Comparative Analysis of Nitrogen Use Efficiency in Boro Rice Under Long-Term Inorganic and Organic Fertilization Practices

Abstract

An experiment was conducted during Boro rice in the permanent experimental field of the Department of Soil Science, Bangladesh Agricultural University (BAU), Mymensingh to investigae the long term outcome of manure and fertilizers on the yield and Nitrogen Use Efficiency (NUE) of BRRI dhan29 in floodplain (Subtropical) soil (Aeric Haplaquepts). The experiment was designed in a randomized complete block design with three replications. There were ten treatment combinations viz, control; Nitrogen (N); (Nitrogen Phosphorus) NP; Nitrogen Potassium (NK); Nitrogen Phosphorus Potassium (NPK); Nitrogen Zinc (NZn); Nitrogen Sulphur (NS); Nitrogen Sulphur Zinc (NSZn), Nitrogen Phosphorus Potassium Sulphur Zinc (NPKSZn) and NPK+FYM. The yield contributing characters and yield of BRRI dhan29 significantly increased due to different treatments. Grain and straw yields were highly influenced by the application of nutrients in various combinations. The longest panicle length (25.3 cm), the highest 1000 grain weight (22.7 g), the maximum grain yield (6.29 t ha^{-1}), the highest nitrogen uptake in grain (70.4 kg ha^{-1}) were found for the NPKSZn treatment. Grain yield increased by 24.8%, 85.8%, 40.7%, 68.9%, 29.2%, 33.2%, 107.1%, 28.9% and 78.9% due to N, NP, NK, NPK, NS, NSZn, NPKSZn, NZn and NPK+FYM treatments respectively and the corresponding straw yields attainment by 49.6%, 51.1%, 82.0%, 95.3%, 37.8%, 34.4%, 82.7%, 41.8% and 90.2 %. The maximum value of apparent nitrogen use efficiency was obtained with NPKSZn (54.06%) treatment which evidently suggested its resultness for the long term fertilized soil.

Key words: Rice, nitrogen use efficiency, fertilization, inorganic and organic

Introduction

Rice (*Oryza sativa L.*) is the most significant cereals in the diets of billions of people of Asia, Africa and Latin America. For the people of Bangladesh, rice is the staple food and it covers some 75% of total cropped area. Bangladesh has three rice crops/seasons within a year; the Boro, the Transplant Aman (T. Aman) and the Aus, which account for approximately 52%, 40% and 8% of total annual rice production respectively (BBS, 2023). Among the three rice growing seasons, Boro cropped area of the country covers approximately 5 million hectares in 2023. About 27.87 million hectares of land are used for rice cultivation, the total annual production was 31.31 million metric tons with an average yield of 2.78 t/ha. However, the average yield of rice in Bangladesh is very much lower than that of the highest ranking country like China is 12.9 tha^{-1} (IRRI, 2010). The reasons for this are manifolds: some are varietal; some are climatic; and some are technological. Efficient fertilizer management could enhance the growth and yield attributes of rice which might contribute a lot to the economy of Bangladesh.

The use of fertilizers and manure in our soils has increased over time, and farmers are encouraged to apply these inputs intensively to ensure sustainable crop production. This intensive application of fertilizers and manure inevitably alters the physical, chemical, and biological properties of the soil

(Karim et al., 1994). Prolonged use of mineral fertilizers and manure in rice-based cropping systems enhances the soil's organic matter and total nitrogen levels (Kader et al., 2013). However, long-term reliance on chemical fertilizers can lead to fertility issues due to soil depletion and interactions with other elements (Rahman and Mian, 1997). Repeated and excessive use of chemical fertilizers can compact the soil, making it less capable of retaining nutrients (Medhi and De Datta, 1996). Relying solely on inorganic fertilizers has a negative impact on soil productivity, and the ongoing decline in rice yields is primarily linked to the loss of natural soil fertility (Nambiar et al., 1998). In Bangladesh, combining organic manures with chemical fertilizers may yield greater benefits for crop production compared to using chemical fertilizers alone (Hasan et al., 2009).

For maximizing yield of rice, nitrogenous fertilizer is very important in rice farming. It is essential for the synthesis of protein, which is the constituent of protoplasm and chloroplasts (Rahman *et al*, 2023). But nitrogen use efficiency is very low and the recovery of N in wetland rice seldom exceeds 40%. Many factors determine the fertilizer use efficiency for rice crop during cultivation such as soil, cultivar, season, environment, planting time, water management, weed control, cropping pattern, source, form, rate, time of application and method of application (Zhao *et al*, 2021). Nitrogen fertilization is widely adopted to enhance grain production and improve nitrogen utilization in rice all over the world. This applied fertilizer is getting lost in the environment through a number of processes including immobilization, denitrification/volatilization, leaching and fixation resulting low crop yield and reduced efficiency of applied nutrients (Silva *et al*, 2020). The loss of volatilized nitrogen from Prilled Urea (PU) is significant, leading to substantial financial losses for farmers. Exploring alternatives to minimize production costs while boosting crop yields could be beneficial (Khalil et al., 2009). Nitrogen use efficiency (NUE) for rice generally ranges from 25% to 35%, rarely exceeding 50%. For broadcast-applied prilled urea in lowland rice fields, NUE has been reported between 30% and 45%, largely due to losses from ammonia volatilization, surface runoff, nitrification-denitrification, and leaching (Sommer et al., 2004; Hayashi et al., 2008; Watanabe et al., 2009; Zhao et al., 2009; Dong et al., 2012). Recently, Huda et al. (2016) measured NUE for Boro, Aus, and Aman rice at the Soil Science field laboratory of Bangladesh Agricultural University, finding values of 32%, 24%, and 24%, respectively. Mostofa (2015) also calculated NUE in a long-term field experiment at same location during Aman season for BRRI Dhan49, reporting NUE values ranging from 27.52% to 65.91%. The highest Recovery Efficiency of Nitrogen (REN) was observed with NPKSZn at 65.91%, while the lowest was found with NS at 27.52%. However, there is limited information on the long-term effects of intensive fertilization on yield, NUE, and soil properties. Thus, an experiment was conducted to investigate the impact of long-term fertilization on yield and nitrogen use efficiency of Boro rice (BRRI dhan29) while assessing its nitrogen recovery efficiency.

Materials and methods

Topographically the experimental area was slightly undulating but the experimental plot was fairly leveled. It was above normal flood level but sometimes the plot remained flooded for short time by rainwater during monsoon season. The soil of the plot was typical rice growing silt loam developed from the alluvial deposits of the river Old Brahmaputra. The soil forming processes of the field was mainly influenced by surface and ground water (AbedinMian, 1991). According to the report of the

Department of Soil Survey (1967-68) the general soil type of the field was "Non-calcareous Dark Grey Floodplain Alluvium" and the soil series was sonatala silt loam. It belongs to the agro-ecological zone of "Old Brahmaputra Floodplain" i.e. AEZ 9.

Table 1. Textural class and chemical characteristic of the permanent experimental fields

Characteristics	Value
Particle size distribution	
%Sand (2-0.05 mm)	11.65
%Silt (0.05- 0.002 mm)	75.70
%Clay (< 0.002mm)	12.65
Textural class	Silt loam
pH	6.92
Organic matter (%)	2.82
Total Nitrogen (%)	0.12
Available Phosphorus (mg kg^{-1})	12.6
Exchangeable Potassium (meq $100g^{-1}$ soil)	0.16
Available Ca (meq $100g^{-1}$ soil)	9.43
Available Mg (meq $100g^{-1}$ soil)	2.72
Available S (mg kg^{-1})	15.6

The experiment was laid out in randomized complete block design with three replications. Each block was subdivided into ten unit plots for placement of ten treatments of the experiment. The size of the unit plot was 11.5 m x 6.5 m (74.75 m^2). The long term field experiment was established since 1978 comprised of ten different treatment combinations of manure and fertilizers namely i. Control, ii. N (120 kg), iii. NP (120 kg- N + 14 kg- P), iv. NK (120 kg-N + 58 kg- K), v. NPK (120 kg-N +14 kg-P + 5 kg-K), vi. NS (120 kg-N + 8 kg- S), vii. NSZn (120 kg- N + 8 kg- S + 1 kg Zn), viii. NPKSZn (120 kg-N+14 kg-P+58 kg-K+8 kg-S+1 kg Zn), ix. NZn (120 kg-N+1 kg Zn) and x. NPK + FYM (120 kg-N +14 kg- P +58 kg- K + 5 ton FYM). The major change was the update of fertilizer recommendation as per FRG 2012 and inclusion of full doses (100%) of N, P and K fertilizers for N (50%) + FYM treatment.

Table 2. Old treatments for the permanent experiment

Nutrient Element	Dose (kg ha^{-1})		Source (Fertilizers)
	Boro rice	Aman rice	
N	120	60	Urea
P	14	4	TSP
K	58	29	MP
S	8	6	Gypsum
Zn	1	-	Zinc Oxide
FYM	5000	-	Decomposed Cowdung

Table 3. The doses and sources of different nutrients and FYM used for Boro rice

The doses and sources of different nutrients and FYM used for Boro rice were as follows**:**

Nutrient Element	Dose (kg ha$^{-1)}$		Source (Fertilizers)
	Boro rice	Aman rice	
N	90	80	Urea
P	20	20	TSP
K	19	19	MP
S	30	30	Gypsum
Zn	5	5	Zinc Oxide
FYM	5000	-	Decomposed Cowdung

BRRI dhan29, a high yielding variety of rice developed by Bangladesh Rice Research Institute, Joydebpur, Gazipur in 1992. It is a transplant boro rice cultivar and matures after 110 days of transplanting with average yield 5.0- 7.5 t/ha. The plant height is 90-95 cm and the cultivar is of non-lodging type. It is somewhat resistant to pests and especially resistant to blast diseases. The seedlings of Boro rice (BRRI dhan29) were transplanted with maintaining spacing were 20 cm between row and 15 cm between hills. Three seedlings were transplanted per hill. Recommended production packages were followed for normal growth and development. The full dose of FYM was applied only in Boro season at the time of final land preparation. The entire quantity of P, K, S and Zn and one third dose of urea were applied at the time of final land preparation one day prior to transplantation. The rest of the urea was applied in three equal splits after 30, 60, 90 days of transplantation. The experimental plots were infested with some weeds which were controlled by uprooting and removing them from the field two times at both the season. Irrigation water was applied in season to the experimental plots before transplanting for the preparation of land. Optimum water was remained in the field during rest of experimental period. From each plot, the area of 4 square meter was harvested and the crop was bundled separately. The harvested crop was threshed plot wise. Grain and straw yields were recorded and moisture percentage was calculated after sun drying. Plant height, effective tillers hill $^{-1}$, filled grains panicle $^{-1}$, unfilled grain panicle^{-1}, panicle length, 1000 grain weight, grain and straw yield were recorded

Chemical analysis of plant sample

The representative grain and straw samples were dried in an oven at 65^0 for about 24 hours before they were ground by a grinding machine. The prepared samples were then stored in paper bags and finally they were kept into desiccators until analysis was done.

For the determination of nitrogen, 0.1g of oven dried ground plant sample (both grain and straw separately) was taken in a micro-kjeldahl flask. 1.1 g catalyst mixture ($K_2SO4:CuSO_4.5H_2O:Se$ = 100:10:1), 2 ml 30% H_2O_2 and 3 ml H_2SO_4 were added into the flask. The flask was swirled and allowed to stand for about 30 minutes. Then heating (380^{0}C) was continued until the digest was clear and colorless. After cooling, the content was taken into a 100 ml volumetric flask and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. The digest was used for nitrogen determination.

After completion of digestion, 40% NaOH was added with the digest for distillation. The evolved ammonia was trapped into 4% H_3BO_3 solution and 5 drops of mixed indicator of bromocresol green ($C_{21}H_{14}O_5Br_4S$) and methyl red solution. Finally, the distillate was titrated with standard 0.01 N H_2SO_4 until the color changed from green to pink (Bremner and Mulvaney, 1982). The amount of N was calculated using the following formula:

$$\% N = (T-B) \times N \times 0.014 \times 100 \div S$$

Where,
T= Sample titration value (ml) of standard H_2SO_4
B= Blank titration value (ml) of standard H_2SO_4
N = Strength of H_2SO_4
S= Weight of soil sample in gram

Nitrogen uptake

After chemical analysis of grain and straw samples, the nutrient content was calculated and from the value of nutrient concentration. Nutrient uptakes were also calculated by the following formula of Jackson (1967).

$$\text{Nitrogen uptake (kgha}^{-1}\text{)} = \frac{\text{Nitrogen content (\%)} \times \text{Yield kg/ha)}}{100}$$

Recovery Efficiency of Nitrogen

Nitrogen use efficiency is referred as kg grain yield increase kg^{-1} N applied. As N Fertilizers were applied in different plots at different doses, the use of N efficiency was calculated by the following formula.

$$REN (\%) = (NU_{NA} - NU_{0N}) / N_{RN} \times 100$$

Where, NU_{NA} = N uptake by grain and straw in treatment due to N addition (kg/ha)
NU_{0N} = N uptake by grain and straw in treatment due to N omission (kg/ha)
N_{RN} = Rate of N addition (kg ha^{-1})

Statistical analysis

The analysis of variances for different yield contributing characteristics, yield and nutrient uptake were done following the ANOVA technique and the mean results in case of significant F-value were adjudged by the Duncan's Multiple Range Test (DMRT).

Results

Effect of long-term mineral fertilization and manuring on yield and yield contributing characters of boro rice

Plant height (cm)

The plant height of Boro rice (BRRI dhan29) in the experimental plot was significantly affected by the different treatments (Table 4). The tallest plant height of 87.3 cm was recorded for the NPK+FYM treatment. The results showed that the plant heights for NP, NPK, NPKSZn, and NPK+FYM were statistically similar. Additionally, plant heights for N, NP, NK, NZn, as well as N, NK, NS, and NZn were also statistically comparable. There was statistical similarity between the control, NS, and NSZn treatments, while the lowest plant height of 72.1 cm was noted for the NSZn treatment.

Effective tillers hill^{-1}

It is denoted from Table 4 that tillering was significantly affected by various treatment combinations. The highest number of effective tillers per hill (12.9) was found for the treatment NPK and the lowest (7.2) was recorded for control. The number of tillers hill^{-1} for the treatments NP, NPK, NPKSZn and NPK+FYM remained statistically similar. Again the tillers hill^{-1} remained statistically similar for the NP, NK, NS, NZn and as well as N, NS, NK, NSZn and NZn treatments.

Non-effective tillers hill^{-1}

There was also several effect of treatments on the production of non-effective tillers. Non-effective tillers ranged between 1.07 for NPK+FYM treatment and 1.8 for Control treatment. The numbers of non-effective tillers for the treatments N, NP, NK, NPK, NS, NSZn, NPKSZn, NZn and Control were statistically similar.

Panicle length (cm)

Panicle length showed a significant increase due to various treatments. The longest panicle length of 25.3 cm was observed in the NPKSZn treatment, while the shortest length of 21.9 cm was recorded for the control group. The results indicated that panicle lengths for the treatments NP, NK, NPK, NPKSZn, and NPK+FYM, as well as N, NP, NK, NPK, and NZn, were statistically similar. Additionally, statistical similarity was found among the control, N, NP, NK, NS, NSZn, and NZn treatments.

Number of filled grains panicle^{-1}

The highest number of filled grains (147.9) was found for NPK+FYM treatment, whereas the lowest number (106.2) was recorded for NS treatment. Filled grains panicle^{-1} for the treatments NP, NPK, NPKSZn and NPK+FYM were statistically similar. (Table 4). Statistical similarity was also found between the N, NP, NK, NPK, NZn treatments. Again Control, N, NK, NS, NSZn and NZn treatments were statistically similar also.

Number of unfilled grains panicle^{-1}

The maximm number of unfilled grains (15.9) was recorded for NK treatment, and the minimum number (13.03) was in NPK+FYM. Unfilled grain panicle^{-1} was found statistically similar for the treatments Control, N, NP, NK, NPK, NS, NSZn and NPKSZn as well as for NPK+ FYM, NZn, NPKSZn, NSZn, NPK, N, Control and NP (Table 4).

1000-grain weight (g)

The 1000-grain weight ranged from 21.3 to 22.7g. Statistically similarity was found between the N, NP, NK, NPK, NPKSZn, NPK+FYM. Again Control, N, NP, NK, NZn and NPK+FYM as well as Control, N, NS, NSZn and NZn were also statistically similar.

Grain yield (t ha^{-1})

Grain yield of rice is the final product of yield components which was found to be significantly influenced by different fertilizer treatments (Table 4). The highest grain yield (6.29 t ha^{-1}) was recorded for the treatment NPKSZn where the lowest (3.04 t ha^{-1}) was recorded for the control. Grain yield due to different treatment ranked in the order of NPKSZn>NP>NPK+FYM>NPK>NK>NSZn>NS=NZn>N>Control. Result indicated that the grain yield for NP, NPKSZn and NPK+FYM as well as NP, NPK, NPK+FYM again NK, NPK and NSZn were statistically similar. Statistical similarity also found between N, NK, NS, NSZn and NZn as well as Control, N, NS, NSZn and NZn. Grain yields were increased by 24.8%, 85.8%, 40.7%, 68.9%, 29.2%, 33.2%, 107.1%, 28.9% and 78.9% for the treatments of N, NP, NK, NPK, NS, NSZn, NPKSZn, NZn and NPK+FYM, respectively (Figure 1).

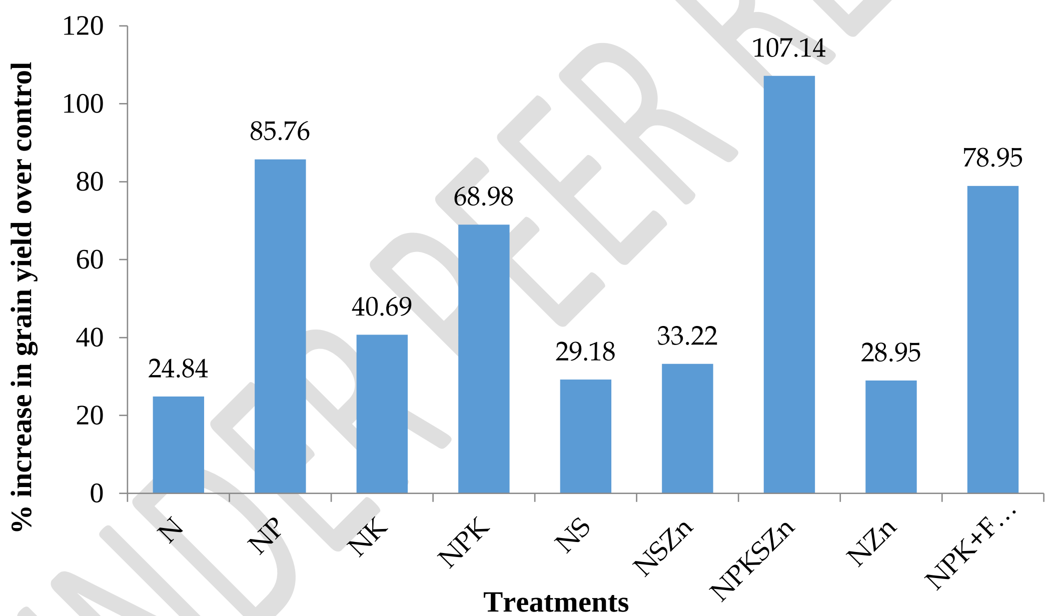

Figure 1. Effects of different fertilizers and manures on % increase of grain yield over the control

Straw yield (t ha^{-1})

Similar to grain yields, the straw yields of Boro rice varied significantly across different treatment combinations (Table 4). The straw yields ranged from 4.7 t ha-1 in the control group to 9.2 t ha-1 for the NPK treatment. The results indicated that straw yields for the treatments NK, NPK, NPKSZn, and NPK+FYM, as well as N, NP, NK, and NPKSZn, were statistically comparable. Likewise, the treatments N, NP, NS, NSZn, and NZn, along with the control and NSZn, also showed similar statistical results. In terms of yield increases, treatments showed enhancements of 49.6%, 51.1%, 82.0%, 95.3%, 37.8%, 34.4%, 82.7%, 41.8%, and 90.2% for N, NP, NK, NPK, NS, NSZn, NPKSZn, NZn, and

NPK+FYM, respectively (Figure 2).

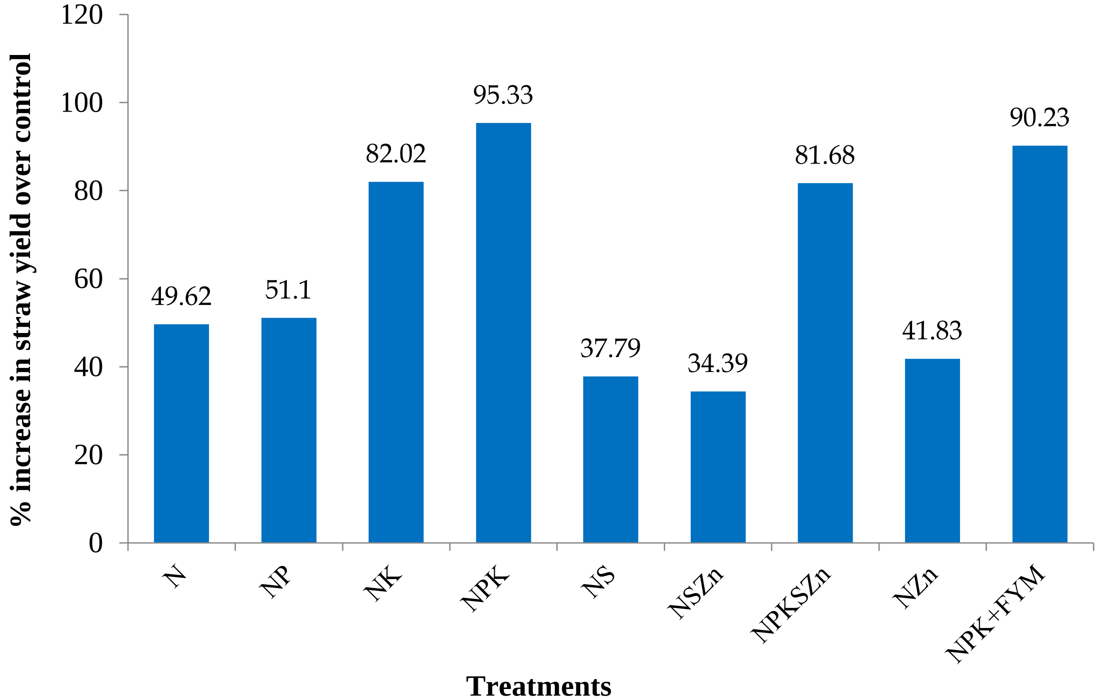

Figure 2. Effects of different fertilizers and manures on % increase of straw yield over the control

Table 4. Yield and yield contributing characters of Boro rice (BRRI dhan29)

Treatment	Plant height (cm)	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Control	73.3d	7.2d	1.8a	21.9c	109.8d	14.6ab	21.8bc	3.04e	4.7d
N	78.7bc	9.3c	1.2a	22.7bc	117.1cd	15.1ab	22.0abc	3.8de	7.05bc
NP	83.3ab	11.3ab	1.5a	23.7abc	134.1abc	14.6ab	22.5ab	5.7ab	7.1bc
NK	79.6bc	9.9bc	1.5a	23.5abc	121.5cd	15.9a	22.5ab	4.3cd	8.6ab
NPK	83.5ab	12.9a	1.2a	24.2ab	133.7abc	14.6ab	22.7a	5.1bc	9.2a
NS	75.2cd	9.8bc	1.3a	22.1c	106.1d	15.8a	21.5c	3.9de	6.5c
NSZn	72.1d	9.0c	1.7a	21.9c	111.9d	14.5ab	21.3c	4.05cde	6.3cd
NPKSZn	86.3a	12.2a	1.3a	25.3a	143.9ab	14.1ab	22.7a	6.29a	8.6ab
NZn	78.7bc	10.3bc	1.4a	22.4bc	124.7bcd	13.4b	21.8bc	3.9de	6.7c
NPK+FYM	87.3a	12.5a	1.07b	25.2a	147.9a	13.03b	22.5ab	5.4ab	8.9a
SE±	2.17	0.73	0.29	0.83	8.21	0.95	0.28	0.46	0.46
CV (%)	7.47	19.29	34.18	7.36	14.61	11.20	2.84	26.01	23.09

Nitrogen uptake

The different treatments significantly affect the total N uptake by both grain and straw of Boro (BRRI dhan29) rice (Table 4). The total N uptake in grains resulted from 28.3 to 70.4 kg ha^{-1}. The maximum N uptake (70.4 kg ha^{-1}) in grains was found in the treatment NPKSZn which statistically varried significantly from all other treatments. The lowest N uptake (28.3 kg ha^{-1}) was found for the control treatment. In Straw, the N uptake ranged from 23.6 to 52.4 kg ha^{-1}. The highest N uptake (52.4 kg ha^{-1}) in straw was recorded in the treatment NPK. The lowest N uptake (23.6 kg ha^{-1}) was observed for the control treatment. It was noted that N uptake in the grain was higher than that of straw in all the treatments except that of NK.

Table 5. Effect of long term fertilization on nitrogen uptake by grain and straw of BRRI dhan29

	N uptake (kg ha^{-1})		
Treatment	**Grain**	**Straw**	**Total**
Control	28.3e	23.6d	51.9e
N	37.5de	36.7bc	74.2de
NP	57.9ab	40.8bc	98.8abc
NK	41.4cd	48.2ab	89.6bcd
NPK	54.6b	52.4a	106.9ab
NS	40.8de	38.9bc	79.7cd
NSZn	40.5de	39.5bc	79.9cd
NPKSZn	70.4a	46.5ab	116.8a
NZn	36.7de	34.9cd	71.6de
NPK+FYM	54.01bc	46.9ab	101.01abc
SE±	5.34	4.79	9.31
CV (%)	31.10	25.75	26.36
LSD at 5%	12.84	11.51	22.36

Recovery Efficiency of Nitrogen (REN)

Recovery Efficiency of Nitrogen (REN) refers to the balance between the amount of nitrogen fertilizer absorbed and utilized by the crop versus the amount lost, relative to the control treatment. In this study, REN values ranged from 16.4% to 54.06% (Figure 3), with the highest value of 54.06% recorded for NPKSZn and the lowest of 16.4% for NZn. These results suggest that applying NPKSZn fertilizers may enhance the efficient uptake and utilization of nitrogen. The REN values observed in this study were slightly higher than the national average for rice fields, which is around 30%. This discrepancy may be attributed to the lack of other fertilizers in the control treatment.

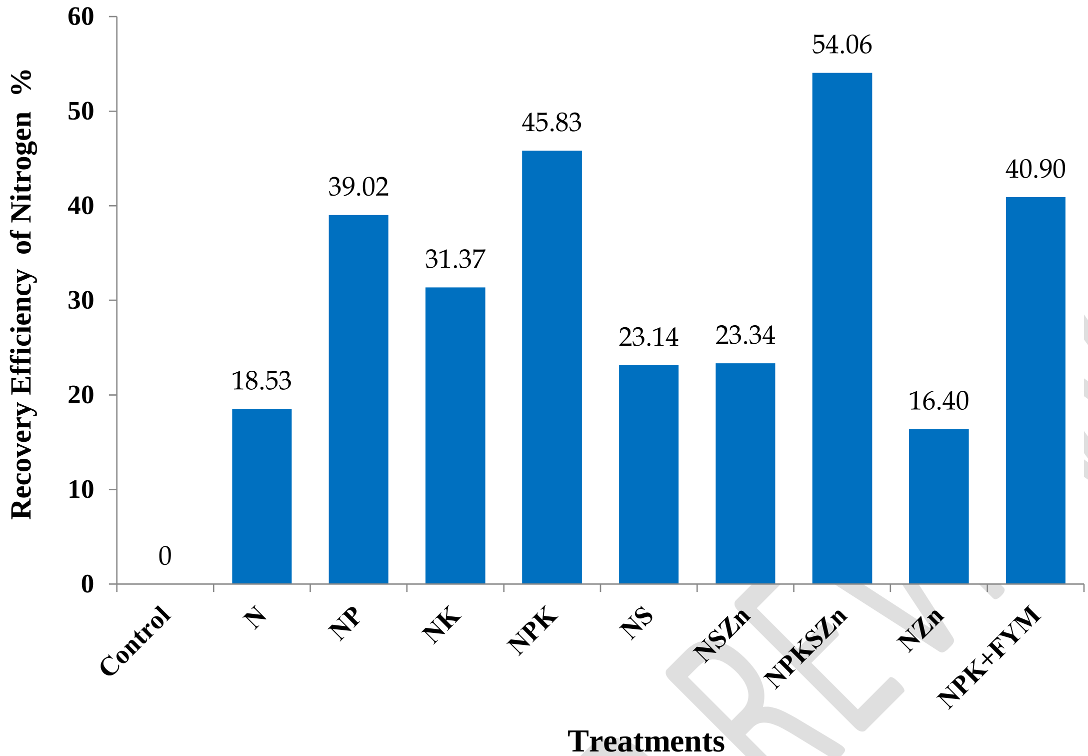

Figure 3. Effect of long term fertilization on Recovery Efficiency of Nitrogen by grain and straw of BRRI dhan29

Discussion

The largest panicle length (25.3 cm), the maximum grain yield (6.29 t ha^{-1}), the NPKSZn treatment recorded the highest nitrogen uptake (70.4 kg ha-1) and nitrogen recovery efficiency (54.06%). This might be due to the fact that the treatment NPKSZn supplied almost all the essential plant nutrients required for rice plants. Therefore, a balanced dose of fertilizers covering most of these nutrients resulted in highest grain yield from the test variety. Haque and Sattar (1974) observed a maximum plant height, effective tiller and grain yield (4.0 t ha^{-1}) under N, P and K fertilizer application with a local variety of rice namely Hashikalmi in the non-calcareous dark grey floodplain soil. Kulkarni et al. (1978) also reported that the grain yield of Joya variety of rice increased with increasing N, P, K and $ZnSO_4$ application. BRRI (1992) also observed the highest number of panicles per meter square (178) and grain yield (3.48 t ha^{-1}) with BR11 rice in the complete fertilized plot where N, P, K, S and Zn were applied.

Grain yields in treatments N (3.8 t/ha), NS (3.9 t/ha) and NZn (3.9 t/ha) were found statistically similar with control (3.04 t/ha) treatment. However, treatment covering at least two major nutrients from NPK viz. NP (5.7 t/ha) and NK (4.3 t/ha) resulted in much better grain yield as compared to N, NS, NZn and NSZn. These findings highlight the importance of applying balanced fertilizer doses that include key nutrients specifically nitrogen, phosphorus, and potassium for effective rice cultivation across various soil conditions.

The NPKSZn treatment was identified as the most effective based on all evaluated parameters, followed closely by the NPK+FYM treatment, which showed similar statistical results in most cases. The tallest plant height recorded was 87.3 cm for the NPK+FYM treatment. In the NPK+FYM treatment, plant height and grain yield increased by 3.8 cm and 0.3 t/ha, respectively, compared to the NPK treatment. These results underscore the benefits of applying FYM, likely due to improved soil conditions and enhanced microbial activity associated with its use alongside NPK.

These findings align with those of Wang et al. (2004) and Chalk et al. (2003), who observed that in many long-term studies, the combination of mineral fertilizers and farmyard manures typically resulted in the highest crop yields and soil quality. Similarly, Rasool et al. (2007) reported that using both manure and inorganic fertilizer in a rice-wheat cropping system enhanced paddy yield, as manure application boosts soil health and supplies essential nutrients for plants.

The recovery efficiency of nitrogen (REN) recorded in this experiment varied from 16.4 to 54.06 %. The highest value of REN was gained with NPKSZn (54.06 %) and lowest value was resulted from NZn (16.4 %). Such results denote that application of NPKSZn fertilizers may lead to efficient uptake and utilization for applied N. The REN values in this study appeared little higher compared to earlier reported REN in rice fields. For an example, REN of broadcast applied prilled urea (PU) in lowland rice field was reported to be varied between 30–45 % due to the losses from ammonia (NH3) volatilization, surface runoff, nitrification–denitrification and leaching (Sommer et al. 2004; Hayashi et al. 2008; Watanabe et al. 2009; Zhao et al. 2009; Dong et al. 2012). Very recently, Huda et al. (2016) found that REN of Boro, Aus and Aman rice cultivated in Soil Science field laboratory of Bangladesh Agricultural University were 32, 24 and 24% respectively.

The higher REN observed in our experiment compared to previous reports may be attributed to the absence of other fertilizers in the control treatment, which served as an absolute control rather than just an N control. Marzia (2015) also assessed NUE in a similar field experiment during the Aman season (BRRI Dhan 49) and found that REN ranged from 27.52% to 65.91%. The highest REN value of 65.91% was again associated with NPKSZn, while the lowest was recorded for NS at 27.52%.

Therefore, it is clear that complete fertilization consisting N, P, K, S and Zn enhanced the vegetative growth of the rice plants and thereby increased the yield, N uptake as well as nitrogen use efficiency of rice.

Conclusion

The highest grain yield of BRRI dhan29 and nitrogen use efficiency were found for the treatment NPKSZn compared to other treatments. It indicates, the necessity of using complete and balanced fertilization i.e. application of N, P, K, S, Zn fertilizer combined to increase yield and nitrogen use efficiency of rice. It also indicates that our soil is deficient in N, P, K, S and Zn. Therefore, the treatment NPKSZn may be recommended for Boro rice (BRRI dhan29) cultivation in the areas with soils, climate and management similar to this study site. However, these results were from the experiment conducted in one location, more studies across different soils, climate and management practices are needed to understand the site and season specific response of long term fertilization and their possible interaction effects on yields, NUE and soil fertility.

Author(s) hereby declare that no generative AI technologies and text-to-image generators have been used during the writing or editing of this manuscript.

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