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Research Article

Growth-stage-sensitivity of Four HYV Rice Cultivars to Irrigation Water Salinity

Mohammad Ashiqur Rahman[1], Mohammad Abdul Mojid[2]✉, Fahmina Yasmine[3] and Tanvir Ahmed[2]

[1]Agricultural Engineering Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh-2202, Bangladesh
[2]Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh
[3]Plant Breeding Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh-2200, Bangladesh

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Correspondence
Md. Abdul Mojid
✉: ma_mojid@bau.edu.bd

ABSTRACT

Application of fresh water at the salinity-sensitive growth stage(s) and saline water of tolerable salinity level at the less sensitive stage(s) may be an effective irrigation technique for rice (*Oryza sativa* L.) cultivation in fresh water-scarce salt-affected areas. However, implementation of this technique requires adequate prior information on the sensitivity of growth stages of the rice cultivars to salinity of irrigation water. The objective of this study was therefore to identify the sensitivity of growth stages of Binadhan-8, Binadhan-10, BRRI dhan28 and BRRI dhan47 to salt-stress by irrigating the crops with fresh water (control), and saline water of 6, 9 and 12 dS m^{-1} at establishment, tillering, panicle formation, flowering, maturity and all growth stages of the crops. The experiment was laid out in a split-split pot arrangement following a completely randomized design (CRD) with three replications. The establishment and flowering stages of the rice cultivars were found to be the most sensitive to salt-stress. Therefore, irrigation at these growth stages with fresh water and at the other growth stages with saline water would be an appropriate strategy for cultivation of the tested rice cultivars in fresh water-scarce saline areas like the coastal saline region of Bangladesh.

Introduction

The salinity of agricultural soil and water is a key wide-ranging abiotic stress that limits crop production globally. Plant growth is adversely affected in the saline environment due to reduced water uptake, salt-toxicity and nutrient imbalances (Shrivastava and Kumar, 2015; Hanin et al., 2016). The most harmful effect of salt-stress is the accumulation of Na^+ and Cl^- ions in plant tissues (Eraslan et al., 2007; Nishimura et al., 2011). Under salt-stress, the ratios of Na^+/K^+, Na^+/Ca^{2+}, Ca^{2+}/Mg^{2+}, and Cl^-/NO^{3-} increase in soil with a consequent ion imbalance and deficiency of N, P, K^+, Ca^{2+}, S, Mn, and Zn^{2+} in various crops including rice (Jung et al., 2009; Garcia et al., 2010; Pandey et al., 2013; Ezeaku et al., 2015). The uptake of Na^+ and Cl^- ions by plants in excess of their requirement causes major physiological disorders in rice plants (James et al., 2011) and reduces plant growth and yield (Hu and Schmidhalter, 2005).

The responses of plants to salt-stress are complex and mostly depend on their genetic characteristics, duration and type of salt-stress, and development stage of the plants among others (Bernardo et al., 2000; Cramer et al., 2001; Mojid et al., 2013a, 2013b). Accordingly, the ability of the plants to tolerate salinity depends on the genes that function at the stage of development of the plants during which the salt-stress occurs (Gupta and Huang, 2014; Van Zelm et al., 2020). Although salt-stress affects all growth stages of plants, the sensitivity levels of most crops generally differ over their growth stages (Uçarlı, 2020) and also among the crop cultivars (Ahmad et al., 2005; Cai and Gao, 2020). Salt-stress adversely affects the plant growth and development by inhibiting seed germination, seedling growth, and cell division (Seckin et al., 2009; Tabur and Demir, 2010; Rajabi et al., 2020), implying that high sensitivity to salinity is observed mainly at the vegetative and reproductive stages in rice (Hussain et al., 2017). These growth phases are the most sensitive in determining rice yields (Cuartero et al., 2006; Rajabi et al., 2020). So, there remains a prospect of minimizing salt-injury of rice plants at the sensitive growth stages by regulating

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the salinity of irrigation water.

Most rice cultivars, compared to other cereals, are susceptible to the rhizosphere salinity (Hussain et al., 2017; Joseph et al., 2010). The productivity of rice is severely affected by the accumulation of soluble salts in soils (Ashraf, 2009). There are many growth-inhibiting effects of salt-stress on rice plants, such as reducing rates of net CO_2 assimilation, leaf growth, leaf cell enlargement, dry matter accumulation (Cramer et al., 2001; Amirjani, 2010), transpiration rate, and ability to uptake water and nutrients as well as altering metabolic activities (Munns, 2002). Moreover, poor development of rice spikelets caused by salt-stress significantly reduces grain yield of rice (Fu et al., 2011; Zhang et al., 2012; Zhang et al., 2015). Excess Na^+ in plant harms cell membrane and hinders plant physiological mechanisms leading to death of plant cells (Quintero et al., 2007; Siringam et al., 2011).

Rice is the most important crop for the agro-economy and staple food of Bangladesh. Boro is the dominant rice and cultivated in dry season (December–May) under irrigation. The growth duration of different rice cultivars, generally ranging from 110 to 210 days, is divided into three major phases: vegetative, reproductive and ripening (Mosleh et al., 2015; Reza et al., 2019). The vegetative phase includes seedling and tillering stages, while the reproductive phase includes the activities from panicle initiation to flowering, and the duration this phase is approximately one month. This phase includes stem elongation, panicle extension and flowering. The ripening phase comprises activities from the flowering to full maturity, and the duration of this phase is usually one month.

Binadhan-8 and Binadhan-10 developed by the Bangladesh Institute of Nuclear Agriculture (BINA) and BRRI dhan47, BRRI dhan55 and BRRI dhan61 developed by the Bangladesh Rice Research Institute (BRRI) are the major high yielding variety (HYV) rice cultivars. Each of these cultivars can tolerate salinity to some degrees. These rice cultivars are suitable to cultivate during the dry season. For increasing rice production in the fresh water-scarce coastal saline area of Bangladesh, along with adequate nutrients, soil and water management practices, selection of suitable salt-tolerant rice cultivar(s), and conjunctive use of saline and fresh water are also important. So far, only a few studies (Faisal et al., 2018; Xue and Ren, 2017; Rahman et al., 2020) have focused on the conjunctive use of saline water and fresh water mainly in the production of wheat, maize and sunflower, and to a limited extent on rice cultivation in Bangladesh. To adopt this water management practice for HYV rice cultivation in the dry season, proper information on the sensitivity levels of the potential rice cultivars to different salinity levels of irrigation water imposed at different growth stages are crucial. This study therefore aimed at evaluating the sensitivity of the growth stages of three salt-tolerant HYV rice cultivars (Binadhan-8, Binadhan-10 and BRRI dhan47) and one popular salinity-sensitive HYV rice cultivar (BRRI dhan28) to various degrees of salinity of irrigation water in a controlled experiment in pots.

Materials and Methods

Site characteristics

The experiment was executed at the Field Lysimeter Yard of BINA at Mymensingh in Bangladesh. The site is situated within the Agro-Ecological Zone (AEZ) 9 lying at 24°75' N latitude and 90°50' E longitude. The sub-tropical climate of the site is characterized by high temperature and humidity, and heavy rainfall with occasional gusty winds from April to September and scanty rainfall associated with moderately low temperature during October to March. The monthly average daily weather parameters during the rice-growing period (December 2014 to May 2015), recorded at the experimental site with a BINA-installed weather station, are presented in Table 1.

Table 1. Monthly average daily weather parameters and reference evapotranspiration during the rice-growing period (December 2014 to May 2015)

Month	Maximum temperature (°C)	Minimum temperature (°C)	Average temperature (°C)	Relative humidity (%)	Monthly total rainfall (mm)
December	30.0	10.6	18.0	90.2	5.4
January	28.8	9.6	17.3	87.0	24.0
February	32.1	10.2	21.0	84.8	22.2
March	37.2	11.9	23.3	78.8	7.2
April	37.4	18.5	25.1	84.8	187.6
May	36.8	20.4	27.6	83.7	153.8

Adequate quantity of soil was collected from 0–15 cm profile from the BINA experimental farm for the pot experiment. The soil was air-dried, cleaned of the plant propagules and inert materials, and the clods were broken with a wooden hammer. An approximately homogeneous soil mass was prepared by mixing the soil thoroughly. Three samples were collected from the homogeneous soil mass for determining initial (pre-crop) soil properties. For the experiment, 288 plastic pots (plastic buckets), each with 16 liters capacity and 707 cm^2 surface area, were used for rice cultivation. Each pot was filled with 15 kg air dry soil. Recommended basal dose fertilizer of triple super phosphate (TSP), muriate of potash (MP) and zinc sulphate @ 100, 70 and 3.6 kg ha^{-1}, respectively was applied and mixed thoroughly with the soil in the pots. The major physico-chemical properties of the soil samples were determined (Table 2) following standard laboratory procedures. Soil textures were analyzed by Hydrometer method (Black, 1965) and the textural classes were determined from Marshall's triangular co-ordinate following USDA system. Soil pH was measured by a glass-electrode pH meter from the suspensions of the collected soil samples by maintaining soil to distilled water ratio of 1:2.5. Organic carbon content of the soil was determined by wet oxidation method (Walkley and Black, 1935). The organic matter was oxidized by 1 N potassium dichromate and the amount of organic carbon in the aliquot was determined by titration against 0.5 N ferrous sulphate heptahydrate solutions in presence of 0.025M 0-phenantholine ferrous complex. Organic matter content of the soil was estimated by multiplying the percentage organic carbon content with the Van Bemmelen factor (1.73). Soil bulk density was measured according to core cutter method, and field capacity and wilting point of the soil were determined based on texture following Saxton and Rawls (2006). The soil was loam with pH of 6.75 and organic matter of 1.26%. The average volumetric soil-water contents at field capacity and permanent wilting point were 39.4% and 17.9%, respectively.

Table 2. Components of water usage and total water used by different treatments

Growth stage	Salinity levels	Fresh-water irrigation		Saline-water irrigation		Total quantity of irrigation (cm)	Soil-water contribution (cm)	Total water used (cm)
		No.	Quantity (cm)	No.	Quantity (cm)			
GS_1	SL_1	25	90.56	0	0.00	90.56	2.96	87.60
	SL_2	21	70.75	4	16.98	87.73	2.96	84.77
	SL_3	21	70.75	4	15.57	86.32	2.96	83.36
	SL_4	21	69.34	4	15.57	84.91	2.96	81.95
GS_2	SL_1	25	91.27	0	0.00	91.27	2.96	88.31
	SL_2	19	67.21	6	20.52	87.73	2.96	84.77
	SL_3	19	66.51	6	19.81	86.32	2.96	83.36
	SL_4	19	65.09	6	19.10	84.19	2.96	81.23
GS_3	SL_1	25	91.27	0	0.00	91.27	2.96	88.31
	SL_2	21	76.41	4	12.74	89.15	2.96	86.19
	SL_3	21	76.41	4	12.74	89.15	2.96	86.19
	SL_4	21	75.00	4	11.32	86.32	2.96	83.36
GS_4	SL_1	25	91.27	0	0.00	91.27	2.96	88.31
	SL_2	20	70.04	5	18.40	88.44	2.96	85.48
	SL_3	20	68.63	5	18.40	87.03	2.96	84.07
	SL_4	20	67.92	5	17.69	85.61	2.96	82.65
GS_5	SL_1	25	91.27	0	0.00	91.27	2.96	88.31
	SL_2	20	70.75	5	18.40	89.15	2.96	86.19
	SL_3	20	70.75	5	16.98	87.73	2.96	84.77
	SL_4	20	70.75	5	16.98	87.73	2.96	84.77
GS_6	SL_1	25	91.27	0	0.00	91.27	2.96	88.31
	SL_2	0	0.00	25	84.19	84.19	2.96	81.23
	SL_3	0	0.00	25	75.70	75.70	2.96	72.74
	SL_4	0	0.00	25	64.38	64.38	2.96	61.42

Experimentation

The pot experiment of the study was laid out in a split-split plot arrangement in a completely randomized design (CRD) with three replications. Each replication was set in a block, which was partitioned into six rows and four columns. The rows in the block contained six growth stages (GS) of rice that were treated as the main plots. Each main plot was divided into four sub-plots in which four salinity levels of irrigation water were distributed. Each sub-plot was divided into four sub-sub plots that contained four rice cultivars. Total 288 pots (6 growth stages × 4 salinity levels × 4 cultivars × 3 replications) were used in the experiment. Based on the growing stages of a typical rice crop (Mosleh et al., 2015; Reza et al., 2019), the six growth stages of rice (main factor) were separated by the Day After Transplanting (DAT) of the seedlings as (i) GS_1: transplanting/establishment (1 to 15 DAT), (ii) GS_2:

tillering (16 to 45 DAT), (iii) GS_3: panicle formation (46 to 60 DAT), (iv) GS_4: flowering (61 to 80 DAT), (v) GS_5: maturity (81 to 110 DAT), and (vi) GS_6: total growth period (1 to 110 DAT). The sub-factor was irrigation with four salinity levels of water as (i) SL_1: fresh water (control), (ii) SL_2: 6 dS m^{-1}, (iii) SL_3: 9 dS m^{-1}, and (iv) SL_4: 12 dS m^{-1}. These salinity levels were selected taking into account the salinity classification of Islam and Gregorio (2013) for BRRI dhan47 and BRRI dhan28 (normal: <4 dS m^{-1}, mild salinity: 4–6 dS m^{-1}, and high salinity: 7–12 dS m^{-1}).

Three salt-tolerant HYV rice cultivars: Binadhan-8 (V_1), Binadhan-10 (V_2) and BRRI dhan47 (V_4), and one popular HYV rice cultivar, BRRI dhan28 (V_3), as ‘check/reference’ were tested in the experiment. The seeds of the rice cultivars were washed thoroughly, incubated into water for 24 hours and then packed in gunny bags for 24 hours for sprouting. The sprouted seeds of the rice cultivars were sown in four separate seed beds on 20 December 2014 to raise seedlings. Before transplanting, the soil in each experimental pot was puddled with 5 liters of water with required salinity dose for irrigation water. The rice seedlings at age 37 days were transplanted in the pots on 27 January 2015. Each pot contained one hill of one plant; each hill occupied 707 cm^2 in the pot. After transplanting, 4.5 g urea per pot corresponding to the recommended dose of 272 kg ha^{-1} was top dressed in three equal splits at 11, 32 and 60 DAT. The plants were kept weed-free by manually uprooting the weeds and the leaves of the plants were protected by applying sunfuran insecticides. To maintain proper control on water budget and salinity levels, the experimental pots were protected from rainfall with a transparent plastic sheet erected over an iron frame. The transparent shed did not prevent sunlight significantly from reaching the rice plants.

Groundwater (EC = 0.37 dS m^{-1}) of a Deep Tube Well (DTW) at the BINA farm was used as fresh water (SL_1) for irrigation. Raw wet salt, collected from a salt field of the coastal area (Chattagram), was used to prepare irrigation water with different salinity levels. A total of 4.8, 7.2 and 9.6 g salt, mixed separately in one-liter fresh water, provided 6, 9 and 12 dS m^{-1} salinity, respectively at 25ºC. The ECs of the water samples were measured with an EC meter (EC5061, Germany) at 25°C. Adequate quantity of irrigation water for each salinity level was prepared prior to the irrigation events. Based on WHO (2006), irrigation water of salinity level SL_1 was under non-saline class, SL_2 moderately saline, and SL_3 and SL_4 strong salinity class. Fresh water was applied to the pots that were designated for SL_1. The other pots were irrigated with water of the required salinity levels.

To maintain specific water height and ensure sufficient soil water for normal growth of the rice plants, 0.5 to 2.5 liters of water was applied per pot at each irrigation event (Table 2). The soil-water content at harvest was measured gravimetrically in each pot by collecting soil samples and drying them in oven at 105°C for 24 h. The contribution of soil water to the growth of rice was determined by subtracting the final soil-water content measured at harvest from the initial/pre-crop soil-water content in each pot. At full maturity, the hills of the rice cultivars were harvested pot-wise on 8 May 2015, bundled separately and tagged by maintaining treatment, salinity levels, cultivars and replications. The bundles were sun-dried properly before data recording.

Data collection and analysis

The growth attributes (plant height, total tillers $hill^{-1}$, effective tillers $hill^{-1}$ and panicle length) and yield attributes (1000-grain weight, grain yield $hill^{-1}$, straw yield $hill^{-1}$, root-biomass yield $hill^{-1}$ and harvest index) of the rice cultivars were measured/determined. The water productivity (WP) of rice was determined by dividing grain yield by total water used in each pot. Note that, the experiment was done in pots and each pot contained one hill of rice. The cross-sectional area of the pot (707 cm^2) was larger than the area to be occupied by one hill in the field condition (~500 cm^2 = 25 cm row spacing × 20 cm plant spacing). Also, the aerodynamic conditions surrounding the plants were different for the pots than from the field condition. In order to avoid these effects, the grain and straw yields were expressed as per pot basis instead of per hectare basis; however, for calculating WP, the yield was expressed as per hectare basis. For pot experiments, the yield data are commonly expressed in this way (Rahman et al., 2020) and this did not hamper comparing relative performance of the factors and treatments of the experiment in this study. Also note that since temperature of the above-ground experimental pots along with their contents (soil and plants) is always higher than the nearby field soil and plants, the ET rate in the pots (not measured) might be higher to some extent compared to that expected in the field. The data were analyzed to know significance of the experimental treatments in the variation of the plant attributes. Analysis of variance (ANOVA) was done by using Statistix 10 software package of the Analytical Software (2019). Comparison of means of the plant attributes was done using Tukey’s HSD test at 5% level of significance ($p \leq 0.05$).

Results

The mean plant height of each rice cultivar varied significantly ($p \leq 0.05$) due to the distribution of salt-stress among the six growth stages (Table 3). The shortest plants were obtained when salinity was imposed at GS_6 followed by GS_4, GS_1, GS_3, GS_2 and GS_5. Significantly lower number of total tillers hill^{-1} was obtained when salinity was imposed at GS_6 than imposed at the other growth stages. GS_1 and GS_6 were found most sensitive to salt-stress in exerting adverse effects on the effective tillers hill^{-1}, unfilled grains panicle^{-1}, 1000-grain weight, grain yield hill^{-1}, harvest index (HI) and WP (Table 3). Irrespective of the salinity levels and rice cultivars, GS_3, GS_4 and GS_6 were the most sensitive growth stages to salt-stress and hence the panicle length decreased significantly when salinity was imposed at these growth stages. The highest straw yield hill^{-1} was obtained when salinity was imposed at GS_5 and the lowest straw yield hill^{-1} was obtained when salinity was imposed at GS_6 followed by GS_2 and GS_4. Significantly higher HI was obtained when salinity was imposed at GS_5 than imposed at the other growth stages. These results reveal that GS_1 and GS_6 are the most sensitive growth stages of the rice cultivars and imposition of salinity at these stages through irrigation exerted severe adverse effects on the attributes of the rice cultivars. Irrespective of the rice cultivars and the growth stages at which salinity was imposed, salinity exerted adverse impacts on all the rice attributes. The plant height, total tillers hill^{-1}, effective tillers hill^{-1}, panicle length, unfilled grains hill^{-1}, 1000-grain weight, grain yield hill^{-1}, straw yield hill^{-1}, HI and WP varied significantly with increasing salinity of irrigation water. SL_1 and SL_2 produced similar but significantly lower plant height and panicle length than the other salinity levels (Table 4).

Table 3. Comparison of the growth and yield attributes, yield, harvest index and water productivity (WP) of rice under the combined effects of four salinity levels of irrigation water imposed at six growth stages and the four rice cultivars. GS_1: establishment, 1 to 15 DAT; GS_2: tillering, 16 to 45 DAT; GS_3: panicle formation, 46 to 60 DAT; GS_4: flowering, 61 to 80 DAT; GS_5: maturity, 81 to 110 DAT and GS_6: all growth stages together, 1 to 110 DAT

Growth Stages	Plant height (cm)	Tillers hill^{-1} Total (no)	Tillers hill^{-1} Effective (no)	Panicle length (cm)	Unfilled grains (%)	1000-grain weight (g)	Yield hill^{-1} Grain (g)	Yield hill^{-1} Straw (g)	Harvest index (%)	WP (kg ha^{-1}cm^{-1})
GS_1	94.8cd	32.4a	21.8c	24.7b	33.9b	20.5c	53.4c	50.8b	46.7c	88.5d
GS_2	98.5b	30.0bc	24.7b	25.7a	29.3c	22.7b	68.8b	48.1c	58.6ab	114.7b
GS_3	95.7c	31.1ab	25.2b	24.0c	29.8c	22.5b	67.4b	48.8bc	56.8 b	110.2bc
GS_4	93.3d	29.0c	23.7b	23.5cd	29.6c	22.3b	63.1b	46.9c	55.7b	104.0c
GS_5	107.5a	32.8a	29.9a	26.2a	29.6c	24.5a	83.3a	54.6a	60.3a	136.5a
GS_6	83.1e	23.1d	16.1d	23.2d	38.2a	18.5d	35.5d	31.8d	42.7d	59.8e
$HSD_{0.05}$	1.829	2.084	1.775	0.852	1.368	0.934	5.875	2.226	3.092	9.512

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

Table 4. Comparison of the growth and yield attributes, yield, harvest index and water productivity (WP) of rice under the combined effects of four salinity levels of irrigation water imposed at six growth stages and four rice cultivars. 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}

Salinity level	Plant height (cm)	Tillers hill^{-1} Total (no)	Tillers hill^{-1} Effective (no)	Panicle length (cm)	Unfilled grains (%)	1000-grain weight (g)	Yield hill^{-1} Grain (g)	Yield hill^{-1} Straw (g)	Harvest index (%)	WP (kg ha^{-1}cm^{-1})
SL_1	100.3a	37.1a	31.5a	25.7a	28.0d	25.5a	91.7a	60.1a	60.4a	147.1a
SL_2	99.9a	32.0b	25.8b	25.3a	30.2c	22.1b	66.8b	50.2b	56.4b	112.8b
SL_3	94.6b	27.0c	20.4c	24.1b	32.0b	20.3c	50.9c	42.3c	51.8c	84.7c
SL_4	87.2c	22.9d	16.6d	23.2c	36.9a	19.3d	38.2d	34.8d	45.3d	64.6d
$HSD_{0.05}$	1.387	1.333	1.212	0.474	1.217	0.513	3.515	2.064	1.426	5.409

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

Under the combined effects of the four salinity levels and six growth stages, the mean plant height varied significantly among the rice cultivars. Also under this interaction, V_2 provided the most improved rice attributes except HI, which was obtained in V_4; V_3 provided the poorest rice attributes except the total tillers hill^{-1} and unfilled grains panicle^{-1}, which were obtained in V_4 (Table 5). V_1 and V_4 produced statistically similar attributes except plant height and straw yield. V_2 produced significantly larger number of effective tillers hill^{-1} than the other cultivars.

The effect of the high salinity levels (SL_3 and SL_4) on plant height was significantly lower when applied at GS_2, GS_3 and GS_5 compared to when applied at GS_1 and GS_4. So, the four rice cultivars produced taller plants when salinity was imposed at GS_2, GS_3 and GS_5 compared to when imposed at the other growth stages. With the imposition of salinity through irrigation, GS_5

produced the highest number of total and effective tillers hill^{-1} followed by GS_3, thus revealing that these two growth stages are more tolerant to salinity than the other growth stages. Both the total tillers hill^{-1} and effective tillers hill^{-1} significantly improved for the rice cultivars when salinity was imposed at GS_5. V_3 produced the highest number of effective tillers hill^{-1} and lowest number of effective tillers hill^{-1} when salinity was imposed at GS_5 and GS_6, respectively. Under the combined effects of the irrigation water salinity and the rice cultivars, V_3 produced the highest number of effective tillers hill^{-1} under SL_1, while V_2 produced such effective tillers hill^{-1} under SL_2, SL_3 and SL_4. Longer panicles were obtained when salinity was imposed at GS_2, GS_3 and GS_5 compared to when salinity was imposes at the other growth stages. Imposition of SL_4 at GS_1 and GS_6 resulted in the higher percentages of unfilled grains panicle^{-1} than imposition of this salinity at the other growth stages. Salinity-stressed GS_6 significantly raised the percentage of unfilled grains panicle^{-1} compared to the salinity-stressed other growth stages irrespective of the imposed salinity levels. Significantly heavier 1000-grain was obtained when salinity was imposed at GS_2, GS_3 and GS_5 than imposed at the other growth stages. The harmful effects of high salinity decreased when the salinity was imposed at GS_2, GS_3 and GS_5 with a consequent improvement in the grain yield compared to GS_1, GS_4 and GS_6 with the same salinity levels. The highest grain yields hill^{-1} were obtained when fresh water was applied at GS_4 and GS_5, and the lowest grain yields hill^{-1} were obtained when SL_4 was imposed at GS_6. The rice cultivars produced better grain yield hill^{-1} when salinity was imposed at GS_5 than imposed at the other growth stages. The detrimental effects of salinity on the vegetative growth of rice plants decreased when saline water was applied at GS_2, GS_3 and GS_5. V_2 produced the highest straw yield hill^{-1} when salinity was imposed at GS_5 and V_3 produced the lowest straw yield hill^{-1} when salinity was imposed at GS_6. V_3 produced the lowest HI when salinity was imposed at GS_1 and GS_6, indicating that this rice cultivar has less potential to tolerate saline-water irrigation. The rice cultivars provided significantly higher WP when salinity was imposed at GS_5 than imposed at the other growth stages.

Table 5. Comparison of the growth and yield attributes, yield, harvest index and water productivity (WP) of four rice cultivars under four salinity levels of irrigation water imposed at six growth stages of the rice cultivars. V_1: Binadhan-8, V_2: Binadhan-10, V_3: BRRI dhan28 an d V_4: BRRI dhan47

Cultivars	Plant height (cm)	Tillers hill^{-1} Total (no.)	Tillers hill^{-1} Effective (no.)	Panicle length (cm)	Unfilled grains (%)	1000-grain weight (g)	Yield hill^{-1} Grain (g)	Yield hill^{-1} Straw (g)	Harvest index (%)	WP (kg ha^{-1} cm^{-1})
V_1	94.7c	29.3a	23.4b	24.9b	32.1a	22.2b	62.0b	46.4b	54.7a	102.7b
V_2	102.3a	30.5a	25.2a	25.9a	30.3b	22.8a	68.7a	53.0a	54.5a	113.9a
V_3	88.4d	30.0a	22.4b	22.5c	32.1a	19.7c	55.7c	43.7c	49.9b	91.4c
V_4	96.7b	29.2a	23.3b	25.0b	32.5a	22.6ab	61.2b	44.3c	54.8a	101.3b
$HSD_{0.05}$	1.188	1.498	1.346	0.492	1.076	0.506	2.998	2.064	1.5	4.987

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

Discussion

Sensitivity of the rice attributes to salinity

The salinity of irrigation water noticeably reduced the growth and yield attributes (plant height, effective tillers hill^{-1}, panicle length, grains hill^{-1}, 1000-grain weight) and yield of the rice cultivars. The gradual decrease in plant height with increasing salinity (Table 3) was due to the inhibition of cell division or cell enlargement or a combination of both under salt-stress (Rahman et al., 2016). The suppressing effect of salinity on tillering increased with the increasing salinity level of irrigation water (Table 4). This is because the salinity-stress reduced production of assimilate and cell division of the meristematic tissue (Linghe et al., 2000; Hussain et al., 2017) that consequently reduced the number of tillers as well as panicle length. The decrease in the effective tillers hill^{-1} due to salt-stress was lesser in V_1, V_2 and V_4 than in V_3. GS_2, GS_3 and GS_5 with the imposition of high salt-stress (SL_3 and SL_4) produced significantly higher 1000-grain weight compared to GS_1, GS_4 and GS_6 with the same salt-stress. The production and translocation of lower quantity of assimilate from the leaves to the grains under salt-stress imposed at GS_1, GS_4 and GS_6 might have reduced the 1000-grain weight. Genotypic variation in the rice cultivars also caused variation in 1000-grain weight and yield (Jabeen et al., 2018; Khatri et al., 2019; Shrestha et al., 2021; Singh et al., 2020). V_3 was less tolerant to salinity than the other three cultivars at the development stage in relation to 1000-grain weight.

Our study implies that salt-stress exerted profound negative effects on the reproductive attributes of rice. It reduced the number of tillers and grain-bearing panicles, leading to the low grain yields of rice. The adverse effects of salinity on these attributes of rice eventually translated into larger reductions in the grain yield hill^{-1} at any given salinity of irrigation water. Our results reveal that saline water applied at GS_2, GS_3 and GS_5 minimized the harmful effects of salt-stress and consequently improved the grain yield under high salinity compared to the imposition of such salinity at GS_6, GS_1 and GS_4. The salt-stress at the vegetative and reproductive phases of rice caused toxic ion accumulation in the plant cells (Aguilar et al., 2017), produced less assimilate (Islam et al., 2004), and eventually suppressed the yield attributes and grain yield. Irrespective of distribution of the salinity levels over the six growth stages of rice, V_3 exhibited less salt-tolerant ability by providing significantly lower grain and straw yields than the other cultivars; it, however, performed better under fresh-water irrigation. The reduction in straw yield due to salt-stress is generally translated in terms of the reduced leaf area and stunted shoots (Aref, 2013) that was clearly visualized in this study. The HI of rice significantly differed among the four rice cultivars and as well as among SL_3 and SL_4 salinity levels imposed at different growth stages. Note that a large HI does not necessarily contributed to the high yield (Yan et al., 2021), which is generally determined by the physiological processes that lead to a high net accumulation of photosynthates and its partitioning into the plant and seeds.

Under saline condition, accumulation of toxic ions in the plant cells reduced grain yield of rice (Qadir et al., 2002) that consequently reduced WP. Since the establishment and flowering stages of the rice cultivars are most sensitive to salt-stress, WP decreased when these stages were irrigated with saline water. The salt-tolerant rice cultivars (V_1, V_2 and V_4) accumulated less Na^+ and more K^+ than the susceptible cultivar (V_3) (Khan et al., 1997). However, the increasing salinity level enhanced Na^+ accumulation with the associated depletion in the accumulation of K^+. As a result, WP decreased with the increasing level of irrigation-water salinity.

Growth-stage sensitivity of rice to salinity

Irrigation with saline water during the vegetative phase of rice affects the yield attributes, spikelet sterility and grain yield in a similar way to the application of saline water during the reproductive phase (Aguilar et al., 2017). So, the salt-stress exerted lower suppressing effect on the rice attributes when imposed at GS_2, GS_3 and GS_5 compared to when imposed at the other growth stages (Table 3). GS_1 and GS_4 were the most salinity-sensitive growth stages of the rice cultivars. These results are mostly in agreement with those of Salam et al. (2011), who found rice crop as tolerant during germination, very sensitive during early seedling stage, tolerant during vegetative stage, sensitive during pollination and fertilization, and then increasingly tolerant at maturity. The high salinity caused sterility of the panicles with a larger reduction in filled grains in the panicles of V_3 compared to the other cultivars. It reduced the number of tillers and grain-bearing panicles in V_3, leading to the lower grain yields. Compared to the other cultivars, V_3, however, performed better in producing the grain and straw yields with fresh water irrigation. The improved WP obtained with high salt-stress imposed at GS_2, GS_3 and GS_5 also reveals that the establishment and flowering stages of the rice cultivars are the most salinity-sensitive growth stages.

Conclusion

Salinity, imposed through irrigation application, exerted lesser suppressing effect on Binadhan-8, Binadhan-10, BRRI dhan28 and BRRI dhan47 rice cultivars when imposed at the tillering (GS_2), panicle formation (GS_3) and maturity (GS_5) stages than imposed at the establishment (GS_1), flowering (GS_4) and all growth stages (GS_6). The suppressing effect of salt-stress on the growth and yield attributes increased with the increasing level of salinity. The establishment (transplanting) and flowering stages being the most sensitive to salt-stress require fresh water for satisfactory production of the rice cultivars. These results, based on one year's experiment that was executed under properly controlled growth environment, are expected to be fairly accurate. The differential sensitivity of the rice crop to salinity during the growth stages is a major concern in the management of saline water for irrigation. This concern could be effectively addressed when the growth stages of rice are well-defined in relation to the sensitivity of salt-stress and the stress is quantified growth-stage-wise. Thus, the results of this study would help managing rice cultivation in the salt-affected areas having scarcity of fresh water for irrigation.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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