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Efficacy and Economics of Different Need Based Nitrogen Management Approaches in Winter Rice

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Abstract

This experiment aimed to study the efficacy of different nitrogen (N) management approaches in winter rice. The experiment consisted of two rice varieties: 1) BRRI (Bangladesh Rice Research Institute) dhan29-an inbred and 2) Dhanigold-a hybrid, and eight N management approaches: 1) BRRI recommended N (control), 2) Soil analysis based N management, 3) N application based on Agro-ecological zone, 4) 20 kg·N·ha^{-1} at ≤35 SPAD (Silicon photon activate diode) value, 5) 30 kg·N·ha^{-1} at ≤35 SPAD value, 6) 20 kg·N·ha^{-1} at ≤3.0 LCC (leaf colour chart) value, 7) 30 kg·N·ha^{-1} at ≤3.0 LCC value and 8) Urea Super Granule. Between two varieties, hybrid Dhani gold produced higher grain yield (6.67 t·ha^{-1}) than the inbred BRRI dhan29. Application of 20 kg·N·ha^{-1} at ≤3.0 LCC value gave the highest grain yield (7.10 t·ha^{-1}), whereas the lowest grain yield (5.92 t·ha^{-1}) was found from the SPAD approach with 20 kg·N·ha^{-1} at ≤35 SPAD value. In case of treatment interaction highest grain yield (7.34 t·ha^{-1}) was found in BRRI dhan29 coupled with 20 kg·N·ha^{-1} at ≤3.0 LCC value with 18 kg·N·savings·ha^{-1} over control, maximum gross income (146,800 BDT·ha^{-1}) and net benefit (142,120 BDT·ha^{-1}), which was statistically identical with the grain yield from the interaction of Dhani gold and 30 kg·N·ha^{-1} at ≤3.0 LCC value but required 42 kg·extra·N·ha^{-1} (over control). The lowest grain yield (5.19 t·ha^{-1}) was found when Dhanigold was coupled with 30 kg·N·ha^{-1} at ≤35 SPAD value, while the 20 kg·N·application·ha^{-1} at ≤35 SPAD value gave moderate yield (6.87 t·ha^{-1}) with considerable higher gross (139,600 BDT·ha^{-1}) and net (136,090 BDT·ha^{-1}) incomes than the control (gross: 121,000 and net: 115,600 BDT·ha^{-1}). The results reveal that 20 kg·N·ha^{-1} at ≤3.0 LCC value appeared as the promising practice for inbred BRRI dhan29, and 30 kg·N·ha^{-1} at ≤35

SPAD value for hybrid Dhanigold in terms of yield, N use efficiency and economic benefit of winter rice.

Keywords

Rice Nitrogen Demand, Leaf Color Chart, SPAD Meter, Nitrogen Use Efficiency, Nitrogen Economics

1. Introduction

Rice (*Oryza sativa* L.) is the staple food of Bangladesh occupying a very significant position in its agriculture and plays a vital role in the livelihood of her people. Bangladesh is now producing about 32.6 million tons of rough rice to feed her 159.5 million people [1]. Among three rice groups of Bangladesh, winter rice (locally known as "*boro* rice") covers 6.74 million hectares, which is 54.97% of total rice area with production of 14.89 million tons [2]. The increased rice production in last few decades has been possible largely due to the adoption of modern rice varieties on around 66% of the rice land, which contributes to about 73% of the country's total rice production [3]. Due to high population pressure, horizontal expansion of land is not possible. Therefore, increasing yield per unit area is the only means to meet food demand of the nation. Among the various factors responsible for increasing yield along with its quality, fertilizer management (especially nitrogenous fertilizer) is of paramount importance.

Under Bangladesh context, rice plants respond significantly to the application of nitrogenous fertilizers, since the soil all over the country lacks sufficient amount of nitrogen (N) due to low organic matter content and insufficient replenishment of N losses as well. In Bangladesh, the most commonly practiced method of applying nitrogenous fertilizer in rice is a basal application of prilled urea before transplanting followed by one or two top-dressings in the floodwater within 3 - 5 weeks after transplanting. Many studies found these practices inefficient since generally only about one-third of the applied N fertilizer through this method is used by plants and most of it goes under severe losses when applied as inorganic source in puddled field [4]. The consequence of high N application is high pesticide use to control pests, more expenditure on pesticides, and reduced yield and poor grain quality due to lodging [5]. It is, therefore, essential to find out the suitable rate of N fertilizer with proper method of application and source for efficient utilization of this element by the crop plants for better yield performance and higher profitability.

According to Bangladesh Rice Research Institute (BRRI) recommendation, fixed rate of nitrogenous fertilizer is applied at certain times for a particular rice variety growing in a large area. This approach has served its purpose in producing good yields, but it is limited in its capacity to increase nutrient use efficiency. Deep placement of Urea Super Granules (USG) at 10 cm depth is another way to reduce N loss by increasing its efficiency for better grain production [6]. Generally, each soil has its inherent nutrient supplying capacity. Thus, soil analysis can be an effective means for location specific and yield goal basis fertilizer recommendation. However, soil test based recommendations remain ignorant about the dynamics of nutrient release from crop residues, organic manures and irrigation water, and hence has not been found very successful in rice. Moreover, the fertility status of soils of different Agro-Ecological Zones (AEZ) of Bangladesh differs from each other. Thus, AEZ based nutrient management is another technique especially for efficient N management although this method does not take into account the high field-to-field variability.

Rice plant requires different amounts of nutrients in different fields, depending on native nutrient supply and crop demand. Excess nutrient application compared to the crop requirement may cause toxicity whereas lower amounts may cause nutrient mining. To increase nutrient use efficiency, the only mantra is to congruence of N supply and crop demand. This is possible with the chlorophyll meter (Silicon photon activate diode or SPAD) and leaf colour chart (LCC) techniques. The SPAD meter is a tool that enables to determine the relative amount of chlorophyll content by measuring leaf greenness [7]. Since chlorophyll content is strongly related to N concentration, SPAD meters can be used as the indicator of need based N application [8] [9]. On the other hand, LCC is an inexpensive and simple tool for monitoring the relative greenness of a rice leaf as an indicator of the leaf N status [10] [11]. It allows farmers to understand whether or not urea is needed by the crop at any point of rice growing, thus helps in improving decisions on both timing and quantity of urea application. Thus, LCC based N management can increase the mean grain yield, ensures vigorous growth of crop plants and also reduces the loss of nitrogenous fertilizers [5].

However, under the present context of very low use efficiency of urea fertilizer in Bangladesh, it is very important to find out the appropriate form and method of nitrogenous fertilizer application for improving the yield of puddled transplanted winter rice. Hence, current research was undertaken to compare the performance of different N management approaches in terms of productivity of hybrid and inbred winter rice varieties, and to find out the most efficient and cost-effective N management approach for increasing grain yield of winter rice.

2. Materials and Methods

2.1. Experimental Site and Soil

The experiment was carried out at the Agronomy Field Laboratory (90˚25'35.2"E and 24˚43'07.3"N), Bangladesh Agricultural University, Mymensingh, Bangladesh during December 2016 to May 2017. The experimental site belongs to the Old Brahmaputra Floodplain Agro-ecological zone (AEZ-9). The land was medium high and the soil was non-calcareous dark-grey, silty-loam textured slightly acidic to neutral (pH 6.82), medium fertile and low in nitrogen (N) content (0.1%).

2.2. Experimental Treatments and Design

The experiment was laid out in a randomized complete block design with three replications consisting of two rice varieties; 1) BRRI dhan29—an inbred and 2) Dhani gold—a hybrid; and eight N management approaches; 1) BRRI recommended N, 2) Soil analysis based N management, 3) N application based on Agro-ecological zone (AEZ), 4) 20 $kg{\cdot}N{\cdot}ha^{-1}$ at ≤35 SPAD value, 5) 30 $kg{\cdot}N{\cdot}ha^{-1}$ at ≤35 SPAD value, 6) 20 $kg{\cdot}N{\cdot}ha^{-1}$ at ≤3.0 LCC value, 7) 30 $kg{\cdot}N{\cdot}ha^{-1}$ at ≤3.0 LCC value and 8) Urea Super Granule (USG). The size of the unit plot was 5 m^2 (2.5 m × 2 m) and the spaces between blocks and plots were 1 m and 0.5 m, respectively.

2.3. Crop Husbandry

Forty days old seedlings were transplanted in the puddled field using two seedlings $hill^{-1}$ on 5 January 2017. Triple super phosphate, muriate of potash, gypsum and zinc sulphate at the rate of 98, 165, 113 and 12 $kg{\cdot}ha^{-1}$, respectively were applied as basal one day before transplanting. Nitrogenous fertilizer-urea was applied as per treatment specification. For the BRRI recommended N approach, prilled urea was applied in three equal splits at the rate of 300 $kg{\cdot}ha^{-1}$ at 15, 35 and 65 days after transplanting (DAT). For the soil analysis based N management, prilled urea at the rate of 313 $kg{\cdot}ha^{-1}$ (according to the soil test value) was applied at 15, 35 and 65 DAT. For the AEZ based N application approach, about 326 $kg{\cdot}prilled{\cdot}urea{\cdot}ha^{-1}$ was applied by following the splits mentioned before. For the SPAD and LCC treatments, prilled urea was applied when needed according to the treatments criteria. The SPAD and LCC readings were taken from the middle portion of the fully expanded leaves from 5 randomly selected hills from 20 DAT to heading at 10 day intervals. When the SPAD reading was down to critical value 35 and LCC value to 3.0, then the respective treatment plots were fertilized with allocated amount of urea. The pellets of USG as per treatment specification were placed at 3 - 4 inch depth at 15 DAT in the center of four hills in alternate rows. Intercultural operations were done as and when necessary. Flood irrigation was applied to maintain a constant level of standing water up to 6 cm in early stage to enhance tillering and 10 - 12 cm in later stage to discourage late tillering. The field was finally drained out 15 days before harvest to enhance maturity. Plants were infested with rice stem borer and rice bug which were successfully controlled by applying Furadan @ 10 $kg{\cdot}ha^{-1}$.

2.4. Data Collection

Five hills (excluding border hills) were randomly selected from each unit plot prior to harvest for recording data on different yield components and yield of rice. The date of harvesting was determined when 90% of the grains became golden yellow in color. An area of central 1 m^2 was harvested in each plot to record the yields of grain and straw. The harvested crop was then threshed, cleaned and dried to a moisture content of 14%. Weight of grain and straw were recorded and converted into t·ha^{-1}.

2.5. Statistical Analysis

Data obtained were analyzed by MSTAT-Cstatistical computer package program using the "Analysis of variance" technique at 5% level of significance and mean differences was adjudged by Duncan's Multiple Range Test (DMRT) [12].

3. Results and Discussion

3.1. Effect of Variety and N Management Approaches on Rice Productivity

Variety, N management approaches and their interactions had significant influence on most of the yield contributing characters except panicle length and yield of winter rice (**Table 1** and **Table 2**). However, varietal effect was insignificant on harvest index, and N management approaches on 1000-grain weight. Hybrid Dhani gold produced higher number of effective tillers·hill^{-1} (10.97), grains panicle^{-1} (91.46), grain (6.67 t·ha^{-1}) and straw yield (8.79 t·ha^{-1}) than BRRI dhan29 (**Table 1**). The variation between the varieties in terms of yield and yield components might occurred due to the differences in their genetic potentiality [13] [14] [15].

Application of 20 kg·N·ha^{-1} at ≤3.0 LCC value produced the highest number of effective tillers hill^{-1} (11.67) (**Table 1**) which resulted inthe highest grain yield (7.10 t·ha^{-1}) as well as straw yield (9.10 t·ha^{-1}) and biological yield (16.21 t·ha^{-1}) (**Table 1**). Use of urea super granule (USG) produced the highest number of grains panicle^{-1} (93.99) with lowest number of non-effective tillers hill^{-1} (1.93). The highest harvest index (44.64%) was found under soil analysis based N management. Application of 20 kg·N·ha^{-1} at ≤35 SPAD value gave the lowest number of effective tillers hill^{-1} (10.07), grain yield (5.92 t·ha^{-1}) and harvest index (41.37%), whereas BRRI recommended N management gave the lowest grains panicle^{-1} (88.89) and straw yield (8.02 t·ha^{-1}). In case of 30 kg·N·ha^{-1} at ≤35 SPAD value, the grain yield (6.75 t·ha^{-1}) was significantly higher than the 20 kg·N·ha^{-1} at ≤35 SPAD value (**Table 1**). Similar results were also reported by [11] [16] [17] [18]. For SPAD treatments, application of 20 kg·N·ha^{-1} might did not meet the requirement of the plant properly or might not have efficiently used the applied N which resulted lowest grain yield.

Considering the interaction between variety and N management approach, the highest grain yield (7.34 t·ha^{-1}) was observed when BRRI dhan29 was fertilized with 20 kg·N·ha^{-1} at ≤3.0 LCC value (**Table 2**). While, the highest grain yield (7.25 t·ha^{-1}), number of effective tillers hill^{-1} (12.60) and straw yield (9.42 t·ha^{-1}) in Dhani gold were obtained from 30 kg·N·ha^{-1} at ≤3 LCC value (**Table 2**). On the other hand, Dhani gold applied with USG gave the highest number of grains panicle^{-1} (94.93) and harvest index (45.26%). Similar result was also obtained when soil analysis based N management was practiced in Dhani gold. The lowest grain yield (5.19 t·ha^{-1}) and harvest index (38.69%) were found from the

Table 1. Effect of variety and nitrogen (N) management approaches on yield components and yield of winter rice.

Treatment	No. of effective tillers hill^{-1}	Panicle length (cm)	No. of grains panicle^{-1}	1000 grain weight (g)	Grain yield (t·ha^{-1})	Straw yield (t·ha^{-1})	Harvest index (%)
Variety							
BRRI dhan29	10.71b	21.61	89.93b	23.58a	6.61b	8.53b	43.67
Dhani gold	10.97a	21.66	91.46a	22.83b	6.67a	8.79a	43.07
Standard error	0.086	0.050	0.465	0.198	0.020	0.073	0.316
Level of significance	*	NS	*	**	*	**	NS
N management approaches							
BRRI recommended N	10.43c	21.40	88.89b	23.77	6.27f	8.02c	43.85a
Soil analysis based N management	11.30ab	21.58	90.93b	22.15	6.85c	8.50b	44.64a
N management based on agro-ecological zone	11.07b	21.59	90.22b	23.50	6.67de	8.77ab	43.18ab
20 kg·N·ha^{-1} at ≤35 SPAD value	10.07c	21.91	90.96b	23.67	5.92g	8.34bc	41.37b
30 kg·N·ha^{-1} at ≤35 SPAD value	10.37c	21.53	89.80b	23.15	6.75cd	8.65ab	43.84a
20 kg·N·ha^{-1} at ≤3.0 LCC value	11.67a	21.68	89.67b	23.43	7.10a	9.10a	43.83a
30 kg·N·ha^{-1} at ≤3.0 LCC value	11.33ab	21.72	91.13b	23.08	6.98b	9.08a	43.48a
Urea super granule (USG)	10.47c	21.65	93.99a	22.87	6.56e	8.79ab	42.77ab
Standard error	0.171	0.101	0.929	0.396	0.039	0.145	0.633
Level of significance	**	NS	*	NS	**	**	*
CV (%)	3.86	1.14	2.51	4.19	1.44	4.12	3.57

In a column, figures with the same letter(s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). CV = coefficient of variation, * = Significant at probability level (p) 0.05, ** = Significant at p 0.01, NS = Non-significant. BRRI = Bangladesh rice research institute, SPAD = Silicon photon activate diode and LCC = Leaf colour chart.

application of 20 kg·N·ha^{-1} at ≤35 SPAD value in Dhani gold, whereas the 30 kg·N·ha^{-1} at ≤35 SPAD value approach gave the second highest grain yield (6.98 t·ha^{-1})of the same variety. Due to the interaction between variety and N management approaches both the varieties might have responded diversely to the N applied through different N management approaches resulted in wide variation in yield contributing parameters and yield [19] [20].

3.2. Efficiency and Economics of Nitrogen Use

Among different N management approaches studied in the experiment, few showed considerable better performance in respect of efficient N management and yield maximization compared to the existing BRRI recommended varietal N management approach (control) in winter rice (Table 3). Total amount of N applied for different management approaches ranged from 60 to 180 kg·ha^{-1}. Soil analysis and AEZ based N managements required 6% - 12% extra N application compared to the control but did not always increase the yield (decrease of 3.08% to increase of 17%) particularly for BRRI dhan29 (Table 3). Application of 20 kg·N·ha^{-1} at ≤35 SPAD value required the least amount of N·ha^{-1} (60 kg) with

Table 2. Effect of interaction between variety and Nitrogen (N) management approaches on yield components and yield of winter rice.

Variety	N-management approaches	No. of effective tillers hill^{-1}	Panicle length (cm)	No. of grains panicle^{-1}	1000 grain weight (g)	Grain yield (t·ha^{-1})	Straw yield (t·ha^{-1})	Harvest index (%)
BRRI dhan29	BRRI recommended N (control)	11.07cd	21.5a-d	89.46bcd	24.07abc	6.49g	8.10ef	44.50a
	Soil analysis based N management	10.67c-f	21.42bcd	92.90ab	22.44c-f	6.63fg	8.44c-f	44.02a
	N management based on agro-ecological zone	11.00cde	21.34cd	88.01cd	22.47c-f	6.29h	8.52c-f	42.49a
	20 kg·N·ha^{-1} at ≤35 SPAD value	10.00fg	21.89ab	89.88bcd	23.87abc	6.65fg	8.45c-f	44.05a
	30 kg·N·ha^{-1} at ≤35 SPAD value	10.27efg	21.46a-d	88.35cd	25.07a	6.53g	8.40c-f	43.72a
	20 kg·N·ha^{-1} at ≤3.0 LCC value	11.93ab	21.85ab	90.37bcd	23.00b-e	7.34a	9.35 ab	43.98 a
	30 kg·N·ha^{-1} at ≤3.0 LCC value	10.07fg	21.60a-d	87.46d	25.05a	6.72ef	8.74b-e	43.47a
	Urea super granule (USG)	10.67c-f	21.82abc	93.05ab	22.67b-f	6.24h	8.22def	43.16a
Dhanigold	BRRI recommended N (control)	9.800g	21.31d	88.32cd	23.47a-d	6.05i	7.95f	43.21a
	Soil analysis based N management	11.93ab	21.74a-d	88.95bcd	21.87def	7.08b	8.56c-f	45.26a
	N management based on agro-ecological zone	11.13cd	21.85ab	92.44abc	24.53ab	7.05bc	9.02a-c	43.87a
	20 kg·N·ha^{-1} at ≤35 SPAD value	10.13fg	21.93a	92.04abc	23.47a-d	5.19j	8.23d-f	38.69b
	30 kg·N·ha^{-1} at ≤35 SPAD value	10.47d-g	21.60a-d	91.25a-d	21.24ef	6.98b-d	8.90a-d	43.96a
	20 kg·N·ha^{-1} at ≤3.0 LCC value	11.40bc	21.51a-d	88.97bcd	23.87abc	6.87de	8.86a-d	43.69a
	30 kg·N·ha^{-1} at ≤3.0 LCC value	12.60a	21.84ab	94.80a	21.11f	7.25a	9.42a	43.49a
	Urea super granule (USG)	10.27efg	21.48a-d	94.93a	23.07b-e	6.89cd	9.37ab	42.39a
Standard error		0.242	0.143	1.31	0.561	0.055	0.206	0.894
Level of significance		**	*	**	**	**	**	*
CV (%)		3.86	1.14	2.51	4.19	1.44	4.12	3.57

In a column, figures with the same letter(s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). CV = coefficient of variation, * = Significant at probability level (p) 0.05, ** = Significant at p 0.01, NS = Non-significant. BRRI = Bangladesh rice research institute, SPAD = Silicon photon activate diode and LCC = Leaf colour chart.

maximum saving (78 kg·ha^{-1}) in terms of required amount of N over control and maximum partial factor productivity for N in BRRI dhan29 (110.83 kg rice grain kg^{-1}·N) followed by Dhani gold (86.5 kg rice grain kg^{-1}·N). However, with this SPAD approach, the grain yield was 6.65 t·ha^{-1} in BRRI dhan29 and 5.19 t·ha^{-1} in Dhani Gold which was an increase of yield by 2.47% and decrease by 14.21% for the respective variety over control. With 30 kg·N·ha^{-1} application at ≤35 SPAD, grain yield was moderate (6.53 - 6.98 t·ha^{-1}) for both varieties with 48% N saving over control, and moderate partial factor productivity for N. Application of 30 kg·N·ha^{-1} at ≤3.0 LCC value required the highest amount of N·ha^{-1} (180 kg) but also had the lowest partial factor productivity for N (37.33 and 40.27 kg rice grain kg^{-1}·N for BRRI dhan29 and Dhani gold, respectively) and did not gave the highest grain yield for BRRI dhan29. Among all the treatments, the highest amount of grain yield (7.34 t·ha^{-1}) was found from BRRI dhan29 with 20 kg·N·ha^{-1} at ≤3.0 LCC value which was the maximum (13.1%) yield increment

Table 3. Comparative performances of different nitrogen (N) management approaches in terms of N saving and yield improvement in winter rice.

N management approaches	Total amount of N added ($kg·ha^{-1}$)	Amount of N saved (−)/extra added (+) compared to control ($kg·ha^{-1}$)	Rice grain yield ($t\ ha^{-1}$)		%Yield increased (+)/decreased (−) over control		Partial factor productivity for N ($kg·grain·kg^{-1}·N$)	
			BRRI dhan29	Dhani gold	BRRI dhan29	Dhani gold	BRRI dhan29	Dhani gold
BRRI recommended N (control)	138	0	6.49	6.05	0	0	47.0	43.8
Soil analysis based N management	144	+6	6.63	7.08	+2.16	+17.02	46.0	49.2
N management based on agro-ecological zone	150	+12	6.29	7.05	−3.08	+16.53	41.9	47.0
20 $kg·N·ha^{-1}$ at ≤35 SPAD value	60	−78	6.65	5.19	+2.47	−14.21	110.8	86.5
30 $kg·N·ha^{-1}$ at ≤35 SPAD value	90	−48	6.53	6.98	+0.62	+15.37	72.6	77.6
20 $kg·N·ha^{-1}$ at ≤3.0 LCC value	120	−18	7.34	6.87	+13.1	+13.55	61.2	57.3
30 $kg·N·ha^{-1}$ at ≤3.0 LCC value	180	+42	6.72	7.25	+3.54	+19.83	37.3	40.3
Urea super granule (USG)	80	−58	6.24	6.89	−3.85	+13.88	78.0	86.1

BRRI = Bangladesh Rice Research Institute, SPAD = Silicon photon activate diode and LCC = Leaf colour chart. For N, + = N extra added compared to control, and − = N saved compared to control; For yield, + = yield increased over control, and − = yield decreased over control; For a treatment, saved /extra added N compared to control ($kg·ha^{-1}$) = N applied in control ($kg·ha^{-1}$)—applied in the treatment ($kg·ha^{-1}$). For a treatment, yield increased/decreased over control (%) = $\frac{\text{Yield in control} - \text{Yield of the treatment}}{\text{Yield in control}} \times 100$. Partial factor productivity for N ($kg·grain·kg^{-1}·N$) = $\frac{\text{Grain yield (kg)}}{\text{Applied N (kg)}}$.

among N management approaches over control for the same variety. Additionally, this approach saved considerable amount of N (18 $kg·ha^{-1}$) compared to control also with notable partial factor productivity for N (61.16 $kg·rice·grain·kg^{-1}·N$) (Table 3). With USG application about 58% N was saved but the grain yield wad decreased by 3.85% for BRRI dhan29 and increased by 13.88% for Dhani gold over control.

The cost for required amount of nitrogenous fertilizer (urea) ha^{-1} ranged from 2340 (for 20 $kg·N·ha^{-1}$ at ≤35 SPAD value) to 7038 BDT (for 30 $kg·N·ha^{-1}$ at ≤3.0 LCC value) depending on the treatments (Table 4). With the lowest N cost investment, both the gross income (130,600 $BDT·ha^{-1}$ and 139,600 $BDT·ha^{-1}$ for BRRI dhan29 and Dhani Gold, respectively) and net benefit (127,090 $BDT·ha^{-1}$ and 136,090 $BDT·ha^{-1}$ for BRRI dhan29 and Dhani Gold, respectively) were higher in 20 $kg·N·ha^{-1}$ at ≤35 SPAD value management approach than control; and moderate among the other treatments. Although maximum N cost was involved in 30 $kg·N·ha^{-1}$ at ≤3.0 LCC value the highest gross income or net benefit was not obtained from this N management approach, particularly for BRRI dhan29. The highest gross income (146,800 $BDT·ha^{-1}$) with maximum net benefit (142,120 $BDT·ha^{-1}$) was found when 20 $kg·N·ha^{-1}$ at ≤3.0 LCC value was applied in BRRI dhan29, even though it had moderate N cost (4680 $BDT·ha^{-1}$) involvement which is still lower than the control (5400 $BDT·ha^{-1}$). For Dhani gold variety, 30 $kg·N·ha^{-1}$ application at ≤35 SPAD value provided considerably higher gross income (139,600 $BDT·ha^{-1}$) and net income (136,090 $BDT·ha^{-1}$) over control (which was moderate among the other treatments) with lower (3510 $BDT·ha^{-1}$) N cost involvement (Table 4) and moderate yield (Table 3).

Table 4. Economic efficiency of different nitrogen (N) management approaches of winter rice.

N management approaches	N cost (BDT·ha^{-1})	Gross income (BDT·ha^{-1})		Net benefit (BDT·ha^{-1})	
		BRRI dhan29	Dhani gold	BRRI dhan29	Dhani gold
BRRI recommended N (control)	5400	129,800	121,000	124,400	115,600
Soil analysis based N management	5634	132,600	141,600	126,966	135,966
N management based on agro-ecological zone	5868	125,800	141,000	119,932	135,135
20 kg·N·ha^{-1} at ≤35 SPAD value	2340	133,000	103,800	130,660	101,460
30 kg·N·ha^{-1} at ≤35 SPAD value	3510	130,600	139,600	127,090	136,090
20 kg·N·ha^{-1} at ≤3.0 LCC value	4680	146,800	137,400	142,120	132,720
30 kg·N·ha^{-1} at ≤3.0 LCC value	7038	134,400	145,000	127,362	137,962
Urea super granule	3132	124,800	137,800	121,668	134,668

BRRI = Bangladesh rice research institute, SPAD = Silicon photon activate diode and LCC = Leaf colour chart. Here, Gross income (BDT·ha^{-1}) = Rice grain yield (kg·ha^{-1}) × Price (kg^{-1}). Net benefit (BDT·ha^{-1}) = Gross income (BDT·ha^{-1}) − Nitrogen fertilizer cost (BDT·ha^{-1}). Various costs in the experiment: Urea (as nitrogenous fertilizer) = 18 BDT·Kg^{-1}. Rice Grains = 20 BDT·Kg^{-1}. 1US$ = 80 BDT (approx.).

4. Conclusion

To conclude, SPAD or LCC based approach for N management in rice seems more effective than the existing BRRI recommended N management approach, and the performances of different N management approaches differ with rice varieties. In winter season, cultivation of BRRI dhan29 coupled with 20 kg·N·application·ha^{-1} at ≤3.0 LCC value and Dhani gold with 30 kg·N·application·ha^{-1} at ≤35 SPAD value can provide maximum grain yield with efficient and cost-effective N management. However, this conclusion is limited to the specific experimental site, varieties and season. Additional site-specific and multi-year research on this aspect is to be conducted to draw a final conclusion for determining best N management approach for a specific rice variety to achieve the maximum benefit.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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