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Plant Nutrient Availability in Soils of Rice Root Zone and Root Free Areas under Different Management Practices

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Abstract

The availability of nutrients in soils is dependent on a number of factors including the sources of the nutrient, moisture level and soil properties. The objective of this study was to determine the effects of irrigation, fertilizer and manure on nutrient availability in rice root zone and root free areas. The experiment was laid out in split plot design with a distribution of irrigation (I_1: continuous flooding and I_2: saturated condition) to the main plots and fertilizers to the sub plots. The fertilizer treatments were T_0: Control, T_1=100% RDCF, T_2=50% RDCF + 5 t ha^{-1} cowdung, T_3:70% RDCF + 3 t ha^{-1} cowdung, T_4: 50% RDCF + 5 t ha^{-1} compost, T_5: 70% RDCF + 3 t ha^{-1} compost, T_6: 50% RDCF + 3.5 t ha^{-1} poultry manure, T_7: 70% RDCF + 2.1 t ha^{-1} poultry manure. A PVC core was installed up to 40 cm depth in the middle of each plot and rice was not grown into the core but treatments were applied similar to the rice growing area and pore-water samples were collected from rice root zone and root free areas and analyzed. There was a positive correlation between rice yield and pore-water K or P of flowering stage. The higher pore-water nutrients and grain yields were obtained from organic plus inorganic fertilizer treatments. The 3 to 4 fold higher levels of pore-water K concentrations, 1.4 to 3 fold higher soil exchangeable K and 1.5 to 2 times soil available P were found in the soils of root free area than root zone area. The higher levels of soil organic matter, N, P and K were obtained in inorganic plus organic fertilizer treatments of root zone and root free areas and available P, K concentrations were highly increased in the soils of root free areas.

Introduction

Rice (*Oryza sativa*) is one of the major cereal crops in the world. Rice is the major staple food of nearly half of the world's population, and is particularly important in Asia, where approximately 90% of world's rice is produced and consumed. The depleted soil fertility is a major constraint to higher crop production in Bangladesh. The increasing land use intensity has resulted in a great exhaustion of nutrients in soils. Rice-rice cropping system is the most important cropping system in Bangladesh. 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. Organic matter decomposition, nutrient mineralization, leaching and efficiency of fertilizer and manures in rice field are greatly affected by the soil moisture level. Pore-water nutrient is considered to be the pool of nutrient that is most readily available for plant uptake (Rahman *et al*.2019). It is necessary to put greater emphasis on strategic research to increase the efficiency of applied nutrients through integration of inorganic fertilizers and organic manures with different moisture level.

The yield of rice is low in Bangladesh than in the other rice growing countries like South Korea and Japan (FAO, 1999). Scientists are trying to improve the production systems with the help of combination of organic and inorganic sources of nutrients. More nutrients are leached out from soil when higher levels of irrigation water are added during *boro* rice growing period. Moisture levels, rice roots affect the organic matter accumulation and mineralization in soil. Yang *et al.* (2004) reported that application of chemical fertilizers with farmyard manure or wheat or rice straw in alternate wetting and drying condition increased N, P, & K uptake by rice plants. It is necessary to use fertilizer and manure in an integrated way in order to obtain sustainable crop yield without affecting soil fertility. Considering the present situation, Ishaque *et al*. (1998) mentioned that

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the major challenges are to (i) save water; (ii) increase water productivity and (iii) produce more rice with less water. This study analyzes the ways in which water-saving irrigation can help to meet these challenges at the field level. Rice root systems may play important role in soil nutrient availability and accumulation in soil. Little is known on the nutrient availability of applied fertilizer and manure with time in the soils of root zone and root free areas during rice culture.

The present research work was, therefore, undertaken to find out the effects of irrigation, chemical fertilizers, organic manure and rhizospheric effect on the change of nutrient availability and fertility in the soils of root zone area and root free areas with rice cultivation. The objectives of the present study were to determine the effects of fertilizer, manure with different water management on the (a) nutrient availability and (b) yield of rice and change of chemical properties in the paddy soils of root zone area and root free areas.

Materials and Methods

Field characteristics

The experiment was conducted in the field of experimental farm at Sher-e-Bangla Agricultural University, Dhaka, during January, 2014 to June, 2014. The university area located at 28°74′ N latitude and 90°35′ E longitude with an elevation of 8.2 meter from sea level. The climate of the experimental area is characterized by high temperature, high humidity and medium rainfall with occasional gusty winds during the *kharif* season (March-September) and a scanty rainfall associated with moderately low temperature in the *rabi* season (October-March). The experimental area belongs to the Tejgaon soil series of Madhupur Tract (AEZ 28) and the soil of the experimental field classified as Deep Red Brown Terrace Soils in Bangladesh soil classification system (UNDP and FAO, 1988). The soil is a silt loam with 6.4 pH, 1.12% organic matter (Walkley and Black, 1975), 0.08% total N (Micro Kjeldahl method; Bremner and Mulvaney, 1982) 12.0 µg g^{-1} available P (0.5M $NaHCO_3$ extraction; Olsen and Sommers, 1982) and 22.5 µg g^{-1} exchangeable K (1MNH_4OAc extraction; Page et al. 1982).

Experimental design and treatment

The experiment consists of 2 factors i.e., irrigation and fertilizer, manure. Two irrigation treatments (I_1= continuous flooding (2-3 cm water), I_2 = saturated condition (disappearance of water on the surface) and eight fertilizer treatments (T_0: Control, T_1: $N_{120kg/ha}P_{25kg/ha}K_{60kg/ha}S_{20kg/ha}Zn_{2kg/ha}$ (Recommended dose of chemical fertilizer, RDCF), T_2: 50% RDCF + 5 ton cowdung ha^{-1}, T_3: 70% RDCF + 3 ton cowdung ha^{-1}, T_4: 50% RDCF + 5 ton compost ha^{-1}, T_5: 70% RDCF + 3 ton compost ha^{-1}, T_6: 50% RDCF + 3.5 ton poultry manure ha^{-1}, T_7: 70% RDCF + 2.1 ton poultry manure ha^{-1} were applied in the experiment during boro rice (dry season rice) cultivation. The experiment was laid out in a split plot design with three replications. The layout was made distributing two irrigations to the main plots and fertilizer plus manure treatments to the sub plots. The total number of plots was 48; measuring 2.5 m × 2.0 m and ailes separated plots from each other.

Field experiment

Initial soil samples were collected from 0- 15 cm depth. The experimental plot was opened by a tractor, and then the land was ploughed followed by laddering to obtain a good tilth and puddled condition. The land was leveled and the experimental plot was partitioned into the unit plots. A PVC core (50 cm length and 20 cm diameter) was installed up to 40 cm depth in the middle of each plot and rice was not grown into the core but fertilizer and manure were applied similar to the rice growing areas. Treatment wise cowdung, compost, and poultry manures were applied before four days of final land preparation. There were 1.46% N, 0.29% P, 0.74% K in cowdung; 2.2% N, 1.99% P, 0.82% K in poultry manure and 1.49% N, 0.28% P, 1.60% K in water hyacinth compost. The triple super phosphate, muriate of potash, gypsum and one third of urea were applied during final land preparation as a source of P, K, S and N, respectively. The remaining one third urea was applied at 30 DAT and last one third was applied at 55 DAT. The fertilizer and manures were mixed in the soils of the core and outside the core of the plots. The crop BRRI dhan29 was transplanted in the plots during first week of January, 2014. The 35-day old seedlings for *boro* rice were transplanted in the plots with a spacing of 20 cm × 20 cm.

A soil pore-water sampling device (Rhizon MOM 10 cm length, 2.5 mm OD, Rhizosphere Research Products, Wageningen, and The Netherlands) was buried diagonally in the middle of each plot of rice root zone area and another Rhizon sampler was buried into the core soil (root free area) for collecting soil solution of 0-15 cm soil. The pore-water samples were filtered through Whatman no. 42 filter paper and analyzed for N, P and K concentrations. After harvest *boro* rice, the grain and straw yields were recorded. After harvest, the post-experiment soils were collected from 0-15 cm of root zone and root free areas and analyzed for N, P, K, pH and soil organic matter content. Before this, *boro* rice cropping experiment, during January, 2014 to June, 2014, *boro-T. aman* rice cropping sequence was maintained in the same plots by using similar treatments from the year 2012.

Soil and pore-water analysis

Soil pH was measured by glass electrode pH meter using soil-water ratio 1:2.5 (McLean, 1982). Organic matter content was estimated by wet oxidation method (Walkley and Black, 1975). The total N content in soil and pore-water samples were determined by micro-Kjeldahl method (Bremner and Mulvaney, 1982). The P (Olsen and Sommers, 1982) and K (Page et al. 1982) of soil, pore-water were determined by using spectrophotometer and flame photometer, respectively.

Statistical analysis

The data obtained for different parameters were statistically analyzed by Mstat-C. The significance of the difference among the treatment means was estimated by the Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

Results and Discussion

Effect of irrigation and fertilizer on N, P and K concentrations in pore-water of rice root zone and root free areas at flowering stage

The pore-water N, P and K concentrations were influenced by different irrigation managements in the rice root zone area and root free area (Table 1). In the root zone area, the pore-water P and K concentrations were significantly affected by irrigation treatments, the higher pore-water P (1.15 ppm) and K (3.27 ppm) concentrations were found in the continuous flooded condition in comparison to saturated condition (0.98 ppm P, 2.82 ppm K). The higher pore-water K concentration was found in the core soil where plant root was absent (Table 1). Compared to the root zone area, the fallow area (into the core) contains 3 (I_1) to 4 (I_2) times higher pore-water K concentrations and it proves that higher levels of applied K present in pore-water for a long duration in absence of plant root in the soil.

The application of fertilizer and manure treatments in the soils significantly influenced the level of P concentrations in root free areas (Table 2) but pore-water N, K concentrations in root zone and root free areas and P in root zone areas were not significantly affected. The almost similar pore-water N concentrations were found in the pore-water of root zone (13.90-18.20 ppm) and root free areas (12.33-17.87 ppm) by using different fertilizer treatments. The similar levels of N were present in the soils of root free areas may be due to higher mobility of N through percolated water. The higher concentrations of N and P were found in the fertilizer treatments where fertilizer plus manures were used. The highest pore-water P concentration (1.43 ppm) was found in the root zone soils of T_5 treatment where 70% RDCF + 3 ton compost ha^{-1} was used but it was only 0.45 ppm in the pore-water of root free area. With some variation, similar pore-water P concentrations were found in the soils of root zone area (0.59-1.43 ppm) and root free area (0.62-1.35 ppm) with different fertilizer treatments. In the soils of root free areas, the highest level of 1.39 ppm P was found in the T_6 treatment which was statistically similar with the T_1 (1.35 ppm), T_2 (1.25 ppm) and T_7 (1.04 ppm) treatments. The 3 to 4 fold higher levels of pore-water K concentrations were found in the soils of root free area than root zone with the application of same fertilizer treatments in the soils of root zone and root free areas (Table 2). The pore-water K concentrations varied from 2.00 to 3.50 ppm in root zone area and this range was 9.01 to 11.54 ppm in the soils of root free area with the application of similar fertilizer treatments. The highest pore water K concentrations of root zone area (3.50 ppm) and root free area (11.54 ppm) were obtained from the T_1 treatment where 100% RDCF was applied. These results indicate that the higher level of available K can exist in the soil solution if K is not uptakes through plant root.

The interaction effect of fertilizer and irrigation did not affect the pore-water N concentration significantly and almost similar pore water nitrogen concentrations were found in the root zone and root free areas (Table 3). The range varied from 13.47 ppm with I_1T_0 to 20.07 ppm with I_2T_2 in root zone area which was varied from 12.87 ppm with I_1T_0 to 19.53 ppm with I_1T_6 in the soils of root free areas. The pore-water P concentrations differed significantly with the interaction of fertilizer and irrigation and there was no definite trend of P concentration in root zone and root free areas. In the root zone area, the highest P concentration of 1.80 ppm was found in the I_1T_4 treatment which was closely similar to I_2T_5 (1.70 ppm), I_1T_3 (1.34 ppm), I_1T_1 (1.35 ppm) and lowest 0.58 ppm in I_2T_0 treatment combination. The higher levels of pore-water P were found in the soils of root zone and root free area where inorganic fertilizer and manure were applied. In the root free area, the highest P concentration of 2.43 ppm was found in the I_2T_6 and lowest 0.40 ppm in I_1T_0 treatment combination.

The pore-water K concentrations in the root zone area were not significantly affected by combined effect of fertilizer and irrigation but significantly affected in root free area (Table 3). The 2 to 5 fold higher levels of soil solution K were found in the root free areas than the soils of root zone area. In the root zone area, the highest K concentration (3.97 ppm) was found in the treatment combination I_1T_7 (continuous flooded plus 70% inorganic fertilizer and 2.1 ton poultry manure ha^{-1}) which was closely similar to I_1T_3 (3.85 ppm) and I_1T_4 (3.67 ppm) treatment combinations where inorganic fertilizer and manure were applied and lowest in I_2T_0 (2.03 ppm) treatment combination.

Table 1. Effects of irrigation on pore-water N, P and K concentrations in root zone area and root free area at flowering stage of boro rice

Irrigation	Pore-water N concentration (ppm)		Pore-water P concentration (ppm)		Pore-water K concentration (ppm)	
	Root zone area	Root free area	Root zone area	Root free area	Root zone area	Root free area
I1	15.64	16.18	1.15a	0.93	3.27a	10.50
I2	18.67	15.44	0.98b	0.95	2.82b	10.21
SE (±)	NS	NS	0.03	NS	0.08	NS

I_1: continuous flooding and I_2: saturated condition; In a column figure(s) with dissimilar letter differ significantly as per DMRT at 5% level of significance

Table 2. Effects of fertilizer and manure on the pore-water N, P and K concentrations in root zone area and root free area at flowering stage of boro rice

Fertilizer and manure	Pore-water N concentration (ppm)		Pore-water P concentration (ppm)		Pore-water K concentration (ppm)	
	Root zone area	Root free area	Root zone area	Root free area	Root zone area	Root free area
T0	13.90	12.33	0.59	0.62b	2.05	8.01
T1	18.20	15.30	1.14	1.35a	3.50	11.54
T2	16.80	14.23	0.73	1.25a	2.70	9.65
T3	16.57	15.07	1.09	0.48b	3.13	10.74
T4	17.27	17.87	1.40	0.45b	3.34	10.26
T5	18.20	15.83	1.43	0.94b	3.12	11.07
T6	16.83	17.70	0.97	1.39a	2.94	10.00
T7	17.50	15.17	1.19	1.04ab	3.60	10.54
SE (±)	NS	NS	NS	0.17	NS	NS

T_0: Control, T_1 =100% RDCF, T_2 =50% RDCF + 5 t ha^{-1} cowdung, T_3:70% RDCF + 3 t ha^{-1} cowdung, T_4: 50% RDCF + 5 t ha^{-1} compost, T_5: 70% RDCF + 3 t ha^{-1} compost, T_6: 50% RDCF + 3.5 t ha^{-1} poultry manure, T_7: 70% RDCF + 2.1 t ha^{-1} poultry manure; In a column figure(s) with dissimilar letter differ significantly as per DMRT at 5% level of significance

Table 3. Interaction effects of fertilizer and irrigation on the pore-water N, P and K concentrations in root zone area and root free area

Treatments	Pore-water N concentration (ppm)		Pore-water P concentration (ppm)		Pore-water K concentration (ppm)	
	Root zone area	Root free area	Root zone area	Root free area	Root zone area	Root free area
I1T0	13.47	12.87	0.60c	0.40b	2.07	8.00b
I1T1	16.33	15.40	1.35abc	2.03a	3.67	14.37a
I1T2	13.53	12.13	0.88bc	2.04a	2.87	8.18b
I1T3	15.87	15.27	1.34abc	0.53b	3.85	11.67ab
I1T4	15.40	19.00	1.80a	0.48b	3.67	10.56ab
I1T5	17.27	15.33	1.16abc	0.79b	3.08	12.52ab
I1T6	15.87	19.53	0.96abc	0.55b	3.00	10.74ab
I1T7	15.40	16.33	1.13abc	1.05b	3.97	8.96b
I2T0	16.33	14.80	0.58c	0.84b	2.03	8.04b
I2T1	20.07	15.20	0.92abc	0.68b	3.33	9.61b
I2T2	20.07	16.33	0.60c	0.55b	2.53	11.11ab
I2T3	17.27	14.87	0.83bc	0.53b	2.40	9.82ab
I2T4	19.13	16.13	1.01abc	0.52b	3.00	9.96ab
I2T5	19.13	16.33	1.70ab	1.10b	3.17	9.63b
I2T6	17.80	15.87	0.98abc	2.43a	2.88	9.26b
I2T7	19.60	14.00	1.04abc	1.03b	3.22	11.11ab
SE (±)	NS	NS	0.29	0.24	NS	0.65

In a column figure(s) with dissimilar letter differ significantly as per DMRT at 5% level of significance.

In the soils of root free area, the highest pore-water K concentration (14.37 ppm) was found in I_1T_1 (continuous flooded + 100% RDCF) which was statistically similar to I_1T_3 (11.67 ppm), I_1T_5 (12.52 ppm), I_2T_2 (11.11 ppm), I_2T_7 (11.11 ppm) and I_1T4 (10.56 ppm) treatment combinations. The present findings indicates that the level of available K increased more in the soils root free area due to residual and renewed application of fertilizer and absence of crop. These results indicate that residual and renewed applied K fertilizer and manure can increase higher level of readily available K in the root free soil in comparison to N and P. The positive relationship between yield of boro rice and root zone pore water P (Figure 1a), and K concentrations were observed (Figure 1b).

Yield of boro rice

Individual and interaction effects of irrigation and fertilizer on yield

The grain and straw yields were not significantly affected by irrigation. The higher grain (7.50 t ha^{-1}) and straw yields (7.30 t ha^{-1}) were obtained in continuous flooded irrigation in comparison to saturated irrigation (grain: 7.25 t ha^{-1}, straw: 7.09 t ha^{-1}). Others have obtained higher rice yields in continuous flooded irrigation (Islam et. al. 2013). Among the different doses of fertilizers, T_5 (70% RDCF + 3 ton compost/ha) showed the highest grain yield (7.78 t/ha) which was closely similar to T_4, T_6 and T_7 treatments (Figure 2 & 3). Similarly, the highest straw yield (7.90 t ha^{-1}) was obtained in T_6 (50% RDCF + 3.5 ton poultry manure ha^{-1}) treatment which was closely similar to T_2, T_5 and T_7 treatments. The lowest grain and straw yields were obtained from T_0 (control) treatment. The results indicate that 70% inorganic fertilizer plus 30% nutrient from manure performed better (Figure 2) for increasing yield.

The grain and straw yields were not significantly affected with the interaction effects of irrigation and fertilizer (Figure 3). The highest grain yield of *boro* rice (7.78 t ha^{-1}) was recorded with the treatment combination I_2T_7 (saturated condition + 70% inorganic fertilizer and 2.1 ton poultry manure ha^{-1}) which was closely similar to I_1T_4 (7.76 t ha^{-1}), I_1T_5 (7.78 t ha^{-1}), I_2T_5 (7.78 t ha^{-1}) and I_2T_6 (7.76 t ha^{-1}) treatment combinations where higher levels pore-water P and K concentrations were obtained. Poultry manure and reduced irrigation performed better in the findings of other researchers (Bari et al 2013; Islam et al. 2013). The highest straw yield of rice (7.96 t ha^{-1}) was recorded with the treatment combination I_1T_6 (continuous flooded + 50% inorganic fertilizer and 3.5 ton poultry manure ha^{-1}) which was similar to I_1T_3, I_1T_5, I_2T_6, I_2T_7 treatment combinations where higher levels of pore-water P and K were found (Figure 3). Lin et al. (2011) reported that reduced irrigation with organic material application increased yield of rice.

Individual effects of irrigation and fertilizer on the change of soil chemical properties in post-experiment soils of root zone and root free area

The similar total N and available P concentrations were found in the post-experiment soils of root zone and root free areas with two irrigation treatments (Table 4). The higher levels of pH (6.8) were found in the soils of root zone and root free areas with saturated irrigation compared to continuous flooded irrigation (pH 6.7). The two times higher levels of available K were obtained in the soils of fallow areas in comparison to the soils of rice cropped area with both irrigation treatments due to absent of rice plant root in the soils of fallow area.

The chemical properties of soils were influenced by application of different fertilizer and manure (Table 5). The pH increased in the soils root zone and root free areas where poultry manure was applied with inorganic fertilizer and higher pH values (7.0 or above) were found in the treatments T_6 and T_7. The applied poultry manure may contain higher levels of basic cations that was responsible for increasing the alkalinity. The levels of organic matter increased more in the soils of rice root zone than the soils of rice root free area with T_2 – T_7 treatments due to application of organic plus inorganic fertilizer (Table 5). In the soils of cropped area, the highest % of organic matter (1.60) was found in T_2 treatment (50% RDCF + 5 ton cowdung ha^{-1}) which was statistically similar to T_3 (1.55%) and T_6 (1.50%) treatments and it was 1.10% in T_0 (Control) treatment. In the soils of root free area, higher level (1.59%) of organic matter was obtained from T_2 (50% RDCF + 5 ton cowdung ha^{-1}) and the soils of other treatments showed lower levels of organic matter accumulation in comparison to the soils of same treatments of rice root zone area. The similar N concentrations were obtained in the soils of root zone and root free areas with different treatments and higher N levels were found in the treatments where manure and inorganic fertilizers were used. The higher levels of available P concentrations were found in the post-experiment soils of root free areas (22.89 in T_0 to 44.72 ppm in T_7) with different treatments which were 1.5 to 2 times higher compared to the soils of root zone areas (12.14 in T_0 to 26.06 ppm in T_6). The highest concentration of root zone soil available P (26.06) was found in T_6 (50% RDCF and 3.5 t poultry manure ha^{-1}) treatment which was 39.0 ppm (1.50 fold higher) in the soils of root free areas with same treatment. The higher levels available K concentrations were found in the post-experiment soils of root free areas (22.58 in T_0 to 63.64 ppm in T_5) with different treatments which were 1.35 to 2.79 times higher compared to the soils of root zone areas (15.67 in T_0 to 34.85 ppm in T_4). The highest concentration of root free soil plant available K (63.64 ppm) was found in T_5 (70% inorganic fertilizer plus 3 ton compost ha^{-1}) treatment which was 2.63 fold higher than the available K (24.24 ppm) in the soils of T_5 treatment where rice plant root was present. After application of fertilizer and manure, significant amounts of available P and K were accumulated by rice plant from root zone area but higher levels of P and K remained in exchangeable pole due to absence of root in the soil.

Interaction effects of irrigation and fertilizer on the change of soil chemical properties in post-experiment soils of root zone and root free area

Almost similar pH values were found in the soils of root zone or root free areas with a specific treatment combination and soil pH was not significantly affected by interaction effect of irrigation and fertilizer (Table 6). The higher pH values (7.0-7.2) were found in the root zone or root free soils of I_2T_6, I_1T_7, I_2T_6, I_1T_7 treatment combinations where poultry manure was applied and lowest (6.3) was recorded in the soils of root zone and root free areas with the I_1T_0 treatment combination. The levels of organic matter in post-harvest soils were significantly influenced by combined effect of fertilizer and irrigation (Table 6). In the soils of root zone area, the highest organic matter (1.64%) was found in the treatment combination of I_2T_2 (saturated condition + 50% inorganic fertilizer and 5 ton cowdung ha^{-1}) which was statistically similar to I_1T_3 (1.58%), I_2T_5 (1.58%) I_2T_6 (1.55%), I_1T_2 (1.54%), I_2T_3 (1.53%), I_2T_7 (1.50%) treatment combinations where organic and inorganic fertilizers were used and lowest 1.07% recorded in I_2T_0 treatment combination. In the soils of root free area, the highest organic matter (1.61%) was found in the same treatment combination of I_2T_2 and lowest (0.99%) was recorded in I_1T_0 treatment combination. Similar results were reported by other scientist (Xu et al. 2008) by using chemical fertilizer with organic manure for increasing soil organic matter. The higher and similar levels of N were obtained in the soils of root zone and root free areas with different inorganic plus manure applied treatments and lower N levels were obtained in the inorganic fertilizer applied soils. In the soils of root zone area, the levels of available P significantly affected by interaction effects of fertilizer and manure and varied from 12.13 in I_1T_0 to 26.63 ppm in I_1T_6 and higher concentrations of available P were found where fertilizer plus manure applied treatment combinations. In the soils of root free area, the levels of available P varied from 22.11 ppm in I_1T_0 to 47.34 ppm in I_2T_7 (saturated condition + 70% inorganic fertilizer and 2.1 ton poultry manure ha^{-1}) treatment combination which was 1.05 to 2.26 fold higher in comparison to the soils of root zone area (Table 6).

The increase of available K was more pronounced in the soils of root free areas than the soils of root zone area by addition of fertilizer and manure in both the soil areas and this result indicate that added K can remain in the soils longer time in exchangeable form. The 1.18 to 3.18 fold higher levels of available K were found in the post-experiment soils of root free areas than the soils of root zone area. In the root zone area, the highest K concentration (36.36 ppm) was found in the treatment combination I_1T_4 (continuous flooded and +50% inorganic fertilizer and 5 ton water hyacinth compost) which was closely similar to I_1T_3 (33.33 ppm), I_1T_6 (30.33 ppm), I_1T_7 (30.33 ppm) and I_2T_4 (33.33 ppm) treatment combinations where inorganic fertilizer and manure were applied and lowest in I_2T_0 treatment combination. In the soils of root free area, the levels of post-experiment soils available K significantly affected by the interaction effects of fertilizer and irrigation, the highest concentration of 66.63 ppm available K was found in the treatment combination I_1T_5 (Continuous flooded + 70% inorganic fertilizer and 3 ton compost ha^{-1}) which was statistically and closely similar to I_2T_3 (63.64 ppm), I_1T_3 (60.61 ppm), I_2T_5 (60.61 ppm), I_2T_2 (57.58 ppm), I_1T_1 (57.58 ppm) and I_2T_6 (54.55 ppm) treatment combinations.

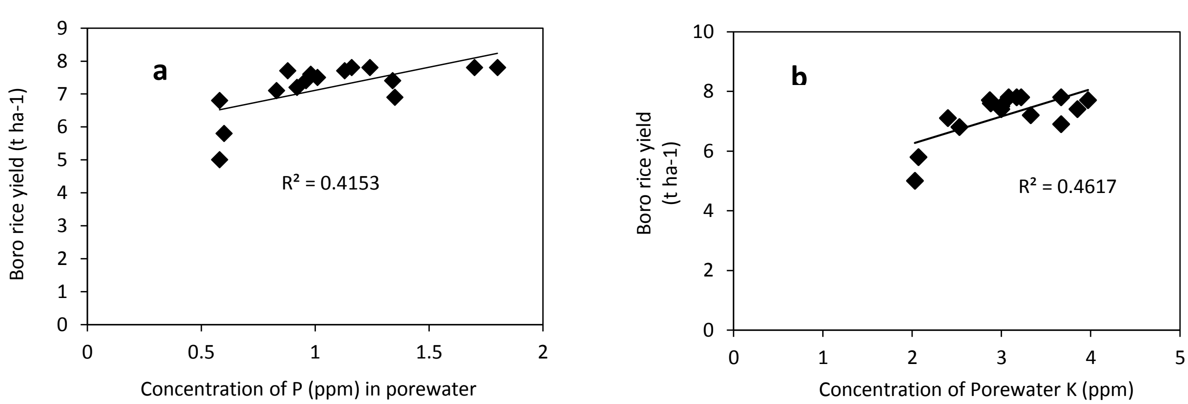

Figure 1. The relationship between grain yield of boro rice and porewater phosphorus (a) and potassium (b) concentration at flowering stage

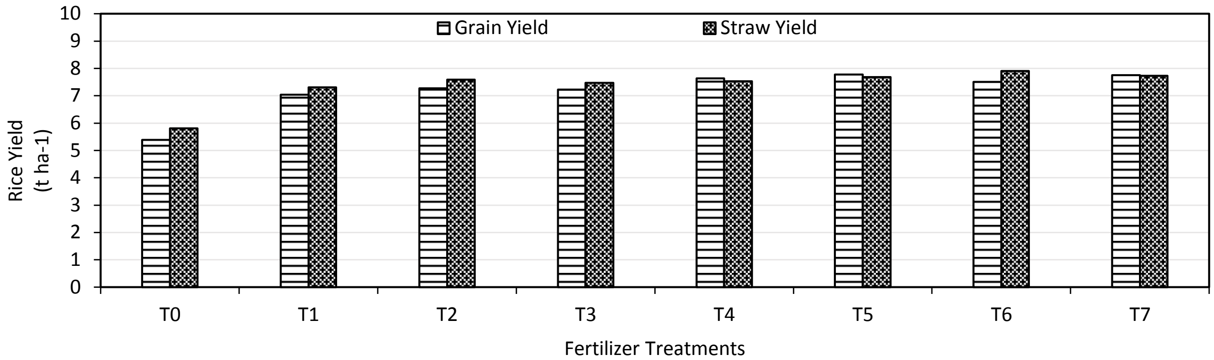

Figure 2. Effects of fertilizer treatments on the grain and straw yield of boro rice

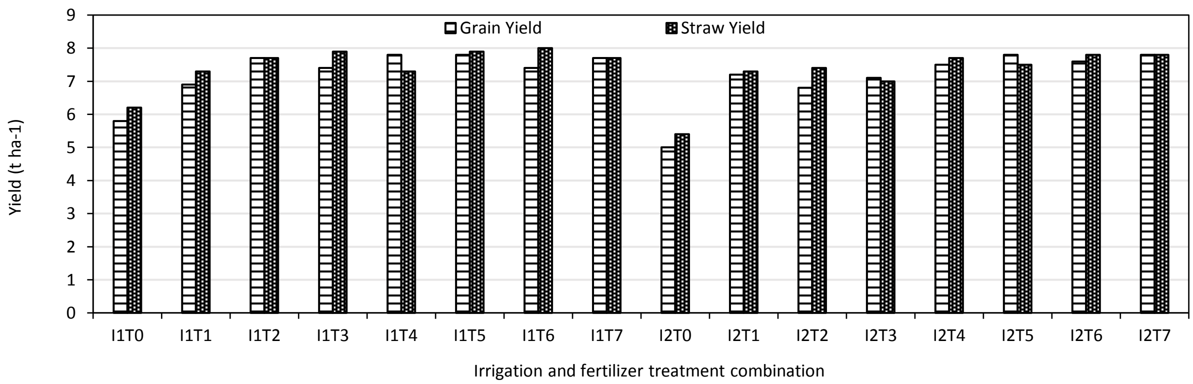

Figure 3. Interaction effects of irrigation and fertilizer on the grain and straw yield of boro rice

Table 4. Effect of irrigation on the nutrient concentration of post-harvest soil (outside the core)

Irrigation	Soil pH		Soil OM(%)		Total N (%)		Available P (mg kg^{-1})		Available K (mg kg^{-1})	
	RZ area	RF area	RZ area	RF area	RZ area	RF area	RZ area	RF area	RZ area	RF area
I1	6.7a	6.66a	1.39a	1.31	0.121	0.121	19.20	19.20	27.02	47.73
I2	6.8b	6.80b	1.48b	1.33	0.120	0.120	18.46	18.46	21.68	49.58
SE (±)	0.013	0.013	0.013	NS	NS	NS	NS	NS	NS	NS

I_1: continuous flooding and I_2: saturated condition; In a column figure(s) with dissimilar letter differ significantly as per DMRT at 5% level of significance; OM = organic matter, RZ = root zone, RF = root free

Table 5. Effects of fertilizer and manure on the soil nutrient concentration and chemical properties of post-experiment soil

Treatments	Soil pH		Soil OM(%)		Total N (%)		Available P (mg kg^{-1})		Available K (mg kg^{-1})	
	RF area	RZ area	RF area	RZ area	RF area	RF area	RZ area	RF area	RZ area	RF area
T0	6.4c	6.5b	1.10d	1.07c	0.105d	0.098	12.14e	22.89c	15.67d	22.58c
T1	6.6bc	6.7b	1.20d	1.06c	0.105d	0.095	16.88cd	33.39b	19.54cd	54.55ab
T2	6.7b	6.7b	1.60a	1.59a	0.12c	0.126	20.63bc	31.84bc	21.71bc	45.45b
T3	6.6b	6.6b	1.55ab	1.40b	0.123c	0.123	17.73bcd	34.41b	27.27b	62.12a
T4	6.7b	6.7b	1.41c	1.37b	0.12c	0.119	19.53bcd	30.11bc	34.85a	46.97b
T5	6.7b	6.6b	1.46bc	1.38b	0.126bc	0.126	16.45d	31.34bc	24.24bc	63.64a
T6	7.1a	7.1a	1.50abc	1.31b	0.131ab	0.125	26.06a	39.00ab	25.76b	50.00ab
T7	7.1a	7.0a	1.47bc	1.41b	0.132a	0.125	21.20b	44.72a	25.76b	43.94b
SE (±)	0.04	0.057	0.030	0.049	0.003	NS	1.06	2.60	1.62	4.24

T_0: Control, T_1 =100% RDCF, T_2 =50% RDCF + 5 t ha^{-1} cowdung, T_3:70% RDCF + 3 t ha^{-1} cowdung, T_4: 50% RDCF + 5 t ha^{-1} compost, T_5: 70% RDCF + 3 t ha^{-1} compost, T_6: 50% RDCF + 3.5 t ha^{-1} poultry manure, T_7: 70% RDCF + 2.1 t ha^{-1} poultry manure; In a column figure(s) with dissimilar letter differ significantly as per DMRT at 5% level of significance; RZ = root zone, RF = root free

Table 6. Interaction effects of irrigation and fertilizer on the change of chemical properties of post-experiment soil of root zone and root free areas

Treatments	Soil pH		Soil OM(%)		Total N (%)		Available P (mg kg^{-1})		Available K (mg kg^{-1})	
	RF area	RZ area	RF area	RZ area	RF area	RF area	RZ area	RF area	RZ area	RF area
I1T0	6.3	6.3	1.12ef	0.993	0.095	0.096	12.13e	22.11	16.18	27.27ef
I1T1	6.5	6.5	1.14ef	1.090	0.090	0.105	18.24cd	37.56	18.18	57.58abc
I1T2	6.7	6.7	1.54ab	1.560	0.117	0.128	24.76ab	26.22	24.24	33.33def
I1T3	6.6	6.6	1.58ab	1.543	0.128	0.126	20.05bcd	35.03	33.33	60.61ab
I1T4	6.7	6.7	1.30def	1.310	0.120	0.123	15.61de	30.89	36.36	54.55a-d
I1T5	6.6	6.6	1.33def	1.327	0.129	0.128	17.20de	34.78	27.27	66.67a
I1T6	7.0	7.0	1.45bcd	1.300	0.132	0.129	26.63a	37.45	30.30	45.45a-e
I1T7	7.1	7.1	1.45bcd	1.383	0.131	0.128	19.93cd	42.11	30.30	36.36c-f
I2T0	6.5	6.5	1.07f	1.143	0.090	0.107	12.13e	23.66	15.15	17.88f
I2T1	6.7	6.7	1.26cde	1.027	0.092	0.098	15.52de	29.22	20.91	51.51a-d
I2T2	6.6	6.6	1.64a	1.610	0.123	0.126	16.50de	37.45	19.18	57.58abc
I2T3	6.6	6.6	1.53ab	1.263	0.119	0.122	15.40de	33.78	21.21	63.64a
I2T4	6.7	6.7	1.51abc	1.430	0.122	0.113	23.45abc	29.33	33.33	39.39b-e
I2T5	6.8	6.8	1.58ab	1.440	0.122	0.125	15.70de	27.89	21.21	60.61ab
I2T6	7.2	7.2	1.55ab	1.320	0.129	0.120	25.50a	40.78	21.21	54.55a-d
I2T7	7.0	7.0	1.50abc	1.440	0.137	0.123	23.46abc	47.34	21.21	51.51a-d
SE (±)	NS	NS	0.04	NS	NS	NS	1.50	NS	NS	6.00

In a column figure(s) with dissimilar letter differ significantly as per DMRT at 5% level of significance.

Conclusion

The application of irrigation, fertilizer and manure in the soils root zone and root free areas changed the pore-water nutrient availability and soil chemical properties differently. There was a positive relationship between grain yields and pore-water nutrient concentrations at flowering stage of *boro* rice. The higher grain yields were obtained from the treatments where 70% and 30% nutrients were supplied from inorganic and organic sources, respectively with saturated irrigation and higher levels of pore-water nutrients were obtained in the similar treatment combinations. The higher concentrations of pore-water K were found in the soils of rice root free area than root zone area and almost similar levels of N and P were found in the pore-water of root zone and root free areas. The P and K levels increased more in the soils of root zone and root free areas where manure plus inorganic fertilizers were used. The application of poultry manure increased the pH in the soils of root zone and root free areas. The highest level of soil organic matter accumulated in the soils where inorganic fertilizer and cowdung were applied. The 70% RDCF and 30% nutrient from manure with saturated levels of irrigation increased the yield of boro rice and application of inorganic plus manure increased the levels of soil organic matter, soil solution and exchangeable P, K, in the soils of root zone & root free areas. The increase of plant available P and K concentrations was higher in the soils of root free areas than the root zone areas

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Conflict of Interests

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

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