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Coupled Irrigation–Drainage Management Practice for HYV Rice Cultivation with Saline-Irrigation Water: Evidence from Lysimeter Experiment

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Abstract

Irrigation with saline water adversely affects rice production and degrades land productivity in the coastal zones of many countries in the world. This study aimed at developing a suitable irrigation management practice to reduce the harmful effects of salinity on rice production under saline water irrigation. An experiment in raise-bed lysimeters was set in a split-split-plot design with irrigation–drainage practice as the main factor, irrigation water salinity as the sub-factor and rice variety as sub-sub factor; the main factor and sub-factor comprised four treatments and the sub-sub factor comprised three treatments, each with three replications. The treatments of the main factor were – T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth. The sub-factor comprised – SL_1: fresh water as control, SL_2: saline water of 6 dS m^{-1}, SL_3: saline water of 9 dS m^{-1}, and SL_4: saline water of 12 dS m^{-1}. The sub-sub factor comprised three salt-tolerant rice varieties V_1: Binadhan-8, V_2: Binadhan-10, and V_3: BRRI dhan-47. The irrigation–drainage practices T_2 and T_3 provided significantly ($p \leq 0.05$) improved growth and yield attributes of the rice varieties under salinity water level SL_3 and SL_4 compared to T_1 and T_4 treatments. The treatment T_3 maintained least exposure of the crop to high degree of salinity and produced satisfactory plant attributes by inhibiting the detrimental effects of salinity. Therefore, T_3 is suggested for adoption in practical fields when provision for removing high saline water from the rice fields can be arranged.

Keywords: rice irrigation, ponding depth, salinity exposure

1. Introduction

Salinity is one of the important physical factors that reduce soil fertility and crop productivity by inhibiting plant growth and development (Mojid & Hossain, 2013). An estimated 955 Mha land was reported to suffer from salinity and sodicity globally (Pandey et al., 2011; Wong et al., 2010). In Bangladesh, 3.56 Mha of arable lands are currently affected by soil salinity (SRDI, 2016). Due to reduction in dry-season river flows, mainly due to increased upstream withdrawal, and rise in sea level, the severity and extent of salinity may even aggravate (Bates et al., 2008; Mojid, 2020). Consequently, the current saline area has been predicted to increase by 39% across the south-west coastal belt by 2050 (Dasgupta et al., 2015). The productivity of the saline area is further hindered since there is severe scarcity of fresh water. Sodium (Na) is the dominant cation both in saline soils and irrigation water that affects soil physicochemical characteristics and plant growth (Ribeiro et al., 2014) and causes toxicity on plant species (Abrol et al., 1988) when it is excess in amount.

Continuous increase in salinity is affecting traditional cropping systems and livelihoods in salinity-affected southern coastal belt of Bangladesh (Rahman, 2011; Mainuddin et al., 2013); specifically, the production levels of rice are becoming much lower compared to the other regions of the country. Scarcity of good quality irrigation water is a major hindrance for crop cultivation, especially High Yielding Variety (HYV) rice cultivation in the saline area. Groundwater in that region being contaminated with high degree of salinity has also restricted the development of irrigation sector (Rahman et al., 2017). The available surface water, which is also limited in the coastal zone, is suitable for irrigation only during October–December, which is generally a wet period and requires only minimal irrigation. But the surface water becomes saline and unsuitable for irrigation during dry period (February–April), which is the main crop season and peak irrigation period (Mahtab & Zahid, 2018).

In the absence or with limited availability of fresh water, the salt-affected areas need to be brought under cultivation by irrigation using saline water for increasing rice production to ensure food security in the rice-producing countries like Bangladesh. However, use of saline water for irrigation requires careful planning and scheduling since the response of rice crop to salinity is controlled by the level of salinity and its duration and timing of exposure (Lee et al., 2004). Growing salt-tolerant rice variety with appropriate water management practices may be one of the approaches for economic utilization of moderately salt-affected land under saline-water irrigation (Mokoi & Verplancke, 2010). Both quality and ponding depth of irrigation water significantly affects growth and yield of rice (El Hasan et al., 2006; Zeng et al., 2003). Consequently, depth of standing water in rice field is regarded as an important agronomic parameter in the management of irrigation-related salinity problems.

To increase crop productivity during dry season (January–April) in the coastal saline area of Bangladesh, it would be imperative to introduce salt-tolerant HYV rice cultivars and develop suitable crop and water management practices for reducing the detrimental effects of salinity on crops. Occasional flush irrigation with fresh water during rice-growing period can remove part of the accumulated salts from the fields (Qadir et al., 1998; Nayak et al., 2008). But, scarcity of fresh water is a limiting factor to implement this management practice. Where available, irrigation with good quality water prior to sowing helps leaching the salts from the top soil. Mixing fresh water and saline water, and intermittent irrigation can also mitigate the detrimental effects of salinity on rice (Rezaei et al., 2013). But, in the absence of fresh water, removing the saline water from the rice field at certain interval to keep water salinity at non-harmful level may be an important practice to develop an effective on-farm water management for rice cultivation on saline soils (Chen et al., 2013). After applying irrigation with saline water, salinity of standing water in the rice field would gradually increase over time due to increased salt concentration with continuous evaporation loss of water. Consequently, maintaining the salinity level of irrigation water at crop-tolerance limit by replacing high saline water from the rice field with relatively low saline water may be a potential option for rice cultivation under saline-water irrigation. The information on reduction of salinity effects by irrigation and associated drainage system, such as removing the applied saline water before reaching the stage of crop tolerance limit, is still inadequate. So, this study was planned to identify a suitable irrigation–drainage management practice for HYV salt-tolerant rice cultivation under saline-water irrigation. This was achieved by evaluating several possible irrigation–drainage practices in lysimeter experiments under controlled conditions. The main purpose was to characterize the expected suitable irrigation–drainage practice for future verification in the practical fields. In this paper, removal of the high-saline water from the rice field has been referred as drainage.

2. Materials and Methods

2.1 Experimental Site and Climate

The experiment was done during December 2016 to May 2017 at Field Lysimeter Yard of Bangladesh Institute of Nuclear Agriculture (BINA) at Mymensingh in Bangladesh. The site is within Agro-Ecological Zone (AEZ) 9 that lays at 24°75' N latitude and 90°50' E longitude; the elevation of the site is 18 m above mean sea level. AEZ 9 has broad ridges and basins, and soils of the region are predominantly silt loams to silty clay loams on the ridges and clay in the basins. Organic matter content is low on the ridges and moderate in the basins. The top soils are moderately acidic, but sub-soils are neutral in reaction. For this study, loamy soil of 0–15 cm profile from the BINA farm was used to fill 16 lysimeters (details of the lysimeters are provided in section 2.2); each lysimeter contained 750 kg air dry soil. Three samples were collected from the soil-lot before filling the lysimeters. The organic carbon, bulk soil electrical conductivity (EC) and soil reaction (pH) were determined by analyzing these samples following standard procedures. The soil contained 0.94% organic carbon. The EC and pH of saturation extract (soil : water = 1:2.5) was 0.45 dS m^{-1} and 6.06, respectively. Sub-tropical climate of the site is characterized by high temperature and humidity, and heavy rainfall with occasional gusty wind from April to September and scanty rainfall associated with moderately low temperature during October to March. The monthly maximum temperature during December to June varied from 26.7 to 33.5ºC and minimum temperature varied from 12.9 to 25.5ºC in 2016–2017. The maximum and minimum relative humidity during that period varied from 97.8 to 100% and 45.2 to 77.6%, respectively. Monthly total rainfall varied from 0 (nil) to 357 mm during the rice-growing season (December 2016 to May 2017) in this experiment.

2.2 Treatments and Experimental Set-up

A three-factor factorial experiment was set in a Split-Split-Plot Design in 16 lysimeters arranged in four blocks. Each lysimeter (120 cm × 100 cm × 62 cm) with inner surface area (soil surface area) of 1.2 m^2 (1.2 m × 1.0 m) had an effective soil depth of 0.5 m. There was a 12-cm empty depth in the lysimeters on the soil surface to accommodate applied irrigation water. Each lysimeter box was equipped with two taps: one at the soil surface and the other near the bottom; only the upper tap was used for draining out water from the soil surface through surface runoff when needed in this study. The main factor was the irrigation-drainage practice, the sub factor was salinity of irrigation water and the sub-sub factor was three salt-tolerant HYV rice varieties. Both the main and sub factors had four treatments and the sub-sub factor had three treatments; all factors were replicated thrice. The factors and their treatments/levels are summarized in Table 1.

Table 1. Factors and treatments of the experiment

Factors	Treatments	Description
Main factor	T_1:	2–5 cm continuous ponding (with no drainage/no removal of applied water)
	T_2:	continuous saturation (with no drainage/no removal of applied water)
	T_3:	changing irrigation water after 3 days of application by maintaining a 2–5-cm ponding
	T_4:	changing irrigation water after 5 days of application by maintaining a 2–5-cm ponding
Sub factor	SL_1:	fresh water (control)
	SL_2:	6 dS m^{-1}
	SL_3:	9 dS m^{-1}
	SL_4:	12 dS m^{-1}
Sub-sub factor	V_1:	Binadhan-8
	V_2:	Binadhan-10
	V_3:	BRRI dhan-47

Based on our design there were three hills of rice for each treatment and each variety. It is noted that because of space limitation in the lysimeters the rice varieties could not be randomized. V_1 can tolerate 10–12 dS m^{-1} salinity at early stage and 8–10 dS m^{-1} at maturity stage, while the salt-tolerant limit of V_2 for the corresponding growth stage is 12–14 dS m^{-1} and 10–12 dS m^{-1} (BINA, 2012). V_3 can tolerate 12–14, 8 and 6 dS m^{-1} at early, pollination and maturity stage, respectively (BRRI, 2015). The three rice varieties were allocated in each lysimeter plot. The layout of the experiment is illustrated schematically in Fig. 1. Basal dose fertilizer of triple super phosphate (TSP), muriate of potash (MP), gypsum, zinc sulphate and cowdung at the rate of 12, 16, 13, 0.5 and 720 g per lysimeter plot (1.2 m^2) were applied and mixed with the soil, corresponding to their recommended dose of 100, 130, 105.88, 3.61 and 6000 kg ha^{-1}. Seeds of the three rice varieties (V_1, V_2 and V_3) were sown in three separate seed beds in BINA farm on 26 December 2016. The seedlings of 32 days age were transplanted on 26 January 2017. Twenty-five (25) hills (each of one plant) were established in each lysimeter with a row to row spacing of 25 cm and plant to plant spacing of 20 cm; the buffer distance surrounding the outer hills was 10 cm (Fig. 1). Each inner hill occupied an area of 500 cm^2. The outer most hills acted as buffer plants to reduce the heterogeneity in the effects of solar radiation and wind in the inner hills. After transplanting seedlings, 40 g urea per plot corresponding to its recommended dose of 326 kg ha^{-1} was top dressed in three splits: 14 g at 11 days after transplanting (DAT), 13 g at 32 DAT and 13 g at 60 DAT. Gypsum @ 18 g per plot corresponding to its recommended dose of 150 kg ha^{-1} was applied in two equal splits at 15 DAT and 60 DAT. Weeds were uprooted manually when required. Sunfuran insecticides were applied to protect green leaves of the rice plants before flowering stage.

2.3 Irrigation and Drainage Practices

Groundwater of a deep tubewell (DTW) inside the BINA farm was used as fresh water (SL_1) for irrigation. Raw wet salt (salt with small quantity water) was collected from a salt field in coastal saline area of Chittagong district. This salt was used to prepare irrigation water with salinity levels SL_2, SL_3 and SL_4 having ingredients similar to that of sea water. A total of 4.8, 7.2 and 9.6 g salt, when mixed separately in one-liter fresh water, provided 6, 9 and 12 dS m^{-1} salinity level, respectively at 25°C. Adequate quantity of irrigation water for each salinity level was prepared during each irrigation event by mixing salt with fresh water. Fresh water was applied to the lysimeter plots that were selected for non-saline/control (SL_1) treatment (Fig. 1). The other plots were irrigated by water with the required salinity levels (SL_2, SL_3 and SL_4). To ensure sufficient soil moisture for normal growth of rice, 2–5 cm water depth was maintained in treatments T_1, T_3 and T_4. T_2 was kept approximately at saturation without any standing water depth. This was done by applying 1-cm irrigation almost daily. Measured quantity of irrigation water was applied in all treatments during the growing period of rice. Conjunctive irrigation water with fresh water and saline water was applied at two critical growth stages of rice: fresh water at 0–15 DAT to ensure establishment (live-saving) of the crop and 61–80 DAT to ensure adequate flowering of the crop since these two growth stages are very sensitive to salinity stress. Irrigation at 16–60 DAT and 81–100 DAT was done by saline water. The applied saline water was drained out through the taps set with the lysimeter boxes at the soil surface and new saline water was applied after 3 days of application in treatment T_3 and 5 days of application in treatment T_4. In T_1, irrigation was applied at 3 to 5 days interval as required to maintain 2 to 5 cm standing water depth. The lysimeter plots were protected from rainfall during the entire growing season with a shade of transparent plastic sheet set over a pre-constructed cast iron frame in the lysimeter yard. The transparent shade did not prevent sunlight significantly from reaching the rice plants. The shade helped maintaining proper control on water budget and salinity levels of the applied irrigation water by preventing rainfall.

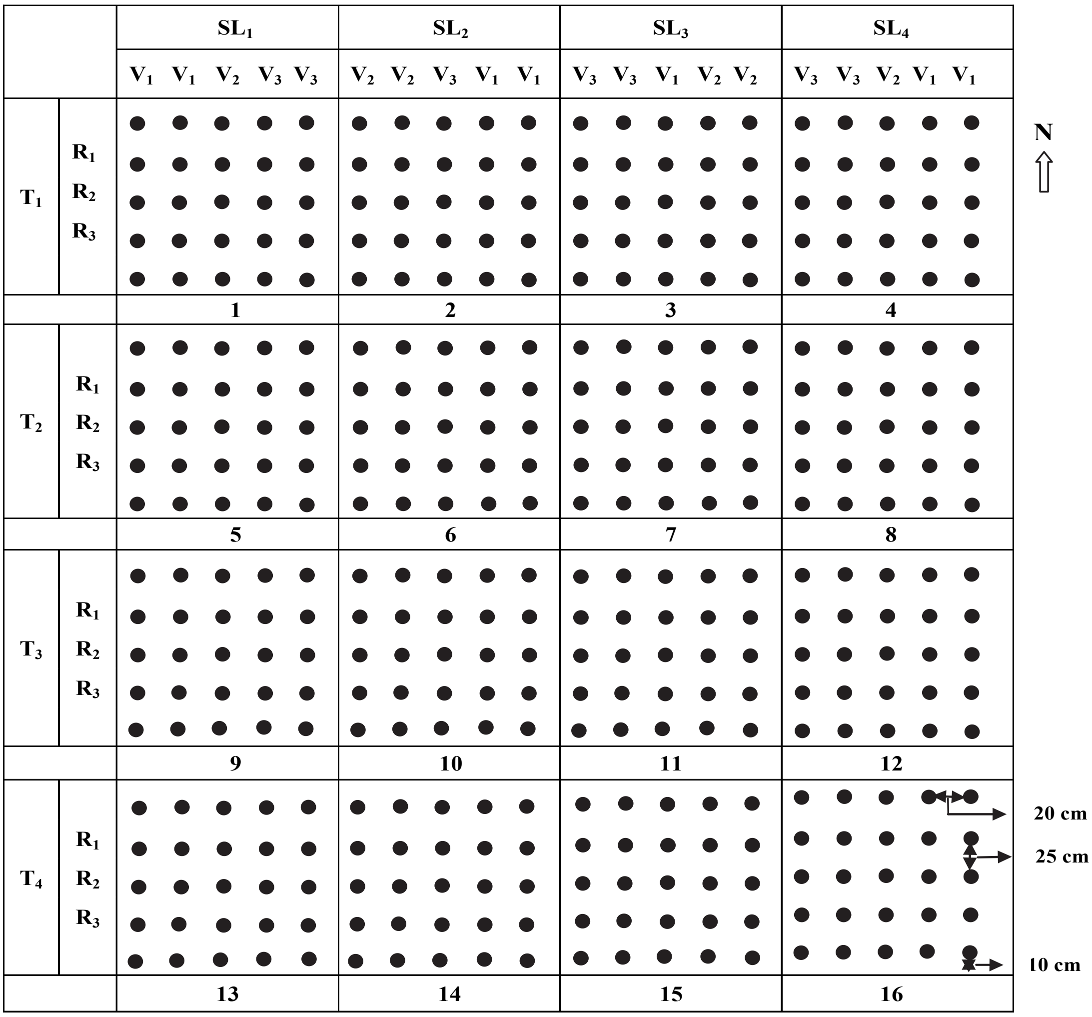

Figure 1. Layout of the experiment in lysimeter plots. T_1–T_4 are the four irrigation–drainage treatments, SL_1–SL_4 are the four irrigation water salinity levels, V_1–V_3 are the three salt-tolerant rice varieties, and the number 1 to16 are the lysimeter plots (Note: without the surrounding buffer plants, there are equal number of plants of each rice variety in each lysimeter)

2.3.1 Data Collection and Analysis

The total number of irrigations and quantity of water applied to each plot in each irrigation event were recorded. Initial soil-moisture content was measured just before transplanting the seedlings in the lysimeters. The final soil-moisture content was measured in each lysimeter plot just after harvesting of rice. Soil-moisture content was determined gravimetrically from the weights of the wet and oven-dry soil samples. Bulk soil electrical conductivity, EC (composite EC of mineral fraction, water and air in a soil volume), of top 0–5 cm soil layer of the lysimeter plots was measured on 13 occasions during the rice-growing season. EC was measured by inserting an EC5061 meter (Germany) into the top soil. The ECs were measured prior to draining out high saline standing water from the treatments T_3 and T_4; ECs of T_1 and T_2 were also measured on the same days. After harvesting of rice, soil samples were collected from 0–15 cm soil layer of each lysimeter plot. These were air-dried in laboratory, grinded and sieved with a 2-mm mesh sieve. Twenty grams of each sample was mixed with 50 g distilled water (soil : water = 1:2.5) and the mixture was shaken vigorously and equilibrated at 25°C for 6 hours. The supernatant was separated, and its EC and pH were measured with a pH110 meter (Cvberscan, Germany) and EC5061 meter (Germany), respectively.

At full maturity, nine (9) inner hills of the three rice cultivars – three for each variety (Fig. 1) – were harvested plot-wise at a time on 22 May 2017. The crop of each plot was bundled separately and tagged properly by maintaining treatments, salinity levels, varieties and replications. Plant heights were measured with a 100-cm measuring tape. The numbers of total tillers and effective tillers (that bear fertile panicles) were counted from each hill at harvest. For recording data on roots, one inner hill for variety V_2 from each plot was uprooted with a soil column of 30 cm depth and 10 cm diameter since most of the root system remained within this soil volume. Note that roots were sampled from only one hill in order to keep the lysimeters' soils mostly intact for the next season's experiment. The roots with the soil were kept on plastic nets and washed manually with water to remove the soil and separate the roots. The depth of roots was measured from the base of the root-node to end of the longest root. After oven-drying the roots at 60°C for 72 hours, weight of the roots was measured with an electronic balance. Panicle length was recorded from the basal node of the rachis to the apex of each panicle. Each observation was made by averaging the lengths of the panicles of each hill. The rice grains of each hill were separated and weighed after sun drying at 12% moisture content. One thousand clean sun-dried grains were taken from the grain stock of each plot and weighed. We expressed the grain and straw yields as 'per hill basis' since the results will be compared with a future pot experiment. This did not hamper comparing relative performance of the factors and treatments of the experiment in this study. After sun drying, the straw of each plot was weighed, and the straw yield was calculated. Harvest index (HI) of the rice crop was calculated from the ratio of grain yield to the total above-ground biomass yield (grain plus straw yield). Water productivity was determined by dividing grain yield by the total water used in each plot (Table 2) that comprised applied irrigation and soil-moisture contribution. Since the crop was protected from rainfall by shading, rainfall did not contribute to the water budget in the plots. Soil-moisture contribution was determined by subtracting the quantity of soil moisture at harvest from the soil moisture at transplanting of seedlings (36% by weight). The components of water usage and total water used by the rice plants of the treatments are given in Table 2. Analysis of variance (ANOVA) was done by using Statistix 10 software package of Analytical Software (2019). Comparison of means of the plant attributes among the irrigation–drainage treatments and salinity levels was done at 5% level of significance ($p \le 0.05$) by implementing Tuky's Honest Significant Difference (HSD) test.

Table 2. Components of water use and total water used in different irrigation-drainage treatments

Irrigation -drainage treatments	Salinity levels	No. of freshwater irrigation	Quantity of freshwater irrigation (mm)	No. of saline water irrigation	Quantity of saline water irrigation (mm)	Total quantity of irrigation (mm)	Soil-moisture contribution (mm)	Total water used (mm)
T_1	SL_1	23	785	00	00	785	25	760
	SL_2	7	274	16	478	752	25	727
	SL_3	7	271	16	455	725	25	700
	SL_4	7	260	16	423	687	25	662
T_2	SL_1	30	394	00	00	394	25	369
	SL_2	9	190	21	166	356	25	331
	SL_3	9	187	21	145	332	25	307
	SL_4	9	177	21	127	304	25	279
T_3	SL_1	33	799	00	00	799	25	774
	SL_2	9	239	24	505	744	25	719
	SL_3	9	237	24	490	726	25	701
	SL_4	9	229	24	465	694	25	669
T_4	SL_1	21	710	00	00	710	25	685
	SL_2	7	250	14	437	687	25	662
	SL_3	7	244	14	421	665	25	640
	SL_4	7	237	14	398	634	25	760

3. Results

3.1 Growth Attributes of Rice

The tallest plant (97.4 cm) of the rice crop, recorded in treatment T_3 (changing irrigation water after 3 days of application by maintaining 2−5 cm ponding depth) under salinity level SL_2 (6 dS m^{-1}), was statistically similar to the plant height in other treatments under this salinity level (Table 3). The shortest plant (88.4 cm) was obtained in T_4 (changing irrigation water after 5 days of application by maintaining 2−5 cm ponding depth) under salinity level SL_4 (12 dS m^{-1}). Treatment T_2 produced taller plants under the two higher salinity levels (SL_3 and SL_4) of irrigation water. Table 3 reveals that the salinity level and duration of exposure of the rice crop to salinity did not exert consistent effect on the plant height of the crop. As for the varietal effect (under the combined impacts of irrigation–drainage treatments and salinity levels), the mean plant height exhibited significant ($p \le 0.05$) variations among the three rice varieties (Table 4). Variety V_2 (Binadhan-10) produced significantly higher plant height (102.2 cm) than the other two varieties. Continuous ponding (T_1) produced the highest number of total tillers (average = 27) under fresh-water (SL_1) irrigation and lowest number of total tillers (17) under the highest salinity level (SL_4) of irrigation water, confirming the findings of Haq et al. (2009) who observed significantly reduced number of total tillers under saline condition compared to non-saline condition. Because of the special irrigation and drainage management practices, treatments T_2, T_3 and T_4 minimized exposure of the crop to the degree of salinity and, consequently, improved the number of total tillers under saline-water irrigation (Table 3). Among the four irrigation–drainage treatments, T_3 produced the highest number of total tillers under saline-water irrigation, with significantly ($p \le 0.05$) higher number of tillers under SL_4 than other treatments. This observation reveals that T_3 is the best irrigation–drainage management practice with saline-water irrigation.

Table 3. Comparison of the mean plant height and number of total tillers and effective tillers per hill of three rice varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47) among four irrigation–drainage treatments (T_1: 2−5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2−5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2−5 cm ponding depth) under four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1}) of irrigation water

Treatments	Plant height (cm)				Total tillers per hill (-)				Effective tillers per hill (-)			
	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4
T_1	92.1b	94.9a	88.4b	93.0a	27a	22a	19a	17b	22a	17a	15a	12b
T_2	97.1a	94.2a	96.2a	93.6a	27a	21a	21a	19ab	21a	17a	16a	15a
T_3	94.3ab	97.4a	93.8a	88.9b	25ab	23a	21a	21a	20a	18a	17a	16a
T_4	92.8b	93.8a	90.4b	88.4b	25b	22a	21a	19ab	20a	17a	15a	13b
$HSD_{0.05}$	3.45	3.87	3.12	3.26	2.2	2.3	2.2	1.9	2.5	2.7	2.4	1.1

Common letter(s) within the same column do not differ significantly at 5% level of significance ($p \le 0.05$).

Compared to fresh-water (SL_1) irrigation, saline-water irrigation suppressed effective tiller numbers; the suppressing effect increased with increasing salinity level of irrigation water. Table 3 reveals that changing/replacing irrigation water after 3 days of application by maintaining 2–5 cm ponding water depth (T_3) produced the highest number of effective tillers per hill in saline condition (SL_2–SL_4); with significantly higher number of effective tillers under SL_4 than the other treatments. Irrigation with saline water throughout the crop period (T_1) imposed strong salinity stress and reduced the effective tillers. Similar to the findings of Akter et al. (2015), the panicle number in our experiment was the maximum in the control and decreased gradually as salinity of irrigation water increased from 4 to 12 dS m^{-1}. The numbers of total tillers and effective tillers per hill were statistically similar for both V_1 (Binadhan-8) and V_3 (BRRI dhan-47) but significantly ($p \le 0.05$) lower than that in V_2 (Binadhan-10) (Table 4). So, BINA dhan-10 gave the most promising results in terms of plant height and tiller number under saline water irrigation.

3.2 Yield Attributes of Rice

The panicle length of rice decreased in the four irrigation-drainage treatments with increasing salinity levels of irrigation water. Treatments T_2 and T_3 provided significantly longer panicle length under high salinity levels (SL_3 and SL_4) than T_1 and T_4, both of which provided statistically similar panicle lengths (Table 5). Continuous saturation (T_2) with fresh-water irrigation (SL_1) provided the longest panicle length (26.2 cm), while 2–5 cm continuous ponding (T_1) with high saline-water (SL_4: 12 dS m^{-1}) irrigation provided the shortest panicle length

(21.4 cm). Under saline-water irrigation, T_3 provided the longest panicle length of rice. Of the practically feasible saline-water irrigation–drainage treatments (T_1, T_3 and T_4), T_3 produced significantly ($p\leq0.05$) longer panicles than T_1 and T_4. The number of grains per panicle in the irrigation–drainage treatments also decreased with the increase in salinity of irrigation water (Table 5). T_1 provided the lowest number of grains per panicle under high saline-water irrigation (SL_4). T_2 and T_3 minimized salinity stress of rice to irrigation-water salinity by reducing crop-exposure to salinity and significantly ($p\leq0.05$) improved the number of grains per panicle under the imposition of the two high salinity levels (SL_3 and SL_4), with the higher number of grains in T_3. The irrigation–drainage treatments T_2 and T_3 performed exactly similarly in providing 1000-grain weight as they did in providing the number of grains per panicle. The weight of 1000-grain increased in T_2, T_3 and T_4 compared to T_1, and decreased with the increase in salinity levels. The mean panicle length and 1000-grain weight under the combined effects of four irrigation-drainage treatments and four salinity levels differed significantly among the three rice varieties (Table 6). BINA dhan-10 (V_2) provided the most improved panicle length (25.8 cm) and 1000-grain weight (28.9 g).

Table 4. Comparison of the mean growth attributes of rice for three varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47) under the combined effects of four irrigation-drainage treatments (T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth) and four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1})

Rice variety	Plant height (cm)	Total tillers per hill (-)	Effective tillers per hill (-)
V_1	87.7c	22b	17b
V_2	102.2a	23a	18a
V_3	89.4b	21b	16b
$HSD_{0.05}$	1.04	0.7	0.7

Common letter(s) within the same column do not differ significantly at 5% level of significance ($p\leq0.05$).

Table 5. Comparison of the yield attributes of rice due to the effects of four irrigation-drainage treatments (T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth) under the application of four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1}) irrespective of the rice varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47)

Treatments	Panicle length (cm)				Grains per panicle (-)				1000-grain weight (g)			
	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4
T_1	25.9a	24.4a	22.6b	21.4b	133a	127ab	113c	110c	30a	28b	27b	26c
T_2	26.2a	24.6a	24.7a	23.9a	136a	134ab	126ab	123ab	30a	29a	28a	27ab
T_3	25.4a	25.8a	24.9a	23.9a	137a	138a	133a	128a	30a	29a	28a	27a
T_4	25.0a	24.7a	22.8b	22.2b	140a	125b	119bc	114bc	30a	28ab	27b	27bc
$HSD_{0.05}$	1.74	2.36	1.16	1.12	18.7	11.7	11.0	12.0	1.2	0.7	0.5	0.5

Common letter(s) within the same column do not differ significantly at 5% level of significance ($p\leq0.05$).

Table 6. Comparison of the mean yield attributes of rice for three varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47) under the combined effects of four irrigation-drainage treatments (T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth) and four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1})

Rice variety	Panicle length (cm)	Grains per panicle (-)	1000-grain weight (g)
V_1	23.2c	127a	28.1b
V_2	25.8a	128a	28.9a
V_3	23.8b	128a	27.5c
$HSD_{0.05}$	0.49	5.1	0.23

Common letter(s) within the same column do not differ significantly at 5% level of significance ($p\leq0.05$).

3.3 Yields, Harvest Index and Water Productivity of Rice

Treatments T_2 and T_3 minimized harmful effects of salinity and improved grain yield under high saline-water (SL_3 and SL_4) irrigation compared to T_1 and T_4 (Table 7). T_3 produced significantly ($p \le 0.05$) higher grain yield per hill under these salinity levels compared to the other treatments. T_2 and T_3 minimized the detrimental effects of salinity on vegetative growth of the rice plants and produced similar straw yield under SL_4 (12 dS m^{-1}) that was significantly higher than the straw yield in T_1 and T_4. Exactly similar effects of the irrigation–drainage treatments under the four salinity levels of irrigation water were observed in producing above-ground biomass (straw plus grain) yield of rice (Table 7). BINA dhan-10 (V_2) produced significantly higher grain yield, straw yield and above-ground biomass yield per hill under the interaction effects of irrigation–drainage treatments and salinity levels of irrigation water than the other two rice varieties, which produced statistically similar yields (Table 8).

Table 7. Comparison of the yield of rice due to the effects of four irrigation-drainage treatments (T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth) under the application of four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1}) irrespective of the rice varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47)

Treatments	Grain yield per hill (g)				Straw yield per hill (g)				Above-ground biomass yield per hill (g)			
	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4
T_1	65.6a	45.3a	34.7b	26.5c	17.7ab	16.5a	12.0a	11.0b	83.3a	61.8a	46.6b	37.5c
T_2	63.9a	45.0a	37.4b	34.3b	19.7a	14.9a	12.1a	13.6a	83.6a	59.8a	49.5b	47.9b
T_3	59.9a	52.8a	43.7a	39.5a	18.1ab	15.4a	13.3a	13.2a	78.0a	68.2a	57.0a	52.7a
T_4	59.9a	44.2a	34.2b	27.3c	16.9b	14.5a	12.0a	11.2b	76.8a	58.7a	46.3b	38.5c
$HSD_{0.05}$	14.9	9.7	6.2	3.7	1.9	2.8	1.7	1.7	17.1	10.9	6.4	3.9

Common letter(s) within the same column do not differ significantly at 5% level of significance ($p \le 0.05$).

Table 8. Comparison of the mean yield of rice for three varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47) under the combined effects of four irrigation-drainage treatments (T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth) and four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1})

Rice variety	Grain yield per hill (g)	Straw yield per hill (g)	Above-ground biomass yield per hill (g)
V_1	42.5b	14.0b	56.5b
V_2	50.9a	15.4a	66.3a
V_3	40.5b	14.1b	55.7b
$HSD_{0.05}$	3.2	0.8	3.7

Common letter(s) within the same column do not differ significantly at 5% level of significance ($p \le 0.05$).

Root-biomass decreased with increasing salinity level of irrigation water (Table 9). Treatments T_1 and T_4 produced lower root-biomass under saline-water irrigation, but T_3 produced significantly higher quantity of root-biomass under high saline-water (SL_3 and SL_4) irrigation than the other treatments. The harvest index of rice decreased with the increase in salinity level and also with the increase in the duration of exposure of the crop to salinity of irrigation water. The observed harvest indices (Table 9) appeared to be generally large as compared to that found for rice at field level, usually around 50%. The higher harvest indices might possibly be due to the rice-growth management under controlled condition in the lysimeters where most of the growth-influencing factors were properly maintained. However, in the relative terms, the four irrigation–drainage treatments did not exert any significant impact on the harvest index under the four salinity levels of irrigation water (Table 9). These results revealed that longer exposure of rice plants to high salinity stress reduced its grain yield more compared to its straw yield. In general, reduction of duration of salinity exposure of rice plants improved water productivity of rice. Continuous saturation (T_2) of rice plot provided significantly ($p \le 0.05$) higher water productivity since it drastically reduced crop-water usage (Table 2) compared to the other treatments (Table 9). In contrast, continuous standing water provided the lowest water productivity under all four salinity levels of irrigation water. Treatment T_3, most practically applicable treatment compared to T_2, resulted in significantly higher water productivity under high salinity (SL_4) of irrigation water. Among the three rice varieties, BINA dhan-10 (V_2) provided significantly higher root-biomass yield, harvest index and water productivity than the other two rice varieties, which resulted in statistically similar harvest index and water productivity but different root biomass yields (Table 10).

Table 9. Comparison of the harvest index of rice due to the effects of four irrigation-drainage treatments (T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth) under the application of four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1}) irrespective of the rice varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47)

Treatments	Root-biomass yield per hill (g)				Harvest index (%)				Water productivity (kg ha^{-1} cm^{-1})			
	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4	SL_1	SL_2	SL_3	SL_4
T_1	17.6b	14.8a	11.4b	9.1bc	78.7a	73.1a	74.2a	70.5a	172.5b	124.6b	99.0b	80.0c
T_2	19.0a	15.2a	12.0b	10.2ab	76.2a	75.0a	75.4a	71.4a	345.9a	271.5a	243.6a	246.3a
T_3	17.7a	15.4a	13.7a	10.9a	76.5a	77.3a	76.6a	74.8a	154.8b	146.9b	124.7b	118.2b
T_4	18.0a	14.8a	11.9b	8.6c	77.9a	74.9a	73.8a	70.5a	174.9b	133.5b	106.9a	89.7c
$HSD_{0.05}$	1.9	2.0	0.9	1.3	2.7	4.6	3.3	4.9	42.4	47.7	29.2	20.8

Common letter(s) within the same column do not differ significantly at 5% level of significance (p≤0.05).

Table 10. Comparison of the mean root biomass yield, harvest index and water productivity of rice for three varieties (V_1: Binadhan-8, V_2 : Binadhan-10 and V_3: BRRI dhan-47) under the combined effects of four irrigation-drainage treatments (T_1: 2–5 cm continuous ponding, T_2: continuous saturation, T_3: changing irrigation water after 3 days of application by maintaining 2–5 cm ponding depth, and T_4: changing irrigation water after 5 days of application by maintaining 2–5 cm ponding depth) and four salinity levels (SL_1: fresh water as control, SL_2: 6 dS m^{-1}, SL_3: 9 dS m^{-1}, and SL_4: 12 dS m^{-1})

Rice variety	Root-biomass yield per hill (g)	Harvest index (%)	Water productivity (kg ha^{-1} cm^{-1})
V_1	13.6b	74.6b	155.7b
V_2	14.8a	76.3a	188.1a
V_3	12.9c	73.5b	150.0b
$HSD_{0.05}$	0.6	1.3	12.5

Common letter(s) within the same column do not differ significantly at 5% level of significance (p≤0.05).

3.4 Soil Salinity Dynamics in Rice Plots

Bulk soil EC in all lysimeter plots increased after rice cultivation from an average initial (before rice plantation) value of 0.45 dS m^{-1} to 0.39–2.85 dS m^{-1}, with a mean value of 1.49 dS m^{-1}. EC varied with irrigation water salinity and length of exposure of irrigation–drainage cycles to the salinity levels. At 1 (one) day after transplanting (DAT), EC was the lowest, ranging from 0.23 to 0.26 dS m^{-1} among the treatments (Table 11) since irrigation was applied during the first 15 DAT with fresh water. Application of the first split of urea on 11 DAT contributed increasing EC of the standing water and/or soil in the plots; consequently, EC increased noticeably on 12 DAT in all treatments. Due to imposition of salinity through irrigation water during 16–59 DAT, EC increased drastically on 18 DAT in all treatments and continued increasing until saline-water in the plots was replaced with fresh-water irrigation during 60–80 DAT. As a result, EC decreased on 66 and 78 DAT, and continued increasing thereafter with the imposition of saline-water irrigation again. The second and third splits of urea application on 32 and 60 DAT, and gypsum application on 12 and 60 DAT also contributed to the bulk soil EC. But, their effects were not visible (Table 11) due to the predominant effect of irrigation water salinity. Soil reaction, pH, also increased from an average initial value of 6.06 ± 0.07 (n = 3) to 7.84 ± 0.22 (n = 16).

3.5 Suitable Irrigation–Drainage Management Practice

In terms of growth and yield attributes, yields, harvest index and water productivity, changing/replacing saline irrigation water after 3 days of application by maintaining 2–5 cm ponding depth (T_3) provided the best results.

However, continuous saturation with saline water (T_2) and changing saline irrigation water after 5 days of application by maintaining 2–5 cm ponding (T_4) provided better results compared to 2–5 cm continuous ponding depth of saline water (T_1). From practical applicability point of view, treatment T_2 is difficult to implement in the field. So, T_3 appeared to be the optimum irrigation–drainage management practice for HYV salt-tolerant rice cultivation by saline-water irrigation. Among the three rice varieties, BINA dhan-10 (V_2) provided significantly ($p \le 0.05$) higher growth and yield attributes, yields, harvest index and water productivity than Binadhan-8 (V_1) and BRRI dhan-47 (V_3) and appeared to be the most suitable rice variety for cultivation under saline-water irrigation for the employed irrigation–drainage management practice (T_3).

Table 11. Bulk soil electrical conductivity (EC, dS m^{-1}) of 0–5 cm soil layer in the lysimeter plots on different days after transplanting (DAT) during the rice-growing period and EC and pH after harvesting the crop

Treatment and salinity level		EC at DAT													EC and pH after harvest	
		1	12	18	20	21	28	40	48	58	66	78	87	98	EC	pH
T_1	SL_1	0.25	0.70	0.67	0.85	0.70	0.70	0.68	0.40	0.46	0.42	0.49	0.49	0.54	0.41	7.43
	SL_2	0.23	0.80	4.70	5.20	6.70	7.20	7.52	6.90	7.10	4.34	2.13	3.25	4.18	1.49	7.87
	SL_3	0.25	0.90	5.60	7.20	9.20	9.50	8.87	8.70	9.30	6.43	4.39	5.19	5.89	2.06	7.84
	SL_4	0.25	1.10	7.50	8.10	10.2	11.2	11.36	11.89	12.39	8.14	5.24	6.34	8.33	2.85	8.25
T_2	SL_1	0.24	1.00	1.00	1.30	1.20	0.80	0.42	0.59	0.56	0.51	0.48	0.45	0.52	0.42	7.77
	SL_2	0.23	0.70	2.10	2.60	3.00	3.20	2.05	2.29	2.84	2.74	1.87	2.58	3.28	1.13	8.03
	SL_3	0.24	0.90	3.65	4.10	4.30	4.40	4.22	4.35	4.55	4.15	2.62	3.68	4.88	1.83	7.91
	SL_4	0.24	0.80	4.60	5.70	6.20	6.12	5.67	6.53	6.95	5.16	3.55	4.85	5.85	2.69	7.86
T_3	SL_1	0.23	0.90	0.63	0.60	0.60	0.60	0.52	0.58	0.55	0.54	0.50	0.52	0.54	0.39	7.47
	SL_2	0.25	0.90	2.10	3.17	4.30	4.50	3.75	4.30	4.61	1.94	1.58	2.16	2.77	0.91	7.63
	SL_3	0.24	0.90	3.80	3.91	4.50	4.90	5.08	5.44	5.73	2.91	2.16	3.22	4.12	1.65	7.90
	SL_4	0.24	0.80	4.60	5.50	6.15	6.20	6.19	6.38	6.57	3.52	3.17	4.33	5.18	2.15	7.87
T_4	SL_1	0.25	0.80	0.50	0.62	0.50	0.80	0.51	0.52	0.56	0.55	0.55	0.55	0.55	0.41	7.77
	SL_2	0.24	0.80	3.90	4.01	4.80	5.30	4.83	5.34	5.63	2.13	1.69	2.99	3.44	1.07	7.85
	SL_3	0.25	0.70	4.42	5.30	6.10	6.50	6.62	6.72	6.87	3.49	2.87	3.87	4.79	2.00	7.83
	SL_4	0.26	0.90	6.59	7.30	7.85	8.40	8.68	8.66	8.95	4.92	3.50	5.39	6.68	2.35	8.20

4. Discussion

4.1 Crop Exposure to Salinity

The root zone of the rice crop always remained water saturated in the four irrigation–drainage treatments (T_1–T_4). Consequently, the crop was always exposed to salinity under saline-water irrigation. The soil in treatment T_2 maintained always saturation condition almost without standing water except for a short period after application of 1 cm irrigation water daily. So, only the roots of the rice crop remained exposed to salinity in this treatment. In the other treatments (T_1, T_3 and T_4), in addition to root zone, 2–5 cm of the rice stems also remained into standing water in the lysimeter plots. However, the duration of exposure of the rice plants to salinity differed among these treatments for the four salinity levels (SL_1, SL_2, SL_3 and SL_4) of irrigation water. Immediate after an irrigation event with saline water in T_1, water salinity in the rice plots became higher than salinity of the applied irrigation water due to mixing of the applied water with the already remaining standing water in the plots with elevated salinity. After the irrigation event, water salinity continued increasing until the next irrigation was applied since salt concentration in the standing water increased due to evaporation loss of water from the plot. In this process, salinity of standing water in the rice plots under T_1 increased continuously during the entire rice-growing period. Consequently, soil salinity in the rice plots also increased in parallel to the standing water salinity (Table 11). In treatment T_3, on the other hand, salinity of the applied water in the rice plots continuously increased for 3 days (irrigation interval) until water depth decreased to ≈ 2 cm from 5 cm. The standing water in the plots was then changed/replaced with irrigation water of the prescribed salinity level, which was lower than the remaining water in the plots. Therefore, both the rice crop and soil in treatment T_3 remained exposed to water salinity, which was low compared to that in treatment T_1. Treatment T_4 was mostly similar to T_3, except that because of larger irrigation interval (5 days) in T_4 compared to T_3 (3 days), salinity of the applied water in the plots increased for a longer period. Consequently, both the rice crop and soil in T_4 remained exposed to water salinity, which was high compared to that in T_3 but still low compared to T_1. So, the crop exposure to high degree of salinity was the least in treatment T_2, slight in T_3, moderate in T_4 and maximum in T_1; this classification is just a relative grading of salinity level.

4.2 Salinity Effects on Growth Attributes

Treatment T_2 that maintained continuous saturation and the least exposure of the rice crop to high salinity produced the tallest plants under most of the salinity levels. However, this treatment is not practically feasible to implement at field level since it is difficult to maintain large rice fields continuously saturated without standing water. But, T_3 maintained specific limiting high degrees of salinity exposure to the crop produced significantly ($p \leq 0.05$) taller plants than in T_1 and T_4 treatments under high salinity levels (SL_3 and SL_4). The observed trend in the plant height thus implies that the longer the exposure of the crop to high degree of salinity, the less was the plant height. Similar trend of salinity effects was also observed in producing total number of tillers and effective tillers of the three rice varieties. So, the least exposure of the crop (crop stem) to high degree of salinity (T_2), although practically not feasible, was the best, and the longest exposure of the crop stem to high degree of salinity (T_1) was the poorest irrigation–drainage practices. Our observations agree with the findings of El Hasan et al. (2006), Haq et al. (2009) and Razzaque et al. (2009), who reported significant suppressing effect of salinity on the number of total tillers and effective tillers. In our study, T_3 produced the largest number of effective tillers under saline-water irrigation (SL_2–SL_4). Continuous standing saline water without replacement (T_1) drastically reduced the number of effective tillers under high salinity level (SL_4, Table 3). Aguilar et al. (2017) also reported similar result by obtaining reduced panicle number under salt-stress due to saline-water irrigation throughout the entire crop season. The three rice varieties in our experiment differed in producing the number of effective tillers and plant height; BINA dhan-10 (V_2) produced significantly ($p \leq 0.05$) higher number of effective tillers than the other two varieties. This variety thus revealed its more salt-tolerant ability than the other two varieties. Less reduction in effective tiller number by a salt-tolerant variety was also reported by Akter et al. (2015).

4.3 Salinity Effects on Yield Attributes and Water productivity

Generally, salinity caused noticeable reduction in yield attributes (e.g., panicle length, grains per panicle, 1000-grain weight) and yield of rice in our experiment similar to that reported by other investigators (e.g., WeonYoung et al., 2003; Hassan et al., 2012; Hasanuzzaman et al., 2009). But, the crop exposure to large degree of salinity (T_1) significantly reduced grain yield. Saline water during both the vegetative and reproductive phases was reported to adversely affect yield attributes and grain yield due to toxic ion accumulation in the plant cells (Aguilar et al., 2017). Standing water in the rice field adversely affects fertile tiller number (Zeng et al., 2003). In treatment T_2, there was no standing water and hence it provided more grain yield than T_1 and T_2 treatments for different salinity levels of irrigation water. But, T_3 provided significantly higher yield than the other treatments under all salinity levels (Table 7). For the same reason, T_3 also provided significantly higher straw yield and above-ground biomass yield (straw plus grain yield) than the other treatments under SL_3 and SL_4. Irrespective of the irrigation–drainage practices and salinity levels, BINA dhan-10 (V_2) exhibited more salt-tolerant ability by providing significantly higher grain, straw and biomass yields than the other two rice varieties.

The reduced rice yield due to Na^+ accumulation in the plant cells of rice grown under saline condition eventually reduced water productivity. But, when the duration of salinity exposure of the crop was reduced by irrigation-drainage practices, water productivity increased due to increase in rice yield. The three tested rice varieties were salt tolerant, and they accumulated less Na^+ and more K^+ than susceptible cultivars (Khan et al., 1997). But, increasing salinity level with longer exposure of the crop to salinity enhanced Na^+ accumulation with associated depletion in K^+ content of the rice plants. Consequently, water productivity in our experiment decreased with increasing level of salinity and also with increasing duration of crop exposure to salinity. Therefore, considering growth and yield attributes and yield of rice, treatment T_3 in which applied saline water was replaced after 3 days of application and a 2 to 5-cm ponding depth was maintained appeared as the optimum irrigation management practice to reduce detrimental effects of salinity on rice production.

4.4 Practical Context of the Results

The main purpose of this study was to identify a suitable irrigation–drainage practice for HYV salt-tolerant rice cultivation under saline-water irrigation by characterizing the possible irrigation–drainage practices for further verification in field conditions with a view to future adoption of the practice in practical fields. For the identified suitable irrigation–drainage practice (T_3), there remain some important queries, which are: how to flush (2–5 cm) saline water from the rice fields, where the flushed water can be disposed of, and what will happen to the accumulated salt in the soil of the rice field? These issues need to be worked out before adopting the proposed irrigation–drainage practice for practical application.

Due to soil salinity, the land usage and cropping intensity in the coastal zone of Bangladesh are low (Rahman & Ahsan, 2001). Consequently, there remain large swaths of fallow land in the dry season. To cultivate rice in these fallow lands under saline water irrigation, both irrigation and drainage canal networks would be needed, preferably for gravity supply (for irrigation) or removal (for drainage) of water. The two different canal network-types can be of side-by-side surface system or one or both of them can be of buried pipe systems. Although some additional cost will be involved for constructing the drainage canal system, it will bring the fallow land under rice cultivation. The saline water expected to be used for irrigating rice crops mostly remains in rivers and channels in the coastal zone. The drainage water from the rice fields could be disposed of to these same rivers and channels; the drainage water, although of higher salinity than the river/channel water, would not perceptively increase the salinity of the water in the rivers and channels because of their large volumes.

In our lysimeter experiments, the vertical and horizontal movement of salt in the rice plots was not considered, and salt from irrigation water continuously accumulated throughout the rice-growing period. Under this situation, the amount of salt in the soil was controlled only by the concentration of salt in irrigation water and total irrigation amount, thus the soil-salt could not be effectively controlled by the irrigation–drainage management practice. However, the practical field conditions would be completely different than the conditions in lysimeter plots in regard to salt dynamics in the soil. Due to standing water (and also saturated condition) there will be continuous leaching of salt from the rice plots through the percolating water. So, salt accumulation in the soil would be lower compared to that in the lysimeter experiments. Furthermore, during the monsoon period (May–September), the accumulated salt would leach down with the infiltrating rain water. Salt accumulation in the soil during dry season due to capillary rise or saline water irrigation and salt leaching during monsoon is a usual natural salt dynamics in the coastal saline zone of Bangladesh. So, the proposed irrigation–drainage practice (T_3) in the practical field is not expected to require any additional management of soil-salt except occasional monitoring.

5. Conclusions

Coupled irrigation–drainage management practices can provide an opportunity to obtain desired yield of HYV salt-tolerant rice in areas with scarcity of fresh water and availability of saline water. Apart from selecting salt-tolerant HYV rice cultivars, an intelligent irrigation and drainage management practice with limited exposure of the crop to high salinity can reduce detrimental effects of salinity. Rice fields often lack drainage facility, although this is an important component of rice-irrigation management. We evaluated four irrigation–drainage practices in reducing salinity effects on rice in lysimeter experiments under controlled conditions. Our observations revealed that replacing irrigation water of 9–12 dS m^{-1} (SL_4) salinities after 3 days of application by maintaining a 2−5 cm ponding depth for salt-tolerant boro rice significantly ($p \leq 0.05$) reduced detrimental effects of salinity in the growth and yield of HYV rice cultivars. Although in our lysimeter experiments irrigation-induced soil salinization remained in place during the crop period, downward movement of salt through leaching will also be in place in practical field conditions. Also there is a long monsoon period (May–September) in Bangladesh during which accumulated salt in the soil would leach down with infiltrating rain water. So, practical field experiments in coastal areas under fresh-water scarcity and saline water availability are necessary to validate our results and evaluate practicability of the practice before adopting it for practical application. One limitation of this study was that it was done only in one year because of time constraint since the study was done under a degree program. However, the results were obtained under controlled conditions with minimum possible errors and the expected field verification of the results would eliminate any discrepancy arising from the single-year observation.

Conflict of interest

The authors declare that there is no conflict of interest.

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