates for maximum grain yields of different varieties is necessary to avoid indiscriminate application of a single N rate for all the varieties. This information will help to reduce N fertilizer losses through indiscriminate application of N and thus reduces environmental pollution to some extent.

**Nitrogen response of short and tall statured varieties.**

Nitrogen response may vary among rice varieties based on their plant stature in addition to growth duration. A field experiment was conducted using four rice varieties (BR1, BR3, BR14 and BRRIdhan 29) having different agronomic parameters (Table 9) in a clay soil at BRRIdhan farm in 1993 (BRRI, 1996). BR1 and BR14 are short duration varieties, while BR3 and BRRIdhan 29 are long duration ones. Again heights of BR1 and BR3 were relatively shorter than BR14 and BRRIdhan 29. Number

**Table 8.** Grain yield of some modern rice varieties without and with fertilizer N

Rice variety	Grain yield (t/ha)			Agronomic efficiency**	Reference
	Without fertilizer N	With fertilizer N (120 kg N/ha)	Difference*		
BR1	2.60	4.70	2.10	17.50	Choudhury <i>et al.</i> , 1997a
BR3	2.60	4.80	2.20	18.33	Choudhury <i>et al.</i> , 1997a
BR14	3.00	5.20	2.20	18.33	Choudhury <i>et al.</i> , 1997a
BR22	2.50	4.30	1.80	15.00	Choudhury <i>et al.</i> , 1997b
BR25	3.10	5.10	2.00	16.67	Choudhury <i>et al.</i> , 1997b
BRRIdhan 29	3.60	5.90	2.30	19.17	Choudhury <i>et al.</i> , 1997a

\* = differences were statistically significant at 5% probability level; \*\* = kg grain per kg added N.

of tiller as well as panicle production per unit area was the highest in BR1 followed by BRRIdhan 29, BR3 and the lowest in BR14. Six rates of N (0, 40, 80, 120, 160 and 200 kg N/ha) were used in the experiment. Grain yield response to added N varied among the varieties (Table 10). The most interesting finding is that the tall statured varieties (BR14 and BRRIdhan 29) out yielded the short statured ones (BR1 and BR3) in N control plots by 0.4 to 0.6 t/ha. This indicates that the

**Table 9.** Some agronomic parameters of four modern rice varieties

Variety	Plant height (cm)	Growth duration (days)*	Tiller number/m <sup>2</sup>	Panicle number/m <sup>2</sup>
BR1	63	150	414	404
BR3	79	170	302	291
BR14	91	155	263	247
BRRIdhan 29	90	168	310	296

\* = period started from date of nursery sowing; source: BRRIdhan (1996).

**Table 10.** Effect of N fertilisation on grain yield of four modern rice varieties

N rate (kg/ha)	Grain yield (t/ha)			
	BR1	BR3	BR14	BRRIdhan 29
0	2.6 <sup>d</sup> B	2.6 <sup>d</sup> B	3.0 <sup>d</sup> AB	3.2 <sup>c</sup> A
40	3.4 <sup>c</sup> BC	3.2 <sup>c</sup> C	3.7 <sup>c</sup> B	4.7 <sup>b</sup> A
80	3.7 <sup>c</sup> C	4.2 <sup>b</sup> BC	4.3 <sup>b</sup> B	5.3 <sup>a</sup> A
120	4.7 <sup>b</sup> B	4.8 <sup>a</sup> B	5.2 <sup>a</sup> AB	5.4 <sup>a</sup> A
160	5.3 <sup>a</sup> AB	5.0 <sup>a</sup> B	5.3 <sup>a</sup> A	5.6 <sup>a</sup> A
200	5.1 <sup>ab</sup> B	5.2 <sup>a</sup> AB	5.2 <sup>a</sup> AB	5.7 <sup>a</sup> A

Source: BRRIdhan (1996); figures followed by a common letter within a column (small letter) or row (capital letter) are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

tall statured varieties can exploit more soil N for grain production. Root mass density was relatively higher in tall statured varieties (BR14 and BRRIdhan 29) compared to short statured ones (BR1 and BR3) at 10-20 cm depth in N control plots (Table 11). This implies that having deeper root system the tall varieties were able to utilize more soil N for grain production compared to the short ones in N control plots which enabled them to produce extra grain without fertilizer input. So, modern rice varieties having relatively taller plant stature will be economically advantageous for marginal farmers to produce extra grain without fertilizer input.

**Table 11.** Effect of N fertilization on root mass density of four modern rice varieties at flowering stage

N rate (kg/ha)	Root mass density (mg/cm <sup>3</sup> )				
	BR1	BR3	BR14	BRRIdhan 29	N Mean
	0-10 cm depth				
0	1.10	2.50	1.98	2.15	1.93 <sup>d</sup>
40	1.35	3.22	2.47	2.44	2.37 <sup>cd</sup>
80	1.56	3.35	3.02	2.61	2.64 <sup>bc</sup>
120	1.86	3.43	3.50	2.88	2.92 <sup>ab</sup>
160	2.05	3.49	3.54	3.07	3.04 <sup>ab</sup>
200	2.12	4.13	3.84	3.57	3.42 <sup>a</sup>
Variety mean	1.67 <sup>B</sup>	3.3 <sup>A</sup>	3.06 <sup>A</sup>	2.79 <sup>A</sup>	–
	10-20 cm depth				
0	0.06	0.08	0.10	0.16	0.10 <sup>b</sup>
40	0.07	0.15	0.17	0.18	0.14 <sup>ab</sup>
80	0.11	0.17	0.17	0.19	0.16 <sup>a</sup>
120	0.12	0.14	0.15	0.18	0.15 <sup>ab</sup>
160	0.04	0.13	0.13	0.15	0.11 <sup>ab</sup>
200	0.03	0.11	0.10	0.15	0.10 <sup>b</sup>
Variety mean	0.07 <sup>B</sup>	0.13 <sup>AB</sup>	0.14 <sup>A</sup>	0.17 <sup>A</sup>	–

Source: BRRIdhan (1996); figures followed by a common letter within a column (small letter) or row (capital letter) are not significantly different at 5% level by DMRT.

**Nitrogen response of traditional and improved plant types.** A field experiment was conducted on a clay soil at BRRRI during 1994 to evaluate the N response behaviour of four rice varieties (NigerSail, BR22, Pajam and BR25) using six N rates (0, 30, 60, 90, 120 and 150 kg N/ha) in wetland culture (Choudhury *et al.*, 1997b). The variety BR22 is the improved plant type of Niger-Sail while BR25 is the improved plant type of Pajam. Grain yield response to added N varied among the varieties (Table 12). While, NigerSail responded to added N up to 90 kg N/ha, its improved plant type BR22 responded up to 150 kg N/ha. Both Pajam and its improved plant type BR25 responded up to 120 kg N/ha. However, BR25 out yielded Pajam at all the rates of added N. Regression analysis indicated that the estimated response function between N rate and grain yield for all the varieties was quadratic in nature (Table 13).

**Table 12.** Effects of N fertilization on grain yield of four rice varieties

N rate (kg/ha)	Grain yield (t/ha)			
	NigerSail	BR22	Pajam	BR25
0	2.6	2.5	3.0	3.1
30	3.2	3.5	3.7	3.9
60	3.3	3.8	4.0	4.7
90	3.6	4.0	4.3	4.8
120	3.3	4.3	4.8	5.1
150	3.2	4.7	4.8	4.9

Source: Choudhury *et al.* (1997b).

**Table 13.** Regression equation and R<sup>2</sup> value relating grain yield and N rate for four rice varieties

Variety	Regression equation	R <sup>2</sup> value	Estimated N rate (kg/ha) for maximum yield
NigerSail	$y=2.681+0.018x-0.0001x^2$	0.86*	90
BR22	$y=2.626+0.023x-0.0001x^2$	0.96**	115
Pajam	$y=3.002+0.021x-0.0001x^2$	0.98**	105
BR25	$y=3.119+0.032x-0.0001x^2$	0.98**	160

\* = significant at 10% level of probability; \*\* = significant at 1% level of probability; source: Choudhury *et al.* (1997b).

However, the rate of response as evidenced from the response co-efficient (b value) was higher in the improved plant types (BR22 and BR25) compared to their respective traditional plant types (NigerSail and

Pajam). While, the b value was only 0.018 for NigerSail, it was 0.023 for its improved plant type BR22. Again the b value for Pajam was 0.021 against the b value of 0.032 for its improved plant type BR25. The b value is the slope of regression line which measures the estimated rate of response (either increase or decrease). This implies that improved plant type can utilize fertilizer N more efficiently for grain production compared to their respective traditional plant type. Estimated N rate for maximum yield varies among the varieties. Estimated N rates for maximum grain yield were 160, 115, 105 and 90 kg/ha for BR25, BR22, Pajam and NigerSail, respectively. This information implies that there are differences among rice varieties for N requirement for maximum grain production.

## Conclusion

Nitrogen use efficiency in rice culture can be increased considerably by using modified forms of urea like USG and ULG. The efficiency of the conventional prilled urea in rice culture can be increased to some extent by injecting it into the sub-surface by the instrument "Pneumatic Urea Injector". In sulphur deficient soils, N use efficiency in rice culture can be increased by combined application of N and S. Modern rice varieties having relatively taller plant stature will be economically advantageous for marginal farmers to produce extra grain without fertilizer input. There are varietal differences for N requirement for maximum grain production. This information will be helpful to avoid indiscriminate application of a single N rate for all the varieties. These ways of increasing N use efficiency will reduce environmental pollution problems due to eutrophication (over enrichment in nutrients), production of greenhouse gases like nitrous oxide, and nitrate toxicity in the ground water.

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