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Growth stage sensitivity of wheat to irrigation water salinity

M. A. Mojid*, M. S. Mia[1], A. K. Saha and S. S. Tabriz
Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh–2202, Bangladesh and [1]Department of Irrigation and Water Management, Sylhet Agricultural University, Sylhet-2100, E-mail: ma_mojid@yahoo.com

Abstract

The effects of irrigation water salinity (12 dS m^{-1}), imposed at maximum tillering (35–40 days after sowing, DAS) or booting (50–60 DAS) or grain filling (75–85 DAS) stage of wheat, on growth and yield of the crop was demonstrated. The experiment comprised four treatments – I_1: irrigation by fresh water (FW) at all three growth stages (control), I_2: irrigation by saline water (SW) at maximum tillering stage and by FW at other stages, I_3: irrigation by SW at booting stage and by FW at other stages, and I_4: irrigation by SW at grain filling stage and by FW at other stages. The experiment was set in a randomized complete block with three replications. Wheat was grown under three irrigations (each of 3 cm) and recommended fertilizer doses (120 kg N, 32 kg P, 62 kg K, 20 kg S, 3 kg Zn and 1 kg B ha^{-1}). Salinity of irrigation water imposed, separately, at the three growth stages did not impart significant ($p = 0.05$) negative influence on plant height, spike density, spike length, spikelets and grains per spike and 1000-grain weight. It, however, significantly hindered leaf area index (LAI), above ground dry matter (ADM), grain and straw yields, grain-straw ratio and water productivity of the crop. The least grain (3.622 t ha^{-1}) and straw (5.772 t ha^{-1}) yields, LAI (1.24 and 2.18 at 50 and 70 DAS, respectively), ADM (0.80, 4.78 and 7.66 t ha^{-1}) and water productivity (186.5 and 297.3 kg ha^{-1} cm^{-1}) obtained under I_3 implied that salinity of irrigation water imposed at booting stage exerted the maximum retarding effects on the growth and yield of wheat. Grain yield decreased by 13.4% in I_3 over the control, I_1. An increase in grain and biomass yields by 14.3 and 11.9%, respectively under I_2 over I_1 demonstrated a positive contribution of irrigation water salinity imposed at maximum tillering stage of wheat.

Keywords: Wheat, Growth stage, Irrigation, Salinity

Introduction

Limited supplies of fresh water are now increasingly in demand for competing uses and creating the need to use marginal quality water in agriculture (Hamdy, 1995), which is the largest user of water accounting for 80% of all consumption. Conservation of the fresh water is an answer to the problem of water scarcity and, certainly, the technology of saline water use is an important component in the conservation strategies. Consequently, the use of saline water in irrigation is a subject of increasing interest. But, soil salinization due to such irrigation is a plague of intensive agriculture (Prajith *et al.,* 2000) since high concentrations of salts exert detrimental effects on plant growth (Pandey and Thakrar, 1997). Soil salinity hinders crop growth and reduces the yield depending on its degree at the critical growth stages. The cropping intensity in the saline area is usually small (e.g., 62–114% in the coastal area of Bangladesh against the national average of 179%; BBS, 2009). So, the use of saline water needs to be controlled in an appropriate level for the specific crops. Many different approaches and practices; depending upon economic, climatic, social as well as edaphic and hydrogeologic situations (Rhoades *et al*., 1992); may need to combine to develop satisfactory systems for irrigation by saline water. One of the ways to grow crops successfully by using saline water is to identify the salt tolerant crop varieties or their salt sensitive stage(s) and to improve the crop yield through management practices like irrigating the crops at the salt sensitive stage(s) by fresh water and at the other stages by saline water, up to the tolerant limit. The use of saline water in irrigation therefore requires careful planning, more complex management practices and stringent monitoring procedures than when good quality water is used (Hamdy, 1996).

The effects of salinity and water stress are, generally, additives in their impacts on the evapotranspiration of crops (Shalhevet, 1994). Salinity induces water deficit by reducing osmotic potential of soil solutes, thus making it difficult for the crop roots to extract water from the soil (Allen *et al*., 1998; Sairam *et al*., 2002; Heidarpour *et al*., 2009). Many plants are however able, by building up higher internal solute contents, to partially compensate for low osmotic potential of the soil water under saline conditions (Allen *et al*., 1998). The inherent ability of the crops to withstand the effects of an elevated salt concentration within their root zone solutions and still produce a reasonable quantity of yield define the magnitude of the

crop tolerance or resistance to salinity (Steppuhn *et al*., 2005). The success of using saline water for economically viable crop production can be achieved by reducing the negative effects of salinity on crop productivity by following the best management practices (Flowers *et al*., 2005).

Wheat, as an important cereal crop, ranks first in acreage as well as production among the crops of the world. Salinity exerts negative influences on its production and reduces the yield (Aldesuquy and Ibrahim, 2002; Parida & Das, 2004; Ghane *et al*., 2011). There are also significant interactions between salinity and wheat cultivars (Zaire & Khuble, 1990). So, knowing the tolerance limits and sensitive stage(s) of different wheat varieties to salinity, potential varieties of the crop can be grown under irrigation by saline water. This study focused on the effects of irrigation water salinity, imposed, separately, at different growth stages, on cultivation of a locally developed wheat variety and identification of its salt sensitive stage(s).

Materials and Methods

Site characteristics

The experiment was conducted during November 2010 to March 2011 in the experimental farm of Bangladesh Agricultural University, Mymensingh, Bangladesh. The site is situated at 24.75^{o}N latitude and 90.50^{o}E longitude. Silt loam underlain by sandy loam in the field belongs to the Old Brahmaputra floodplain (BARC, 2005). Organic matter, field capacity, permanent wilting point and bulk density of the top soil (0 – 20 cm) were 0.48%, 38.19% (v v^{-1}), 18.37% (v v^{-1}) and 1.33 g cm^{-3}, respectively. Pre-sowing soil pH was 7.9, 8.0 and 8.2 for 0–20, 20–40 and 40–60 cm soil layer, respectively. The electrical conductivity (EC) of saturation extract (soil: water = 1: 2.5) of the corresponding soil layer was 0.18, 0.12 and 0.08 dS m^{-1}. The mean maximum and minimum air temperature varied from 22.2 to 30.0^{o}C and 10.7 to 20.0^{o}C, respectively. The mean relative humidity, pan evaporation and sunshine varied over 74–86%, 1.9–3.9 mm and 4.3–8.4 h, respectively. A 53-mm rainfall (41 mm in December and 12 mm in February) during the period of experiment provided 5.02 cm effective rainfall.

Treatments and experimental design

The experiment consisted of a single factor, irrigation water salinity, which was expressed by electrical conductivity of the water (12 dS m^{-1}). The treatments were – I_1: irrigation by fresh water (FW) at maximum tillering, booting and grain filling stages (control), I_2: irrigation by saline water (SW) at maximum tillering stage and by FW at other two stages, I_3: irrigation by SW at booting stage and by FW at other two stages, and I_4: irrigation by SW at grain filling stage and by FW at other two stages. The experiment was laid out in a Randomized Complete Block with three replications. The plot size was 3 m $\times$ 2 m, buffer space between adjacent plots was 1 m and that between adjacent replications was 0.5 m. Recommended (BARC, 2005) fertilizer dose for wheat (120 kg N, 32 kg P, 62 kg K, 20 kg S, 3 kg Zn and 1 kg B ha^{-1} in the form of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and borax, respectively) was used. Two-thirds of urea and the entire doses of the other fertilizers were applied to the plots as a basal dose. The remaining urea was top-dressed at 20 DAS. Wheat seeds (cv. *Shatabdi*), @ 120 kg ha^{-1}, were sown at 2–3 cm depth in 20-cm apart rows on 23 November 2010. Weeds were uprooted at 33 and 58 DAS. Bavistine and Ridomil Gold were sprayed to the crop to control prevalence of insect pests. Soil samples were collected in 5 cm $\times$ 5 cm soil cores from five representative spots in the field before setting up experiment. The samples were collected at the middle of 20 cm depth increments up to 60 cm to know the initial soil properties. The depth-average soil-water content of the field was 0.35 (v v^{-1}) at sowing.

Irrigation was scheduled at maximum tillering (35–40 DAS), booting (50–60 DAS) and grain filling (75–85 DAS) stages. It is noted that one irrigation was planned at the critical root initiation (CRI) stage (20–25 DAS) but could not be applied due to 41 mm rainfall at 14–15 DAS. The quantity of water for irrigation was calculated by the difference in soil-water contents at field capacity and prior to application of irrigation for an effective root zone depth of 60 cm. The water content at field capacity was measured, in situ, before the first irrigation through controlled ponding and subsequent drainage in three plots. The soil-water contents were measured with a Trime FM soil moisture meter (Eijkelkamp, The Netherlands). Saline water was prepared for irrigation by mixing sodium chloride (table salt) @ 8.8 g L^{-1} with fresh water (from a deep tubewell) to obtain an EC of 12 dS m^{-1} at 25^{o}C. Same amount of water (3 cm) was applied to each plot in all irrigations in check basins. Three irrigations (at 40, 60 and 80 DAS), totaling 9 cm of water, were applied cautiously so that the saline water did not adhere to the leaves of the crop.

Leaf area index, LAI, and above-ground dry matter, ADM, in different plant parts of wheat were determined at booting (50 DAS), flowering (70 DAS) and grain filling (90 DAS) stages. The area of leaf was measured with an LI-3100 AREA METER (LI-Cor. Inc. Lincoln, Nebraska, USA). Yield and yield attributes were recorded. At harvest, soil samples were collected from three plots as before to determine soil-water content, the average of which was 0.26 (v v^{-1}). A combined analysis of variance of the growth and yield attributes, grain, straw and biomass (defined by the summation of the grain and straw yields) yields, and harvest index (HI) of wheat was done for the RCBD by using MSTAT-C (Russel & Eisensmith, 1983).

Results and Discussion

Growth and yield attributes

Leaf area index, LAI, at 50, 70 and 90 DAS responded significantly ($p = 0.05$) to the salinity of irrigation water for all treatments (Table 1). Treatment I_2 (SW irrigation at maximum tillering stage) always produced the highest LAI and I_4 (SW irrigation at grain filling stage) produced the lowest LAI except for 50 DAS in which case I_1 produced the lowest LAI. At 50 DAS, an increase in LAI of 20.0, 12.7 and 0.9% was obtained under I_2, I_3 and I_4, respectively compared to the control. Due to retarded leaf development, the LAI decreased at 70 DAS by 6.0 and 12.4% under I_3 and I_4, respectively and increased by 7.7% under I_2 compared to I_1. At 90 DAS, the LAI decreased by 15.3 and 3.4% in I_3 and I_4, respectively and increased by 18.9% in I_2 compared to I_1. Maas and Poss (1989) also obtained a retarded leaf development of wheat due to reduction of cell division and enlargement in leaves in response to increased salinity of irrigation water (Allen *et al*., 1998). An attention-grabbing observation was that the salinity of irrigation water, imposed at maximum tillering stage, significantly augmented LAI with respect to a similar irrigation at the other growth stages of wheat. Salinity of irrigation water imposed, separately, at the three growth stages did not however exert significant influence on plant height (Table 1), spike density, spike length, spikelets and grains per spike and 1000-grain weight (Table 2) of the crop. First irrigation was applied at maximum tillering stage and hence it played only a limited positive role in tillering of wheat. Consequently, spike density (number of spike per unit area) improved insignificantly.

Table 1. Growth attributes of wheat under four irrigation treatments

Treatment	Plant height (cm)	Leaf area index (LAI)		
		50 DAS	70 DAS	90 DAS
I_1	82.24^{a}	1.10^{a}	2.34^{a}	1.10^{a}
I_2	84.64^{a}	1.32^{b}	2.52^{b}	1.32^{b}
I_3	84.13^{a}	1.24^{c}	2.18^{c}	0.93^{c}
I_4	85.52^{a}	1.11^{d}	1.89^{d}	0.96^{d}
$LSD_{0.05}$	5.69	0.01	0.03	0.02

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

Above ground dry matter, ADM, of wheat responded significantly (Table 2) to the salinity of irrigation water imposed separately at different growth stages. Treatment I_2 helped producing the highest ADMs (1.07 and 5.18 t ha^{-1}) at 50 and 70 DAS. The lowest ADM was obtained under I_3 (0.80 t ha^{-1}) at 50 DAS and under I_4 (4.11 t ha^{-1}) at 70 DAS. I_1 helped producing the highest ADM (9.75 t ha^{-1}) at 90 DAS while I_4 caused the lowest ADM (7.45 t ha^{-1}) at that growth stage. The ADM increased by 32.1 and 6.2% under I_2 and I_4, respectively and decreased by 1.2% under I_3 compared to I_1 at 50 DAS. Treatments I_1 and I_3 were statistically alike in terms of their role in ADM production. At 70 DAS, ADM decreased by 0.8 and 14.7% under I_3 and I_4, respectively and increased by 7.5% under I_2 compared to the control. At 90 DAS, ADM decreased by 15.8, 21.4 and 23.6% under $I_{2,}$ I_3 and I_4, respectively compared to I_1. These results are in agreement with those of Chartzoulakis and Klapaki (2000) who found that salt stress considerably reduced the fresh and dry weights of leaves, stems, tillers, fertile tillers and roots. A reduced ADM in response to a reduced shoot growth due to inhibitory effect of salt on cell division and enlargement at the growing stages was also reported by (Mccue & Hanson, 1990).

Table 2. Yield attributes of wheat under four irrigation treatments

Treatment	No. of spikes m^{-2}	Spike length (cm)	No. of spikelets $spike^{-1}$	No. of grains $spike^{-1}$	Weight of 1000 grains (g)	Above ground dry matter (ADM) (t ha^{-1})		
						50 DAS	70 DAS	90 DAS
I_1	206.7^{a}	8.93^{a}	21.86^{a}	38.42^{a}	51.69^{a}	0.81^{a}	4.82^{a}	9.75^{a}
I_2	231.0^{ab}	8.77^{a}	21.81^{a}	39.06^{a}	54.74^{a}	1.07^{b}	5.18^{b}	8.21^{b}
I_3	215.0^{abc}	8.81^{a}	21.74^{a}	33.59^{a}	54.75^{a}	0.80^{a}	4.78^{c}	7.66^{c}
I_4	180.7^{ac}	9.15^{a}	22.23^{a}	34.75^{a}	56.42^{a}	0.86^{c}	4.11^{d}	7.45^{d}
$LSD_{0.05}$	37.7	1.89	1.00	8.14	6.60	0.02	0.04	0.06

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

Yields

Irrigation water salinity, imposed at maximum tillering stage, exerted a significant positive influence and that imposed at booting stage exerted a significant negative influence on the grain yield of wheat compared to the control (Table 3). Treatments I_1 and I_4 played a statistically indifferent role in grain production, while I_2 contributed producing the highest (4.78 t ha^{-1}) grain yield and I_3 caused the lowest (3.62 t ha) yield. The grain yield increased by 14.3 and 0.5% under I_2 and I_4, respectively and decreased by 2.1% under I_3 compared to the control. So, grain yield was the most sensitive to salinity of irrigation water when imposed at booting stage. In contrast, salinity, when imposed at maximum tillering stage, improved grain yields with respect to a similar irrigation at other growth stages. Straw yields differed significantly under all treatments. The highest straw yield (7.07 t ha^{-1}) was obtained under I_2 and the lowest (5.77 t ha^{-1}) was under I_3. The straw yield decreased by 16.5 and 11.2% under I_3 and I_4, respectively and increased by 2.2% under I_2 compared to I_1. So, straw yield was the most sensitive to irrigation water salinity when imposed at booting stage, while salinity at maximum tillering stage produced the highest straw yield. Grain-straw ratio increased by 11.9, 3.8 and 13.2% under I_2, I_3 and I_4, respectively compared to the control. Salinity of irrigation water affected biomass yield of wheat (Table 3) in the similar fashion it affected the grain yield. An increase in harvest index (a ratio of grain to biomass yields) by 7.1, 2.3 and 5.5% under I_2, I_3 and I_4, respectively compared to I_1 implied that the degree negative impact of salinity was more in straw that in grain production.

Table 3. Yield, harvest index (HI) and water productivity (WP) of wheat under four irrigation treatments

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biomass yield (t ha^{-1})	HI	WP (grain) (kg ha^{-1} cm^{-1})	WP (biomass) (kg ha^{-1} cm^{-1})
I_1	4.184^{a}	6.914^{a}	11.098^{a}	0.6057^{a}	215.5^{a}	356.1^{a}
I_2	4.784^{b}	7.066^{b}	11.850^{b}	0.677^{b}	246.4^{b}	363.9^{b}
I_3	3.622^{c}	5.772^{c}	9.394^{c}	0.628^{a}	186.5^{c}	297.3^{c}

I_4	4.207^{a}	6.140^{d}	10.347^{d}	0.685^{b}	216.7^{a}	316.2^{d}
$LSD_{0.05}$	0.241	0.094	0.250	0.039	12.4	4.8

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

Water productivity

Salinity of irrigation water, imposed at booting and grain filling stages of wheat, significantly reduced water productivity for grain and biomass production (Table 3). When imposed at maximum tillering stage, salinity helped providing the highest water productivity of 246.4 kg ha^{-1} cm^{-1} for grain and 363.9 kg ha^{-1} cm^{-1} for biomass production. Water productivity in I_2 was significantly larger than other treatments. The lowest water productivity of 186.5 kg ha^{-1}cm^{-1} for grain and 297.3 kg ha^{-1}cm^{-1} for biomass production was obtained when salinity was imposed at the booting stage. The water productivity for grain production increased by 14.3 and 0.6% under I_2 and I_4, respectively and decreased by 13.5% under I_3 compared to the control. For biomass production, it decreased by 16.5 and 11.2% under I_3 and I_4, respectively and increased by 2.2% under I_2 compared to I_1. The highest water productivity obtained under I_2 revealed a positive impact of salinity, imposed at maximum tillering stage, on grain production and the lowest water productivity under I_3 revealed the utmost negative impact of salinity, imposed at the booting stage, on grain production.

Conclusion

Booting stage was the most sensitive growth stage of wheat variety ‘Shatabdi’ at irrigation water salinity level of 12 dS m^{-1} followed by grain filling stage. Grain yield reduced by 13.4% when salinity was imposed at booting stage. Maximum tillering stage was the most salt-tolerant and salt-loving stage of this wheat variety. Irrigation water salinity at this stage improved plant height, leaf area index, spike density, grains per spike, above ground dry matter (at 50 and 70 DAS), grain and straw yields and water productivity of wheat over the control treatment. The sequence of salt tolerant stage was: maximum tillering> grain filling> booting stage. The observed responses of the three growth stages of the wheat variety to salinity have important practical implications for its cultivation in areas having limited fresh water but ample saline water (e.g., the coastal area of Bangladesh). Wheat can be irrigated with saline water during maximum tillering and grain filling stages. Booting stage needs to be irrigated with salinity levels at or below the salt tolerance threshold of the crop.

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