ISSN: 2518-2021 (Print), 2415-4474 (Online) Fundam Appl Agric 2016, 1(3): 124-129

Fundamental and Applied Agriculture

Journal homepage: www.f2ffoundation.org/faa

Fertilizer Management
ORIGINAL ARTICLE

Integrated nitrogen management of monsoon rice under two different plant spacings

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A R T I C L E I N F O

Article history:

Received: 16 June 2016
Received in revised form: 12 August 2016
Accepted: 25 August 2016
Available online: 02 September 2016

Academic Editor: Md Parvez Anwar

Keywords:

Transplant *aman*
Nutrient management
Urea super granule
Poultry manure
Plant density

A B S T R A C T

Proper management practices such as plant spacing and nutrient management are the most effective means for increasing yield of rice. To date no single spacing or nutrient management has been recommended as ideal for all field conditions for a particular variety which must be established experimentally. The current experiment was, therefore, conducted to study the effect of integrated nitrogen management and plant spacing on the growth, yield and yield components of monsoon rice (rainfed transplanted rice) cv. BRRI dhan41. The experiment consisted of the following sets of treatments: factor (A) integrated nitrogen management: control, *i.e.*, no urea super granule (USG), prilled urea (PU) and poultry manure (PM) (T_1), 1.8 g USG 4 hill^{-1} (T_2), 2.7 g USG 4 hill^{-1} (T_3), PM at 5 t ha^{-1} (T_4), PM at 7.5 t ha^{-1} (T_5), 1.8 g USG 4 hill^{-1} + PM at 5 t ha^{-1} (T_6), 2.7 g USG 4 hill^{-1} + PM at 7.5 t ha^{-1} (T_7), 1.8 g USG 4 hill^{-1} + PM at 2.5 t ha^{-1} (T_8), 2.7 g USG 4 hill^{-1} + PM at 3.75 t ha^{-1} (T_9), recommended dose of PU *i.e.*, 240 kg ha^{-1} (T_{10}), 1/2PU + PM at 5 t ha^{-1} (T_{11}), full dose of PU + PM at 7.5 t ha^{-1} (T_{12}), 1/2PU + PM at 2.5 t ha^{-1} (T_{13}) and full dose of PU + PM at 3.75 t ha^{-1} (T_{14}); and factor (B) plant spacing: 25 cm × 15 cm (S_1) and 25 cm × 20 cm (S_2). The experiment was laid out in a randomized complete block design with three replications. Integrated nitrogen management showed significant effect on all the yield and yield contributing characters except number of non-effective tillers hill^{-1}, panicle length and weight of 1000 grains. The results revealed that the highest grain yield (3.67 t ha^{-1}) was obtained from T_6 and the lowest grain yield (1.39 t ha^{-1}) was obtained from T_1. All the yield and yield contributing characters were significantly affected by plant spacing except number of total tillers hill^{-1}, number of non-effective tillers hill^{-1}, panicle length and weight of 1000 grains. The spacing 25 cm × 20 cm resulted in higher grain yield (3.05 t ha^{-1}) than the spacing 25 cm × 15 cm. Grain yield was affected by the interaction of integrated nitrogen management and plant spacing. The highest grain yield (3.74 t ha^{-1}) was recorded with the interaction between T_6 and S_2 while the lowest one (1.36 t ha^{-1}) was obtained from T_1 and S_1 combination. Therefore, for higher yield monsoon rice cv. BRRI dhan41 should be planted following 25 cm × 20 cm spacing and fertilized with 1.8 g USG 4 hill^{-1} + 5 t ha^{-1} PM to meet nitrogen requirement.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most extensively cultivated cereals of the world with the third-highest worldwide production (FAO 2012), and the most widely consumed staple food for a big part of the world's human population, especially in Asia. Bangladesh, a South Asian country, is currently the world's fourth largest rice producer after China, India and Indonesia (GRiSP 2013). About 11.42 million hectares of land are used for rice cultivation in Bangladesh producing 33.83 million tons of rice with average yield of only 3.3 t ha^{-1} (MoA 2014), which contributes 95% to her total food grain production. However, the country has experienced a continued annual shortage of nearly 1.5 million tons of food grains (Karim 1999). Therefore, rice production of the country must be amplified at a faster rate to feed the burgeoning population.

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There is no way to increase rice cultivation area, and moreover, the areas are continuously shrinking to meet the growing demand for high-value crops and for urban and industrial development. So, the only means to solve the problem is to increase the average yield on existing land. Rice varieties cultivated in the country are grouped into five distinct ecotypes, such as (i) *boro*, (ii) transplanted *aus*, (iii) transplanted *aman* (here referred to as monsoon rice), (iv) upland or direct-seeded *aus*, and v) deep-water or floating rice (Sattar 2000). Monsoon rice is grown under rainfed ecosystems during July to December, and the majority of rice area in Bangladesh is covered by this rice comprising 52% of the total rice area.

Proper management practices are the most effective means for increasing yield of rice. Among different management practices, use of proper plant spacing and nutrient (both organic and inorganic) management are important as the growth and development of rice are greatly influenced by these factors. Optimum plant density ensures the plant to grow properly with their aerial and underground parts by utilizing more solar radiation and soil nutrients (Islam et al. 2007; Mohaddesi et al. 2011). In a densely populated crop, the inter-plant competition is very high which usually results in mutual shading, lodging and thus favors more straw yield than grain yield (Moradi and Azarpour 2011; Thawait et al. 2014). On the other hand wider spacing causes low yield due to low plant population (Gozubenli 2010; Wang et al. 2010; Wang et al. 2014). Therefore, spacing should be optimal to obtain higher grain yield of rice.

Crop yield including rice is exceedingly constrained by soil nutrient deficiency in Bangladesh. Most of the soils of Bangladesh have less than 1.5% of organic matter (OM) and in some cases it is less than 1% (BARC 2005). The crops are grown here mostly based on high doses of synthetic fertilizers. Long-term intensive use of chemical fertilizers creates some fertility problems through soil exhaustion as well as through interaction with other elements (Rahman and Abedin 1997; Sarkar et al. 2007). Presently the OM content of the main agricultural land is reported to be declining and nutrient balances are negative for the major nutrients, especially nitrogen (N) which is the most important limiting nutrient in rice production and has heavy system losses when applied as inorganic sources in puddle field. It was reported that broadcast application of prilled urea (PU) on the surface soil causes losses up to 50% whereas point placement of urea super granules (USG) at 10 cm depth could result in negligible loss (Crasswell and De Datta 1980). Savant et al. (1991) reported that, USG can save 30% N than PU, increase absorption rate, improve soil health and ultimately increase rice yield. Almost all soils of Bangladesh are deficient in N mainly due to low level of OM caused by continuous intensive cropping. Poultry manure (PM) may play a vital role in soil fertility improvement as well as supply primary, secondary and micronutrients. As for example, 4.6% total N (% dry weight basis) was reported from PM (chicken), and from which 68% was available for crops in first year (Pratt and Castellanos 1981). The possibility of returning OM to the field is very low because of other necessary alternative uses. In recent years, rapid development of poultry industry is giving an opportunity to use poultry manure as a vital organic source. Combined application of PM and recommended chemical fertilizers can increase grain yield by >26% than the recommended chemical fertilizers alone without degrading soil fertility (Channabasavanna and Biradar 2001). But knowledge for integrated nutrient management is still general rather than specific for particular crop and/or cropping pattern. The information of optimum supply rate and the effectiveness of combined use of poultry manure and N-fertilizer in rice are very insufficient. Therefore, the present investigation was conducted with the objective to reveal the effect of USG, PU, PM and plant spacing on the performance of monsoon rice cv. BRRI dhan41.

MATERIALS AND METHODS

Experimental Site and Soil

The experiment was conducted at the Agronomy Field Laboratory of Bangladesh Agricultural University (90º25'45" E longitude and 24º43'07" N latitude; central coordinates), Mymensingh, Bangladesh having an altitude of 18 m above the mean sea level. The site belongs to the *Sonatala* series of 'Old Brahmaputra Floodplain' agro ecological zone (AEZ-9) of Bangladesh having non-calcareous dark grey floodplain soils (UNDP-FAO 1988). The land was medium high and well drained with silty-loam texture with pH value 6.8, low in OM content (1.19%) and the general fertility level of the soil was also low. The experimental site was characterized by high temperature, high humidity and heavy rainfall with occasional gusty wind in April-September (*Kharif* season) and scanty rainfall associated with moderately low temperature during October-March (*Rabi* season).

Experimental Treatments and Design

The experiment consisted of with two factors: factor (A): integrated N management, *viz.* control, *i.e.*, no urea super granule (USG), prilled urea (PU) and poultry manure (PM) (T_1), 1.8 g USG 4 hill^{-1} (T_2), 2.7 g USG 4 hill^{-1} (T_3), PM at 5 t ha^{-1} (T_4), PM at 7.5 t ha^{-1} (T_5), 1.8 g USG 4 hill^{-1} + PM at 5 t ha^{1} (T_6), 2.7 g USG 4 hill^{-1}+ PM at 7.5 t ha^{-1} (T_7), 1.8 g USG 4 hill^{-1}+ PM at 2.5 t ha^{-1} (T_8), 2.7 g USG 4 hill^{-1}+ PM at 3.75 t ha^{-1} (T_9), recommended dose of PU *i.e.*, 240 kg ha^{-1} (T_{10}), 1/2PU+PM at 5 t ha^{-1} (T_{11}), full dose of PU+ PM at 7.5 t ha^{-1} (T_{12}), 1/2PU + PM at 2.5 t ha^{-1} (T_{13}) and full dose of PU + PM at 3.75 t ha^{-1} (T_{14}); and factor B: Spacing, *viz.* 25 cm × 15 cm (S_1) and 25 cm × 20 cm (S_2). The experiment was laid out in a randomized complete block design with three replications. The size of unit plot was 4.0 m× 2.5 m.

Plant Material

A short duration aman rice cultivar BRRI dhan41 was used as the test crop for this study. BRRI dhan41 is one of the important salt tolerant transplant aman rice cultivar developed by the Bangladesh Rice Research Institute (BRRI) from the cross between BR23 and BR1185-2B-16-1 lines and was released in 2003 as transplant aman rice. It can tolerate salinity up to 8 ds m-1 during seedling and booting stage and grain yield ranges from 4-4.5 t ha^{-1}.

Crop Husbandry

The land was puddled thoroughly by repeated ploughing and cross ploughing subsequently leveled by laddering. Forty-day old seedlings were transplanted on 10 August at the rate of three seedlings hill^{-1} by maintaining spacing as mentioned in the treatment (factor B). The PM was mixed thoroughly with the soil at the time of final land preparation as per treatment. The amount of phosphorus, potassium, sulphur and zinc required for total land was calculated on hectare basis and applied in the form of triple superphosphate (TSP), muriate of potash (MoP), gypsum and zinc sulphate, respectively as per BRRI recommendation (TSP= 76 kg ha^{-1}, MoP= 60 kg ha^{-1} and gypsum= 30 kg ha^{-1}). Full dose of those fertilizers were applied at the time of final land preparation in the respective unit plots. PU was applied in three equal splits. The first split of PU was top dressed after 15 days of transplanting (DAT), the second split of PU was top dressed after 35 DAT and the third split of PU was top dressed after 50 DAT (panicle initiation stage). USG were placed at 8 cm depth after 15 DAT in the center of four hills in alternate rows according to treatment specification. Intercultural operations *e.g.* gap filling, weeding, irrigation and drainage have been done as per requirement.

Data Collections and Statistical Analysis

Five hills (excluding border hills) were selected randomly from each unit plot and uprooted before harvesting on 12 December for recording data related to yield and yield components. In each plot central 2.5 m × 2.0 m area was harvested to record the yields of grain and straw. The recorded data on various plant characters were statistically analyzed using analysis of variance technique with the help of a computer package program MSTAT-C and the mean differences were adjudged by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez 1984).

RESULTS

Effect of Integrated Nitrogen Management on Yield and Yield Contributing Characters

All the yield-contributing characters were significantly influenced by integrated N management except 1000-grain weight (Table1). The tallest plant (121.98 cm) was recorded at T_7 (2.7 g USG 4 hill^{-1} + PM at 7.5 t ha^{-1}), which was statistically identical to plant height under treatment T_5 (PM at 7.5 t ha^{-1}), T_6 (1.8 g USG 4 hill^{-1} + PM at 5 t ha^{-1}), T_8 (1.8 g USG 4 hill^{-1} + PM at 2.5 t ha^{-1}), T_{10} (recommended dose of prilled urea: 240 kg ha^{-1}), T_{11} (1/2 PU + PM at 5 t ha^{-1}), T_{12} (full dose of PU + PM at 7.5 t ha^{-1}) and T_{14} (full dose of PU + PM at 3.75 t ha^{-1}) (Table 1). The shortest plant (113.37 cm) was obtained from T_1 (control: no USG, PU and PM). In case of total tillers hill^{-1}, T_5 produced the highest (12.17), which was statistically identical to T_6, T_{10} and T_{14} (Table 1), whereas control (T_1) gave the lowest (7.96). The highest number of effective tillers hill^{-1} (9.15) was produced in T_6 and the lowest (4.29) was obtained from T_1 (Table 1).

The highest number of grains panicle^{-1} (160.12), grain yield (3.67 t ha^{-1}), and harvest index (48.46%) were produced in T_6, whereas the lowest grains panicle^{-1} (110.99), grain yield (1.39 t ha^{-1}), and harvest index (33.31%) were obtained from T_1. However, grain yield of $T_6$was at par with T_{10} and T_{12} (Table 1). On the other hand, the highest number of sterile spikelets panicle^{-1} (19.44) was recorded in the treatment T_1, and the lowest one (8.43) was observed in treatment T_5 (Table 1). Treatment T_9 (2.7 USG 4 hill^{-1} + PM at 3.75t ha^{-1}) produced the highest straw yield (4.63t ha^{-1}) and the lowest one (2.77 t ha^{-1}) was observed in treatment T_1 (Table 1).

Table 1. Effect of integrated nitrogen management on yield and yield contributing characters of monsoon rice cv. BRRI dhan41

Integrated nitrogen management	Plant height (cm)	No. of total tillers hill^{-1}	No. of effective tillers hill^{-1}	No. of grains panicle^{-1}	No. of sterile spikelets panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_1	113.37c	7.96d	4.29f	110.99i	19.44a	25.64	1.39f	2.77g	33.31g
T_2	115.88bc	9.34cd	5.72e	128.95h	14.36bc	25.84	2.21e	3.47f	38.78f
T_3	119.05ab	9.61bc	6.18de	134.60gh	14.28bcd	25.72	2.56d	3.72e	40.74de
T_4	119.61ab	10.43abc	6.42de	136.83fg	15.01b	25.91	2.60d	3.96d	39.60ef
T_5	120.66a	12.17a	8.52ab	138.60fg	8.43f	26.07	3.14b	4.32bc	41.99cd
T_6	121.65a	12.15a	9.15a	160.12a	12.98bcd	26.21	3.67a	3.91de	48.46a
T_7	121.98a	10.60abc	6.56de	139.97efg	13.96bcd	26.26	2.70cd	4.11cd	39.66ef
T_8	120.49a	10.50abc	6.74cde	143.52c-f	12.83bcd	26.19	2.90c	4.23bc	40.66de
T_9	118.17ab	10.43abc	6.97cde	155.04ab	9.95ef	26.11	3.23b	4.63a	41.07de
T_{10}	121.29a	11.59a	8.43ab	148.91bc	11.53de	25.90	3.52a	4.34bc	44.73b
T_{11}	120.53a	10.43abc	6.64de	141.33d-g	12.50b-e	26.10	2.85c	4.09cd	40.97de
T_{12}	121.47a	11.27ab	7.32bcd	146.40cde	11.72cde	26.10	3.57a	4.39b	44.90b
T_{13}	119.58ab	10.97abc	7.89bc	148.95bc	12.01cde	26.20	3.28b	4.42ab	42.53cd
T_{14}	121.35a	11.59a	7.90bc	147.38cd	12.37b-e	26.00	3.26b	4.23bc	43.49bc
CV (%)	2.49	12.17	13.60	3.81	15.76	1.05	6.00	4.92	3.56
Level of sig.	**	**	**	**	**	NS	**	**	**

In a column, figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT).

** = significant at 1% level of probability, NS = not significant.

T_1=control (no USG, PU and PM), T_2= 1.8 g USG 4 hill^{-1}, T_3=2.7 g USG 4 hill^{-1} , T_4= PM at 5 t ha^{-1}, T_5= PM at 7.5 t ha^{-1},T_6= 1.8 g USG 4 hill^{-1} + PM at 5 t ha^{-1},T_7=2.7 g USG 4 hill^{-1} + PM at 7.5 t ha^{-1},T_8=1.8 g USG 4 hill^{-1} + PM at 2.5 t ha^{-1},T_9= 2.7 g USG 4 hill^{-1} + PM at 3.75 t ha^{-1},T_{10}= recommended dose of PU (240 kg ha^{-1}), T_{11}=1/2 PU + PM at 5 t ha^{-1}, T_{12}=full dose of PU + PM at 7.5 t ha^{-1}, T_{13}=1/2 PU + PM at 2.5 t ha^{-1} and T_{14}= full dose of PU + PM at 3.75 t ha^{-1}.

Effect of Plant Spacing on Yield and Yield Contributing Characters

Except number of total tillers hill^{-1} and 1000-grain weight, all other yield contributing characters and yield of BRRI dhan41 were significantly influenced by spacing (Table 2). The spacing S_1 (25 cm×15 cm) produced taller plants (120.36 cm) and higher sterile spikelets panicle^{-1} (14.25) compared to spacing S_2 (25 cm × 20 cm). On the other hand, S_2 produced higher number of effective tillers hill^{-1} (7.26), grains panicle^{-1} (144.98), grain yield (3.05t ha^{-1}), straw yield (4.11 t ha^{-1}) and harvest index (42.20) than spacing S_1.

Interaction Effect of Integrated Nitrogen Management and Plant Spacing on Yield and Yield Contributing Characters

The interaction of integrated N management and plant spacing did not show any significant influence on the yield and yield contributing characters, except grain yield (Table 3).The lowest grain yield (1.36 t ha^{-1}) was obtained from $T_1 \times S_1$ whereas the highest grain yield (3.74 t ha^{-1}) was produced in $T_6 \times S_2$; which was statistically identical to $T_6 \times S_1$ (3.60 t ha^{-1}), $T_{10} \times S_1$ (3.41 t ha^{-1}), $T_{12} \times S_1$ (3.58 t ha^{-1}), $T_9 \times S_2$ (3.46 t ha^{-1}), $T_{10} \times S_1$ (3.62 t ha^{-1}), $T_{12} \times S_1$ (3.57 t ha^{-1}) and $T_{14} \times S_2$ (3.52 t ha^{-1}) (Table 3).

Table 2. Effect of plant spacing on yield and yield contributing characters of transplant a*man* rice cv. BRRI dhan41

Spacing	Plant height (cm)	No. of total tillers hill^{-1}	No. of effective tillers hill^{-1}	No. of grains panicle^{-1}	No. of sterile spikelets panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
S_1	120.36a	10.87	6.84b	138.10b	14.25a	25.97	2.79b	3.98b	40.79b
S_2	118.93b	10.42	7.26a	144.98a	11.67b	26.07	3.05a	4.11a	42.20a
CV (%)	2.49	12.17	13.60	3.81	15.76	1.05	6.00	4.92	3.56
Level of sig.	**	NS	**	**	**	NS	**	**	**

** = significant at 1% level of probability, NS = not significant. S_1 = 25 × 15 cm, S_2 = 25 × 20 cm.

Table 3. Interaction effect of integrated nitrogen management and plant spacing on yield and yield contributing characters of monsoon rice cv. BRRI dhan41

Fertilizer level × spacing	Plant height (cm)	No. of total tillers hill^{-1}	No. of effective tillers hill^{-1}	No. of grains panicle^{-1}	No. of sterile spikelets panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
$T_1 \times S_1$	111.74	8.31	4.52	119.97	20.88	25.56	1.36k	2.72	33.26k
$T_2 \times S_1$	116.37	10.47	6.31	127.30	18.72	25.74	1.88j	3.33	36.29j
$T_3 \times S_1$	116.73	10.27	6.21	139.20	16.13	25.82	2.43i	3.62	40.21ghi
$T_4 \times S_1$	121.80	10.93	6.68	144.12	16.52	25.86	2.47hi	3.91	38.66ij
$T_5 \times S_1$	120.25	12.33	9.66	143.76	9.43	26.08	2.97efg	4.19	41.48f-i
$T_6 \times S_1$	125.30	12.07	8.76	163.37	14.53	26.14	3.60ab	3.83	48.48a
$T_7 \times S_1$	122.77	11.13	7.12	144.67	15.03	26.17	2.62hi	3.89	40.24ghi
$T_8 \times S_1$	121.87	10.20	6.59	144.23	13.67	26.14	2.80fgh	4.11	40.49ghi
$T_9 \times S_1$	120.07	10.93	7.34	158.73	10.43	26.10	3.01efg	4.63	39.36hi
$T_{10} \times S_1$	121.37	11.33	8.13	150.11	12.03	25.78	3.41a-d	4.42	43.60b-f
$T_{11} \times S_1$	122.10	10.67	6.89	144.70	14.63	26.25	2.60hi	4.07	38.98i
$T_{12} \times S_1$	122.00	11.27	7.80	150.20	12.58	25.92	3.58ab	4.33	45.25bc
$T_{13} \times S_1$	121.43	10.80	7.89	152.07	12.22	26.07	3.33bcd	4.46	42.75c-g
$T_{14} \times S_1$	121.30	11.53	7.79	147.34	12.63	25.89	3.01efg	4.16	41.97e-h
$T_1 \times S_2$	115.00	7.61	4.06	102.01	17.99	25.72	1.42k	2.82	33.37k
$T_2 \times S_2$	115.40	8.22	5.12	130.60	10.00	25.95	2.54hi	3.61	41.27f-i
$T_3 \times S_2$	121.37	8.95	6.15	129.99	12.43	25.63	2.68ghi	3.81	41.28f-i
$T_4 \times S_2$	117.42	9.93	6.16	129.53	13.50	25.95	2.73ghi	4.01	40.54ghi
$T_5 \times S_2$	121.07	12.00	7.37	133.43	7.43	26.07	3.30b-e	4.45	42.50c-g
$T_6 \times S_2$	118.00	12.23	9.55	156.88	11.43	26.27	3.74a	3.98	48.44a
$T_7 \times S_2$	121.20	10.07	6.00	135.26	12.88	26.35	2.78fgh	4.33	39.08i
$T_8 \times S_2$	119.10	10.80	6.89	142.80	12.00	26.24	3.00efg	4.34	40.83f-i
$T_9 \times S_2$	116.28	9.93	6.59	151.34	9.47	26.12	3.46abc	4.63	42.78c-g
$T_{10} \times S_2$	121.22	11.85	8.74	147.71	11.03	26.01	3.62ab	4.27	45.87b
$T_{11} \times S_2$	118.95	10.20	6.39	137.97	10.37	25.94	3.10def	4.11	42.95c-g
$T_{12} \times S_2$	120.93	11.27	6.83	142.59	10.87	26.27	3.57ab	4.44	44.55b-e
$T_{13} \times S_2$	117.73	11.13	7.89	145.83	11.80	26.33	3.22cde	4.39	42.31d-g
$T_{14} \times S_2$	121.40	11.65	8.01	147.42	12.10	26.10	3.52abc	4.29	45.02bcd
CV (%)	2.49	12.17	13.60	3.81	15.76	1.05	6.00	4.92	3.56
Level of sig.	NS	NS	NS	NS	NS	NS	*	NS	NS

In a column, figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT).

* = significant at 5% level of probability ** = significant at 1% level of probability, NS = not significant. Other details are same as Table 1 and 2.

DISCUSSION

Deep placement of USG in an anaerobic zone of the puddled paddy soils produces ammonium N (from hydrolyzing urea), which is more available and stable due to low ammonia volatilization loss and nitrification (Kapoor et al. 2008; Rochette et al. 2013). Deep-placed N might stay in the root zone for a longer time and ensure constant supply of N for plant growth and development during the crop growth period, ensuing increased number of effective tillers (Table 1), which further increases N uptake; thus, it increases grain yield as well (Miah et al. 2016). On the contrary, when PU is broadcasted, ammonium is oxidized and converted to nitrate, which is unstable due to further denitrification and surface runoff loss. This unstable N supply from PU may cause relatively poor plant growth and development, and ultimately lower yield compared to USG. Although the grain yield of the tested rice variety of this study was highest in T_6 (1.8 USG 4 hill^{-1} + PM at 5 t ha^{-1}), it was statistically similar to the grain yield of T_{10} (recommended dose of prilled urea: 240 kg ha^{-1}) and T_{12} (full dose of PU + PM at 7.5 t ha^{-1}). This might happened probably because of the dependence of the performance of USG relative to broadcast PU on the timing and frequency of urea application. In a N management study, Alam et al. (2013) compared yields and economic returns of USG and broadcast PU application using the leaf color chart for five rice-growing seasons and found similar grain yields and economic returns from USG and PU, and suggested the real time N management, *i.e.*, synchronizing N application with plant need, which increases N use efficiency.

Urea super granule in combination with PM treatment gave better grain yield than other treatments. This might be due to optimum release of N from deep placed USG for prolonged period and adequate release of N and other nutrients from PM (Gupta et al. 1995). Rajput et al. (1992) reported higher grain yield from using PM, farm yard manure and cowdung with chemical fertilizers than from chemical fertilizers alone. In this study, the integrated N management with 1.8 USG 4 hill^{-1} + PM at 5 t ha^{-1} accompanied with wider spacing (25 cm × 20 cm) provided the highest grain yield (Table 3) which can be attributed to the higher number effective tillers hill^{-1}, grains panicle^{-1} and lower no. of sterile spikelets panicle^{-1} with increased spacing (Table 2). However, statistically identical high grain yield from the interactions of closer spacing (25 cm × 15 cm) with T_6 (1.8 USG 4 hill^{-1} + PM at 5 t ha^{-1}), T_{10} (recommended dose of PU: 240 kg ha^{-1}), T_{12} (full dose of PU + PM at 7.5 t ha^{-1}) and also wider spacing with T_{10} and T_{12} suggests that spacing effect on grain yield was relatively less compared to the N treatments.

CONCLUSIONS

This study concluded that application of USG, PU, and PM with two different plant spacings showed significant variation in the performance of grain yield of BRRI dhan41. Application of 1.8 g USG hill^{-1} + PM at 5 t ha^{-1} with 25 cm × 20 cm plant spacing was found to be the most promising practice in this transplant *aman* rice variety cultivation. However, application of 1.8 g USG hill^{-1} + PM at 5 t ha^{-1} in combination with 25 cm ×15 cm plant spacing, full dose of PU + PM at 7.5 t ha^{-1} with 25 cm × 15 cm plant spacing and recommended dose of PU (240 kg ha^{-1}) with 25 cm × 20 cm plant spacing exhibited similar behaviour in producing the grain yield. Therefore, farmers may choose any one of these practices based on profitability for high yield. Moreover, concerning soil fertility and sustainable agriculture, integrated N management (chemical fertilizer + manure) is preferable to chemical fertilizer application alone.

CONFLICT OF INTEREST

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

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