

# EFFECTS OF FERTILIZER AND WATER MANAGEMENT ON NITROGEN AND PHOSPHORUS AVAILABILITY AND YIELD OF BORO RICE

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## Abstract

Fertilizer and water management is crucial for crop production especially in rice which yet to receive attention for sustainable agriculture. The present study was conducted to determine the effect of organic and inorganic fertilizers and water management on nutrient availability and yield of Boro rice. The experiment was laid out in a split-plot design using two irrigation ( $I_1$ : continuous flooding and  $I_2$ : saturated condition) and six levels of fertilizer ( $T_0$ : Control;  $T_1$ : 100% recommended dose of fertilizer (RDF);  $T_2$ : 70% RDF + 30% from cowdung;  $T_3$ : 50% RDF + 50% from cowdung;  $T_4$ : 70% RDF + 30% from compost;  $T_5$ : 50% RDF + 50% from compost) where irrigation and fertilizers were employed at the main plots and sub plots, respectively. The growth and yield parameters were significantly affected by fertilizer treatments where the higher grain yield was obtained from  $T_1$  and  $T_4$ . The highest grain yield ( $7.02 \text{ t ha}^{-1}$ ) was obtained from  $I_2T_1$  followed by  $I_1T_1$  and  $I_2T_4$  treatment combination. The higher levels of ammonium-N and phosphate concentrations were found in  $I_2T_1$  followed by  $I_1T_1$  and  $I_2T_4$  treatment combinations. Combined application of organic and inorganic fertilizers was found efficient in increasing grain and straw N and P concentrations. The study demonstrates that integrating inorganic fertilizers with appropriate water management, particularly saturated irrigation combined with recommended fertilizer dose or partial compost substitution, significantly enhances nutrient availability and grain yield of Boro rice.

**Keywords:** Fertilizer, manure, irrigation, Boro rice, nutrient availability

## 1. Introduction

The depleted soil fertility is a major constraint to higher crop production in Bangladesh (Al-Amin *et al.*, 2025). The increasing land use intensity has resulted in a great exhaustion of nutrients in soils. Rice-rice system is the most important cropping system in Bangladesh (Islam *et al.*, 2024). Continuous cultivation of this highly exhaustive cropping sequence in most of the irrigated fertile lands has resulted in the decline of soil physico-chemical condition in general and particularly soil organic matter (SOM) content (Rahman *et al.*, 2016; Rahman *et al.*, 2024). This has led to a reduction in the total factor productivity and raised questions on the sustainability of this cropping system. This implies increased use organic manures and of

fertilizers, optimum adoption of pest management strategies and shifting from mono-to double-and triple cropping on the same piece of land year after year. It will, therefore, be necessary to place greater emphasis on strategic research to increase the efficiency of applied nutrients through integration with organic manures, which will help in accomplishing twin objectives of sustaining soil health and ensuring food security and environmental protection. Yang *et al.* (2004) reported that application of chemical fertilizers with farmyard manure or wheat straw in alternate wetting and drying condition increased N, P & K uptake by rice plants. Findings from several researches exhibited that different doses of chemical fertilizers in combination with cowdung (CD), poultry manure etc., increased crop yield and enhanced P uptake and P supplying power of the soil (Saleque *et al.*, 2004; Salma *et al.*, 2022; Hasnat *et al.*, 2022). Dao and Cavigelli *et al.* (2003) used animal manure as a source of plant nutrients which improved the fertility condition and soil health.

Irrigated Boro rice represents 50% of total rice production in the country. The efficiency of used fertilizers in the rice field is greatly affected by the level of soil moisture during rice growing periods (Alam *et al.*, 2019; Billah *et al.*, 2024). Organic matter decomposition, nutrient mineralization and leaching are greatly affected by the soil moisture level. Anaerobic conditions in paddy soil leads to mobilization of some nutrients and thus affect nutrient bioavailability to rice plants. Qinghua *et al.* (2002) carried out an experiment with different levels of irrigation and the highest yield was obtained under flooded condition. Ebrahim *et al.* (2011) conducted experiment with four water managements and the highest grains yield was found from submerge irrigation. Gani *et al.* (2002) reported that intermittent (Alternate wet and drying) irrigation consistently performed better than continuously flooded irrigation as it produced more effective-tillers, leaf area, and biomass.

The bioavailability, uptake and movement of nutrients in soil are dependent on a number of factors including the source and concentration of the nutrient, soil properties such as clay content, pH and redox conditions, ions and amount and type of organic matter present. Now, the situation demands judicious fertilizer and water management without affecting normal crop growth. The minimum irrigation would also reduce the cost of crop cultivation. Further, this would reduce the consumption of electricity. At present, this is the priority research in Bangladesh. The effect of fertilizer and manures on rice under different water management has not much studied. Identification of the fate of added fertilizers in the soil column with water management is a new area of research which may generate novel data. To increase the efficiency of added nutrients in rice cultivation, it is necessary to determine the suitable level of manure and fertilizer with proper water management. Soil is a heterogeneous system; it is important to carry out studies to understand the effects of applied manures and fertilizers in paddy soil with different irrigation practices. The objectives of the research are to determine the effects of fertilizer and manure with different water management on the yield of Boro rice, and to quantify the effect of fertilizer and manures on nutrient accumulation in Boro rice. The study is expected to improve nutrient use efficiency and sustain or enhance Boro rice yield

through optimized combinations of fertilizers, manures, and water management, while reducing production costs and electricity consumption through minimum irrigation practices. Additionally, it will generate novel insights into nutrient dynamics in paddy soils, supporting environmentally sound management strategies and evidence-based policy decisions for sustainable rice production in Bangladesh.

## 2. Materials and Methods

The experiment was started at Sher-e-Bangla Agricultural University farm, Dhaka. Rice (BRRRI dhan 29) was grown in 36 plots (six fertilizer and manure treatments x 2 different levels of irrigation x 3 replications). The experiment consists of 2 factors i.e., irrigation and fertilizer. Two Irrigation treatments ( $I_1$  = Continuous flooding,  $I_2$  = Saturated condition) and six fertilizer treatments  $T_0$ : Control;  $T_1$ : 100% Recommended Dose of Fertilizer ( $N_{180}P_{25}K_{70}S_{15}Zn_2$ );  $T_2$ : 70% RDCF + 30% nutrient from cowdung;  $T_3$ : 50% RDCF + 50% from nutrient cow dung;  $T_4$ : 70% RDCF + 30% nutrient from compost;  $T_5$ : 50% RDCF + 50% nutrient from compost. The experiment was laid out in a split plot design (SPD) with three replications. The layout was made distributing two irrigations (continuous flooding and saturated condition) to the main plots and fertilizer plus manure treatments to the sub plots. The total number of plots was 36, measuring 2.0 m x 2.0 m and Ailes separated plots from each other. Initial soil samples were collected from 0- 15 cm depth. Cow dung, and compost were applied before four days of final land preparation. Forty days old seedlings of BRRRI dhan29 were carefully uprooted from the seedling nursery and transplanted in first week of January, 2022 in well puddled plot. Initial soil samples were collected from the plots and composite soil sample was prepared for analysis. Soil samples were collected from the rice field during panicle initiation stage and analyzed for  $NH_4$ -N and available P. The rice grain samples were collected and ground for nutrient analysis.

### 2.1 Methods of soil and plant analysis

Soil pH was measured by glass electrode pH meter (McLean, 1982), organic carbon by wet oxidation method, total N by micro-Kjeldahl method, available P by Olsen method, exchangeable K by IN  $NH_4OAc$ , pH 7.0 extraction, available S by 0.15%  $CaCl_2$  extraction (Page *et al.*, 1982).

### 2.2 Determination of ammonium-N in soil samples

The soil samples were collected and extracted by KCl solution for extracting ammonium. Ammonium concentration in soil extract was determined by phenolhypochloride method (Solorzano (1969).

The  $NH_4^+$ -N in the soils of rice field was determined by phenol hypochlorite method. First 25 mL soil extract samples were taken into a 50 mL volumetric flask and then 2.0 mL phenol solution, 2.0 mL sodium nitroprusside and 5.0 mL oxidizing solution were added and mixed

thoroughly. After each addition of reagents, the solution was shaken for five minutes to mix well. Then the solution was left for 1 hour for colour development. After colour development, the absorbance of the solution was measured at 640 nm by a spectrophotometer. The value of  $\text{NH}_4^+\text{-N}$  was determined from absorbance by preparing a standard curve using standard solution and expressed in ppm. The collected rice grain from each plot was dried in an oven at 65 °C for about 48 hours after drying the samples were ground by a grinding machine. Later the ground samples were sieved through a 20-mesh sieve. The prepared samples were chemically analyzed for N and P following kjeldahl and diacid digestion procedure (Watson and Issac, 1990). After harvest, the total number of effective tillers hill<sup>-1</sup>, plant height, panicle length, filled grains panicle<sup>-1</sup>, grain and straw yields were recorded.

### 3. Results and Discussion

The soil of experimental site belongs to the Tejgaon soil series of Madhupur Tract (AEZ 28) and general soil type, deep red brown terrace soil. Soil samples from 0-15 cm depths were collected before transplanting the rice seedling and analyzed for physico-chemical properties of soil. The soil is a silty clay loam with 5.7 pH, 1.12% organic matter, 0.08% total N, 12.0 µg g<sup>-1</sup> available P and 52.5 µg g<sup>-1</sup> exchangeable K.

**Table 1.** Effect of irrigation on the growth parameters of Boro rice

Treatments	Total number of effective tillers hill <sup>-1</sup>	Total number of non-effective tillers hill <sup>-1</sup>	Plant height (cm)	Panicle length(cm)
I <sub>1</sub>	15.80	0.46	101.81	26.95
I <sub>2</sub>	16.32	0.29	102.31	26.77
S.E. (±)	NS	NS	NS	NS

I<sub>1</sub>= Continuous flooding, I<sub>2</sub> = Saturated condition

#### 3.1 Effects of irrigation, fertilizer and manure on the growth parameters of Boro rice

The number of effective tillers hill<sup>-1</sup>, plant height, panicle length and filled grains panicle<sup>-1</sup> were not significantly affected by different irrigation levels but significantly influenced by different fertilizer and manure application. Among the different doses of fertilizers, T<sub>1</sub> (100% RDCF) showed the highest number of effective tillers/hill (17.77) which was statistically similar to T<sub>2</sub> (17.47) (70% RDCF + 30% nutrient from cow dung), T<sub>3</sub> (50% RDCF + 50% nutrient from cow dung) and T<sub>4</sub> (70% RDCF + 30% nutrient from compost) treatments. On the contrary, the lowest number of effective tillers/hill (12.43) was observed in T<sub>0</sub> treatment where no fertilizer was used. The number of non-effective tillers hill<sup>-1</sup> was not significantly affected by different fertilizer treatment. The highest number of non-effective tillers hill<sup>-1</sup> (0.47) was found in T<sub>4</sub> treatment. Among the different fertilizer doses, T<sub>5</sub> (50% RDCF + 50% nutrient from compost) showed the lowest number of non-effective tillers hill<sup>-1</sup> (0.33). The highest plant height (109.36 cm) was obtained in T<sub>1</sub> treatment which was statistically similar

to  $T_2$  (70% RDCF + 30% nutrient from cowdung treatment) and lowest plant height was observed in  $T_0$  treatment. The highest panicle length (27.56 cm) was obtained in  $T_2$  (70% RDCF + 30% from cow dung treatment) which was statistically similar to all other fertilizer treatment except  $T_0$  and lowest plant height was observed in  $T_0$  treatment.

**Table 2.** Effects of fertilizer and manure on the yield parameters of Boro rice

Treatments	Number of effective tillers hill <sup>-1</sup>	Number of non-effective tillers hill <sup>-1</sup>	Plant height (cm)	Panicle length (cm)
$T_0$	12.43c	0.43	89.20c	25.38b
$T_1$	17.77a	0.43	109.36a	27.16a
$T_2$	17.47ab	0.40	104.99ab	27.56a
$T_3$	16.90ab	0.17	103.20b	26.89a
$T_4$	16.00ab	0.47	103.59b	27.13a
$T_5$	15.80b	0.33	102.02b	27.02a
S.E. ( $\pm$ )	0.51	NS	1.38	0.31

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per DMRT.

### 3.3 Combined effects of irrigation and fertilizer on the growth parameters of Boro rice

The number of non-effective tillers hill<sup>-1</sup>, plant height and panicle length were not significantly affected by the interaction effect of fertilizer and manure. The number of effective tillers hill<sup>-1</sup> was significantly affected by the interaction effect of irrigation and fertilizer and the highest number of effective tillers hill<sup>-1</sup> (19.20) was found in  $I_2T_2$  (Saturated irrigation plus 70% RDCF + 30% nutrient from cow dung) which was statistically similar to  $I_1T_1$ ,  $I_1T_3$ ,  $I_2T_1$  and  $I_2T_3$  treatment combinations. The lowest number of effective tillers hill<sup>-1</sup> (11.67) was found in  $I_1T_0$  treatment combination. The lowest number of non-effective tillers hill<sup>-1</sup> was obtained in  $I_2T_3$  (Saturated irrigation plus 50% RDCF + 50% nutrient from cow dung) treatment combination. The higher levels of plant height, panicle length were noted in  $I_1T_1$ ,  $I_1T_2$ ,  $I_1T_3$ ,  $I_2T_1$ ,  $I_2T_2$  and  $I_2T_4$  treatment combinations and lower levels of plant height, panicle length were recorded in  $I_1T_0$  and  $I_2T_0$  treatment combinations.

**Table 3.** Combined effects of fertilizer and irrigation on the yield parameters of Boro rice (BRRI dhan 29)

Treatments	Number of effective tillers hill <sup>-1</sup>	Number of non-effective tillers hill <sup>-1</sup>	Plant height (cm)	Panicle length (cm)
I <sub>1</sub> T <sub>0</sub>	11.67e	0.40	87.73	25.68
I <sub>1</sub> T <sub>1</sub>	18.60ab	0.53	108.43	27.36
I <sub>1</sub> T <sub>2</sub>	15.73cd	0.60	105.57	27.35
I <sub>1</sub> T <sub>3</sub>	17.13abc	0.20	103.57	27.27
I <sub>1</sub> T <sub>4</sub>	15.80cd	0.60	103.49	27.03
I <sub>1</sub> T <sub>5</sub>	15.87bcd	0.40	102.09	27.01
I <sub>2</sub> T <sub>0</sub>	13.20de	0.47	90.67	25.09
I <sub>2</sub> T <sub>1</sub>	16.93abc	0.33	110.30	26.97
I <sub>2</sub> T <sub>2</sub>	19.20a	0.20	104.41	27.78
I <sub>2</sub> T <sub>3</sub>	16.67abc	0.13	102.82	26.51
I <sub>2</sub> T <sub>4</sub>	16.20bc	0.33	103.69	27.24
I <sub>2</sub> T <sub>5</sub>	15.73cd	0.27	101.95	27.02
S.E. (±)	0.72	NS	NS	NS

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

**Table 4.** Effect of irrigation on the grain and straw yields of Boro rice

Treatments	Number of Filled grains panicle <sup>-1</sup>	Number of un-filled grains panicle <sup>-1</sup>	Straw yield (t ha <sup>-1</sup> )	Grain yield (t ha <sup>-1</sup> )
I <sub>1</sub>	162.76	13.02	6.68	6.14
I <sub>2</sub>	162.93	14.93	6.33	5.63
S.E. (±)	NS	NS	NS	NS

### 3.4 Effects of fertilizer, manure and irrigation on the grain and straw yields of rice

The effect of irrigation on the grain and straw yield of rice are presented in Table 4. Insignificant variation was observed on the grain and straw yields of rice when the field was irrigated with two different irrigations. Among these irrigations, I<sub>1</sub> (continuous flooded condition) showed the highest grain yield (6.14 t/ha) and I<sub>2</sub> (saturated condition) irrigation

showed lowest grain yield (5.63 t/ha). In case of straw yield, similar results were recorded and highest straw yield (6.68 t/ha) was recorded in  $T_1$  treatment.

The number of filled grains panicle<sup>-1</sup>, un-filled grains panicle<sup>-1</sup>, grain and straw yields were significantly affected by fertilizer treatments. The highest number of filled grains panicle<sup>-1</sup> was found in  $T_2$  (70% RDCF + 30% nutrient from cow dung) treatment which was statistically similar to all other treatment except  $T_0$  and lowest number was obtained in  $T_0$  treatment where fertilizer was not applied. The highest number of unfilled grains panicle<sup>-1</sup> (15.83) was found in  $T_1$  (100% RDCF) treatment which was statistically similar to all other treatment except  $T_0$  and lowest number was obtained in  $T_0$  treatment where fertilizer was not applied. The application of fertilizers and manure had a positive effect on the grain and straw yields of Boro rice.

**Table 5.** Effects of fertilizer and manure on the grain and straw yields of Boro rice

Treatments	Number of Filled grains panicle <sup>-1</sup>	Number of un-filled grains panicle <sup>-1</sup>	Straw yield (t ha <sup>-1</sup> )	Grain yield (t ha <sup>-1</sup> )
$T_0$	137.6b	10.8b	4.90b	3.81d
$T_1$	172.5a	15.8a	6.99a	7.01a
$T_2$	175.0a	14.1ab	6.43a	5.98bc
$T_3$	165.5a	14.5ab	6.98a	6.03bc
$T_4$	156.0ab	14.2ab	7.16a	6.78ab
$T_5$	170.3a	14.4ab	6.56a	5.7c
S.E. ( $\pm$ )	6.8	1.0	0.24	0.26

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per DMRT.

The highest straw yield (7.16 t ha<sup>-1</sup>) was obtained in  $T_4$  (70% RDCF + 30% from compost) treatment which was statistically similar to all other treatment except  $T_0$  and lowest straw yield was obtained in  $T_0$  treatment where fertilizer was not applied. The highest grain yield (7.01 t ha<sup>-1</sup>) was observed in  $T_1$  treatment where 100% RDCF was used which was statistically similar with the  $T_4$  treatment where 70% RDCF + 30% from compost were applied. On the contrary, the lowest grain yield (3.81 t/ha) was observed with  $T_0$  where no fertilizer was applied. The results indicate that  $T_1$  (100% RDCF) and  $T_4$  (70% RDCF + 30% nutrient from compost) treatments performed better for increasing grain and straw yield of rice.

### 3.5 Combined effects of irrigation and fertilizer on the yield of Boro rice

The combined effect of different doses of fertilizer and irrigation on the number of filled grains panicle<sup>-1</sup>, number of unfilled grains panicle<sup>-1</sup>, straw yield and grain yield of Boro rice

were not significantly different (Table 6). The highest number of filled grains panicle<sup>-1</sup> (179.3) was recorded in I<sub>2</sub>T<sub>2</sub> (saturated condition + 70% RDCF + 30% nutrient from cow dung) treatment combination. The I<sub>1</sub>T<sub>1</sub>, I<sub>1</sub>T<sub>2</sub>, I<sub>1</sub>T<sub>5</sub>, I<sub>2</sub>T<sub>5</sub> treatment combinations produced higher number of filled grains panicle<sup>-1</sup> and lowest number of filled grains panicle<sup>-1</sup> was obtained in I<sub>2</sub>T<sub>0</sub> treatment combination. The highest number of unfilled grains panicle<sup>-1</sup> (18.40) was recorded in I<sub>2</sub>T<sub>1</sub> (saturated condition + 100% RDCF + 30% nutrient from cow dung) treatment combination and lowest number (10.27) was found in I<sub>1</sub>T<sub>0</sub> treatment combination.

**Table 6.** Combined effects of fertilizer and irrigation on the grain and straw yield of Boro rice

Treatments	Number of Filled grains panicle <sup>-1</sup>	Number of unfilled grains panicle <sup>-1</sup>	Straw yield (t ha <sup>-1</sup> )	Grain yield (t ha <sup>-1</sup> )
I <sub>1</sub> T <sub>0</sub>	138.5	10.3	5.54	4.45
I <sub>1</sub> T <sub>1</sub>	176.2	13.3	7.05	6.99
I <sub>1</sub> T <sub>2</sub>	170.7	12.5	6.31	6.22
I <sub>1</sub> T <sub>3</sub>	167.7	15.5	7.18	6.40
I <sub>1</sub> T <sub>4</sub>	151.6	13.1	7.10	6.7
I <sub>1</sub> T <sub>5</sub>	171.7	13.5	6.87	6.10
I <sub>2</sub> T <sub>0</sub>	136.7	11.3	4.26	3.17
I <sub>2</sub> T <sub>1</sub>	168.9	18.4	6.94	7.02
I <sub>2</sub> T <sub>2</sub>	179.3	15.7	6.54	5.74
I <sub>2</sub> T <sub>3</sub>	163.3	13.6	6.77	5.67
I <sub>2</sub> T <sub>4</sub>	160.5	15.4	7.22	6.86
I <sub>2</sub> T <sub>5</sub>	168.9	15.3	6.24	5.30
S.E. (±)	NS	NS	NS	NS

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per DMRT.

The highest grain yield of rice (7.02 t/ha) was recorded with the treatment combination I<sub>2</sub>T<sub>1</sub> (Saturated condition plus 100% RDCF) which was closely similar to I<sub>1</sub>T<sub>1</sub> (6.99 t/ha) treatment combinations. On the other hand, the lowest grain yield (3.17 t/ha) was found in I<sub>2</sub>T<sub>0</sub> (saturated condition + control treatment) treatment combination. The highest straw yield of rice (7.22 t/ha) was recorded with the treatment combination I<sub>2</sub>T<sub>4</sub> (Saturated condition plus 70% RDCF + 30% nutrient from compost) which was closely similar to I<sub>1</sub>T<sub>1</sub> (7.05 t/ha), I<sub>1</sub>T<sub>3</sub> (7.18 t/ha) I<sub>1</sub>T<sub>4</sub> (7.10 t/ha) treatment combinations. On the other hand, the lowest grain yield (4.26 t/ha) was found in I<sub>2</sub>T<sub>0</sub> (saturated condition + control treatment) treatment

combination. The results indicate that application of 100% inorganic fertilizer with saturated condition ( $I_2T_1$ ) performed best for increasing Boro rice yield and Ebrahim *et al.* (2011) found similar results in his experimental research. Similarly,  $I_1T_1$  (100% inorganic fertilizer with continuous flooded condition) and  $I_2T_4$  (70% RDCF + 30% nutrient from compost) performed better for increasing grain and straw yield of Boro rice (BRRIdhan 29).

### 3.6 Effects of irrigation on the pH, ammonium and phosphate concentration of soil

The soil pH, ammonium-N and phosphate concentrations were not significantly influenced by different irrigation management in the Boro rice field. The soil pH, ammonium-N concentrations were not significantly influenced by different levels of irrigation but higher pH and ammonium-N concentration were found in saturated condition and lower in continuous flooded condition. The higher levels of available P were found in the soil extract of continuous flooded condition.

**Table 7.** Effects of irrigation on the ammonium and phosphate concentrations in paddy soil

Treatments	Soil pH	Ammonium concentration (ppm)	Phosphate concentration (ppm)
$I_1$	6.5	57.0	26.6
$I_2$	6.6	90.6	25.1
S.E. ( $\pm$ )	NS	NS	NS

### 3.7 Effects of fertilizer and manure on the soil pH, ammonium and phosphate concentrations

The soil pH, ammonium and phosphate concentrations were significantly influenced by the application of different fertilizer treatments. The highest level of soil pH was found in  $T_2$  and  $T_5$  treatments and lower pH level was found in  $T_1$  treatment. The highest soil ammonium-N (98.73 ppm) concentration was recorded in  $T_2$  (70% RDCF + 30% nutrient from cow dung) which was statistically similar to  $T_5$  (50% RDCF + 50% nutrient from compost) treatment and lowest ammonium-N concentration was recorded in  $T_0$  treatment where fertilizer was not used. The higher levels of soil ammonium-N were obtained in the treatments where fertilizer and manure were used with together. The highest level of available P (29.81 ppm) concentration was obtained from  $T_1$  treatment which was statistically similar to  $T_4$  (70% RDCF + 30% nutrient from compost) and  $T_5$  (50% RDCF + 50% nutrient from compost) treatments and lowest phosphate concentration was recorded in  $T_0$  treatment. The higher available P concentrations were observed in the fertilizer treatments where higher yields were recorded.

**Table 8.** Effects of fertilizer and manure on the soil pH, ammonium and phosphate concentrations

Treatments	Soil pH	Ammonium concentration(ppm)	Phosphate concentration (ppm)
T <sub>0</sub>	6.6ab	38.5d	19.7c
T <sub>1</sub>	6.5b	80.1bc	29.8a
T <sub>2</sub>	6.6ab	98.7a	24.0bc
T <sub>3</sub>	6.5b	65.5c	25.1b
T <sub>4</sub>	6.5b	73.5bc	28.4ab
T <sub>5</sub>	6.6a	86.5ab	28.2ab
S.E. (±)	0.03	4.48	1.21

### 3.8 Combined effects of irrigation and fertilizer on the soil pH, ammonium and phosphate concentrations

The combined effects of different doses of fertilizer and irrigation on the pH was not significantly different (Table 9). The highest pH (6.7) was recorded in I<sub>1</sub>T<sub>5</sub> (50% RDCF + 50% nutrient from compost) treatment combination and lowest (6.4) was recorded in I<sub>1</sub>T<sub>1</sub> treatment combination. The ammonium-N and phosphate concentrations were significantly influenced by the interaction effects of irrigation and fertilizer treatments. The highest ammonium-N concentration (141.28 ppm) was found in I<sub>2</sub>T<sub>2</sub> (saturated condition plus 70% RDCF + 30% nutrient from cow dung) and lowest concentration (36.25 ppm) was obtained in I<sub>1</sub>T<sub>0</sub> (continuous flooded irrigation plus fertilizer control) treatment combination. The highest phosphate concentration (32.83 ppm) was recorded with the treatment combination I<sub>1</sub>T<sub>4</sub> (Continuous flooding + 70% RDCF plus 30% nutrient from compost) which were statistically similar to I<sub>1</sub>T<sub>1</sub>, I<sub>1</sub>T<sub>5</sub>, I<sub>2</sub>T<sub>1</sub> and I<sub>2</sub>T<sub>5</sub> treatment combinations and lowest phosphate (19.20 ppm) was obtained in I<sub>1</sub>T<sub>0</sub> (continuous flooded irrigation plus fertilizer control) treatment combination. The higher available-P containing treatment combinations (I<sub>1</sub>T<sub>4</sub>, I<sub>1</sub>T<sub>1</sub>, I<sub>2</sub>T<sub>1</sub>) performed better for increasing grain and straw yield of Boro rice. The soil NH<sub>4</sub>-N and available-P concentrations were determined at panicle initiation of rice. Soil available P was strongly correlated with grain and straw yield of rice. The NH<sub>4</sub>-N was not strongly correlated with the grain and straw yield of rice (Fig. 1). The positive correlation between pore-water nutrient concentrations and rice yields were also noticed by Khan *et al.* (2021a & b).

**Table 9.** Combined effects of fertilizer and irrigation on the soil pH, ammonium and phosphate concentrations

Treatments	Soil pH	Ammonium (mg kg <sup>-1</sup> )	Phosphate (mg kg <sup>-1</sup> )
I <sub>1</sub> T <sub>0</sub>	6.6	36.3f	19.2d
I <sub>1</sub> T <sub>1</sub>	6.4	66.9e	31.5ab
I <sub>1</sub> T <sub>2</sub>	6.5	56.2ef	23.0cd
I <sub>1</sub> T <sub>3</sub>	6.5	59.2ef	25.3bcd
I <sub>1</sub> T <sub>4</sub>	6.5	54.5ef	32.8a
I <sub>1</sub> T <sub>5</sub>	6.7	69.2de	27.7abc
I <sub>2</sub> T <sub>0</sub>	6.5	40.8f	20.36d
I <sub>2</sub> T <sub>1</sub>	6.6	93.3bc	28.1abc
I <sub>2</sub> T <sub>2</sub>	6.6	141.3a	24.9cd
I <sub>2</sub> T <sub>3</sub>	6.5	71.7cde	24.9cd
I <sub>2</sub> T <sub>4</sub>	6.6	92.54bcd	23.91cd
I <sub>2</sub> T <sub>5</sub>	6.6	103.80b	28.80abc
S.E. (±)	NS	6.34	1.71

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per DMRT.

## 2.9 Effects of irrigation and fertilizer on N and P concentrations of rice grain and straw

Insignificant variation was observed in N and P concentrations in grain and straw of Boro rice when the field was irrigated with two different irrigations. The grain and straw N concentrations were significantly influenced by fertilizer and manure treatments. The highest grain N concentration (1.33%) was found in T<sub>5</sub> treatment which was closely similar to T<sub>1</sub> and T<sub>3</sub> treatments. Similarly, the highest P concentration (0.29%) in T<sub>3</sub> treatment where organic plus inorganic fertilizers were used (Table 10). The highest straw N concentration (0.75%) and highest straw P concentration (0.07%) were recorded in T<sub>2</sub> and in all cases the lowest concentration was found from T<sub>0</sub> treatment. Higher levels of N and P were accumulated in combined application of organic plus inorganic fertilizer. The grain and straw N, P concentrations were not influenced by interaction effect of irrigation and fertilizer. The straw N concentration was significantly influenced by interaction effect of irrigation and fertilizer. The highest straw N concentration (0.763%) was obtained from I<sub>1</sub>T<sub>2</sub> where continuous flooded and 70% inorganic fertilizer plus 30% nutrient from cow dung were used.

**Table 10.** Effects of fertilizer and manure on N and P concentrations of Boro rice grain and straw

	Concentration (mg kg <sup>-1</sup> ) in Grain		Concentration (mg kg <sup>-1</sup> ) in Straw	
	N	P	N	P
T <sub>0</sub>	1.17bc	0.23	0.54bc	0.05
T <sub>1</sub>	1.29a	0.24	0.63ab	0.06
T <sub>2</sub>	1.28ab	0.24	0.75a	0.07
T <sub>3</sub>	1.30a	0.29	0.65ab	0.05
T <sub>4</sub>	1.14c	0.24	0.47c	0.06
T <sub>5</sub>	1.33a	0.22	0.56bc	0.06
S.E. (±)	0.034	NS	0.031	NS

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per DMRT.

#### 4. Conclusions

The yield of Boro rice was not significantly influenced by continuous flooding and saturated condition. Higher yield and yield parameters were obtained where recommended dose of fertilizer was used. Higher yields of BRRI dhan 29 were found in I<sub>2</sub>T<sub>1</sub> (saturated irrigation plus 100% RDCF) followed by I<sub>1</sub>T<sub>1</sub> (continuous flooded irrigation plus 100% RDCF) and I<sub>2</sub>T<sub>4</sub> (saturated irrigation plus 70% RDCF + 30% nutrient from compost) treatment combinations. The level of grain N increased where fertilizer was applied in combination with manure. The findings indicate that saturated irrigation can replace continuous flooding without yield penalty, enabling water-saving rice cultivation when combined with appropriate fertilizer management. Application of the recommended fertilizer dose alone or integrated with compost enhances soil nutrient availability, grain nitrogen content, and yield of BRRI dhan29, providing a practical strategy for improving productivity and nutrient management in Boro rice systems.

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#### Conflicts of Interest

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

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