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An advantageous level of irrigation water salinity for wheat cultivation

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Abstract

Response of wheat (*Triticum aestivum L.*, cv. Shatabdi) to irrigation water of five salinity levels was investigated at the Bangladesh Agricultural University (BAU) farm with a view to search for a possible advantageous salinity level for the crop. The experiment comprised five treatments – I_1: irrigation by fresh water of background salinity 0.385 dS m^{-1} (control) and I_2 – I_5: irrigation by synthetic saline water (prepared by mixing sodium chloride salt with fresh water) of electrical conductivity (EC) 4, 7, 10 and 13 dS m^{-1} (at 25°C), respectively. Wheat was grown under three irrigations applied at maximum tillering, booting and milking/grain filling stages, and with recommended fertilizer dose. Irrigation water of EC ≥10 dS m^{-1} significantly ($p = 0.05$) suppressed most growth and yield attributes, and yield of wheat compared to irrigation by fresh water (I_1). An attention-grabbing observation was that irrigation by saline water of 4 dS m^{-1} (I_2) contributed positively to the crop attributes. Leaf area index (LAI), spike length, spikelets and grains per spike, 1000-grain weight and above ground dry matter (ADM) of wheat increased by 1.9–3.4, 0.9, 2.6, 7.4, 2.1 and 2.8–6.0%, respectively in I_2 compared to the control. The improvement in the LAI and ADM in I_2 was significant over I_1. Because of the largest spike density, the utmost grain (3.85 t ha^{-1}), straw (5.09 t ha^{-1}) and biomass (8.93 t ha^{-1}) yields of wheat were however obtained under I_1. The proposition of the advantageous irrigation water salinity level of 4 dS m^{-1} thus warrants further investigation.

Keywords: Irrigation water, Salinity level, Wheat yield

Introduction

Limited supplies of fresh water are now increasingly in demand for competing uses and creating the need to use marginal quality water, especially in agriculture (Hamdy, 1995; Mojid *et al*., 2012). Use of saline water for irrigation has the advantages of reducing fresh water requirement for salt-tolerant crops. But, salinity affects crops depending on its degree at critical growth stages and reduces the yield. So, irrigation by saline water needs to be controlled in an appropriate level for the specific crops. There is, however, no any single way to achieve the safe use of saline water in irrigation. Many different approaches and practices may need to be combined to develop satisfactory systems for saline water irrigation. An appropriate combination depends upon economic, climatic, social as well as edaphic and hydrogeologic situations (Rhoades *et al*., 1992). In general, crops tolerate salinity up to a threshold level, above which yields of the crops decrease, approximately linearly, as the salt concentration increases. Therefore, crop response to salinity levels is an important factor for irrigation by saline water. The use of marginal quality waters in irrigation requires careful planning, more complex management practices and stringent monitoring procedures than when good quality water is used (Hamdy, 1996; Rahman *et al*., 1995).

The effects of salinity and water stress are, generally, additives in their impacts on evapotranspiration of crops (Shalhevet, 1994). Salts in soil water reduce evapotranspiration by making the soil water less available for extraction by plant roots (Allen *et al*., 1998; Heidarpour *et al*., 2009). Salinity reduces plant growth by suppressing the rate of leaf elongation due to reduction of cell division and enlargement in leaves (Allen *et al*., 1998). Many plants are however able, by building up higher internal solute contents, to partially compensate for low osmotic potential of soil water under saline conditions (Allen *et al*., 1998). The inherent ability of the crops to withstand the effects of elevated salt concentration within their root zone solutions and still produce a reasonable quantity of agricultural product defines the magnitude of the crop tolerance or resistance to salinity (Steppuhn *et al*., 2005). Crops vary in their relative salt tolerance ability, and hence knowing their salt-tolerant limits and soil salinity levels, potential crops can be grown in saline area. 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). For example, selection of the crops for their tolerance is an important aspect for the management of saline soils (Gupta and Gupta, 1987).

Wheat is an important cereal crop that ranks first in acreage as well as production among the crops of the world (UNDP and FAO, 1988). Salinity exerts negative influences on wheat with an ultimate reduction in yield (Aldesuquy and Ibrahim, 2002; Ghane *et al*., 2011). In addition to yield reduction, Zaire and Khuble (1990) reported significant interactions between salinity and wheat cultivars. Yet, wheat may be grown effectively under irrigation by saline water if an optimum tolerable salinity for its cultivation can be established (Ghane *et al*., 2011). It is therefore important to identify the salt-tolerant level of wheat and its yield variation with salinity of irrigation water. This study investigated the effects of irrigation water salinity on growth and yield attributes, and yield of wheat with a view to search for an advantageous salinity level for the crop.

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°N latitude and 90.50°E longitude. Silt loam underlain by sandy loam in the field belongs to the Old Brahmaputra floodplain (BARC, 2005). Organic matter content, field capacity, permanent wilting point and bulk density of the top soil were 0.48%, 38.19% (v/v), 18.37% (v/v) 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. 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}. Mean maximum and minimum air temperature at the site varied from 22.2 to 30.0°C and 10.7 to 20.0°C, respectively. 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 during the period of experiment (41 mm in December and 12 mm in February) provided an effective rainfall of 5.02 cm.

Treatments and experimental design

The experiment consisted of a single factor, irrigation water salinity. The treatments were I_1: irrigation by fresh water with a background EC of 0.385 dS m^{-1} (control) and $I_2 - I_5$: irrigation by saline water of EC 4, 7, 10 and 13 dS m^{-1}, respectively. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The plot size was 3 m × 2 m, buffer space between the adjacent plots was 1 m and that between the adjacent replications was 0.5 m. Recommended 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; BARC, 2005) was used. Two-thirds of urea and the entire doses of other fertilizers were applied to the plots as a basal dose. The remaining urea was top-dressed at 20 days after sowing (DAS). Wheat seeds (cv. *Shatabdi*), @ 120 kg ha^{-1}) were sown at 2–3 cm depth in 20-cm apart rows on 24 November 2010. Weeds were uprooted when required. Prevalence of insect pests was controlled by spraying Bavistine and Ridomil Gold.

Irrigation was scheduled on the basis of growth stages of wheat: maximum tillering (35–40 DAS), booting (50–60 DAS) and milking/grain filling (75–85 DAS). Quantity of irrigation water was calculated by the difference in soil-water content at field capacity and that measured prior to application of irrigation for an effective root zone depth of 60 cm. The field capacity of the soil was measured in situ before the first irrigation. The soil-water contents were measured with a Trime FM soil moisture meter (Eijkelkamp, The Netherlands). Saline water (for irrigation) was prepared by mixing sodium chloride (table salt) (@ 2.85, 5.08, 7.31 and 9.55 g salt per liter water) with fresh water that was pumped from a deep tubewell to obtain 4, 7, 10 and 13 dS m^{-1} salinity (at 25°C), respectively. Same amount of water was applied to each plot in a particular irrigation in check basins. Three irrigations, totaling 9 cm of water, were applied cautiously so that saline water did not adhere to the leaves of the crop. Leaf area index (LAI) and above-ground dry matter (ADM) of wheat was determined twice: at booting (49 DAS) and grain filling (90 DAS) stages. In order to measure the LAI and ADM of wheat, ten randomly selected plants from the buffer portion (area surrounding one square meter central portion) of each plot were clipped at the ground level on 49 and 90 DAS. The leaf blades were separated from the sheath at the collar and their areas were measured with a LI-3100 Leaf-Area Meter (LI-COR Biosciences, USA). The LAI for each plot was calculated by the ratio of the total leaf area in the sample plants to the average ground area occupied by them; the average ground area was calculated from the area of a plot and its plant population. The ADMs of the plots were determined by drying the stems and leaves of the sample plants in oven at 70°C for 72 h. The yield and yield attributes were recorded. A combined analysis of variance of the growth and yield attributes, grain and biomass yields (sum of grain and straw yields), and harvest index (HI) of wheat was done for the RCB by using MSTAT-C (Russel and Eisensmith, 1983).

Results and Discussion

Growth and yield attributes

Plant height of wheat decreased from 75.4 cm under I_1 to 67.6 cm under I_5. It decreased by 0.7, 2.2, 9.3 and 10.3% in I_2, I_3, I_4 and I_5, respectively compared to I_1. For irrigation water salinity ≤7 dS m^{-1}, plant height was statistically similar; the higher salinity reduced plant height significantly ($p = 0.05$) compared to I_1. Leaf area index, LAI, at 49 and 90 DAS decreased significantly as salinity of irrigation water increased except for I_2 (4 dS m^{-1}) in which the LAI increased significantly compared to the other treatments (Table 1). This observation exposed that irrigation water salinity of 4 dS m^{-1} exerted a positive impact on leaf growth of wheat. Irrigation water salinity hindered tillering of wheat; the negative effect increased with the increase in salinity. Consequently, number of spikes per unit area (spike density) decreased as irrigation water salinity increased (Table 1). The largest spike density (199 m^{-2}) was obtained under fresh water irrigation (I_1) and, I_4 and I_5 produced significantly lower spike density compared to I_1. It is noted that salinity suppressed late tillering only since the first irrigation was applied at the maximum tillering stage. A reduced tiller density due to increased salinity of irrigation water was also reported by Chhipa and Lal (1995).

Table 1. Growth and yield attributes of wheat under five irrigation water salinities

Treatment	Plant height (cm)	Leaf area index		Spike (m^{-2})	Spike length (cm)	Spikelet ($spike^{-1}$)	Grain ($spike^{-1}$)	1000-grain weight (g)
		49 DAS	90 DAS					
I_1	75.4^{a}	1.42^{a}	0.95^{a}	206.0^{a}	9.59^{a}	19.5^{a}	35.2^{a}	54.7^{a}
I_2	75.4^{a}	1.64^{b}	1.12^{b}	201.0^{a}	9.86^{ab}	20.0^{ab}	37.8^{a}	55.9^{ab}
I_3	73.8^{a}	1.32^{c}	0.71^{c}	198.3^{a}	9.10^{abc}	19.2^{abc}	34.1^{ab}	53.2^{abc}
I_4	68.4^{b}	1.35^{d}	0.93^{d}	188.0^{b}	8.74^{ac}	18.8^{acd}	30.8^{abc}	50.1^{ac}
I_5	67.6^{b}	0.96^{e}	0.46^{e}	182.3^{c}	8.31^{c}	17.9^{d}	29.7^{bc}	47.8^{c}
$LSD_{0.05}$	3.15	0.03	0.02	14.22	0.99	1.11	4.98	5.23

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

Salinity of irrigation water >4 dS m^{-1} exerted a negative impact on spike length, number of spikelets and grains per spike, and 1000-grain weight of wheat. These yield attributes continued decreasing with the increase in salinity of irrigation water (Table 1). It is remarkable that I_2 (4 dS m^{-1}) enhanced, although insignificantly, all these yield attributes over the control treatment. The spike length decreased by 6.9, 10.5 and 15.0% under I_3, I_4 and I_5, respectively but increased by 0.9% under I_2 compared to I_1. Treatments I_1 – I_4 produced indifferent spike lengths while I_5 produced significantly smaller spike length than I_1 and I_2. I_1–I_4 produced identical number of spikelets and grains per spike, and 1000-grain weight, while I_5 produced significantly lower values of these yield attributes compared to I_1. The number of spikelets per spike decreased by 1.7, 3.7 and 8.3% under I_3, I_4 and I_5, respectively, but increased by 2.6% under I_2 over I_1, indicating a systematic decrease in spikelets with the increase in salinity of irrigation water. The number of spikelets per spike was a function of spike length; the larger the spike length, the higher was the number of spikelets per spike. Number of grains per spike decreased by 3.2, 12.4 and 16.7% under I_3, I_4 and I_5, respectively but increased by 7.4% under I_2 compared to I_1. The number of grains per spike was therefore very sensitive to salinity of irrigation water ≥7 dS m^{-1}. Although Behrouz *et al*. (2009) obtained a significantly different 1000-grain weight, plant height, spike length and LAI of wheat under irrigation water of salinity 2, 8 and 12 dS m^{-1}, significantly reduced values of these crop attributes only for irrigation water salinity ≥10 dS m^{-1} were obtained during this study.

Above-ground dry matter

Above-ground dry matter, ADM, of wheat at 49 and 90 DAS decreased significantly as irrigation water salinity increased except for 4 dS m^{-1} salinity (I_2) compared to the control (Table 2). Treatment I_2 augmented ADM and, consequently, provided the utmost and significantly larger ADMs compared to the other treatments at both stages of the crop. A positive impact of salinity on AMD was also reported by Al-Saadi *et al*. (1982) who observed significant increase in plant dry matter of wheat at 6.8 dS m^{-1} soil salinity. At 49 DAS, ADM decreased by 13.0, 19.4 and 29.6% under I_3, I_4 and I_5, respectively compared to the control. At 90 DAS, the decrease in ADM of 6.1, 8.4 and 34.8%, under the corresponding treatments demonstrated an extensive negative impact of 7, 10 and 13 dS m^{-1} salinities of irrigation water on ADM production.

Table 2. Yield and water productivity of wheat under five irrigation water salinities

Treatment	Above-ground dry matter (t ha^{-1})		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biomass yield (t ha^{-1})	Grain-straw ratio	Water productivity for grain (kg ha^{-1} cm^{-1})	Water productivity for biomass (kg ha^{-1} cm^{-1})
	49 DAS	90 DAS						
I_1	2.26[a]	5.21[a]	3.847[a]	5.085[a]	8.932[a]	0.76[a]	192.1[a]	254.0[a]
I_2	2.76[b]	6.54[b]	3.820[a]	4.797[ab]	8.617[ab]	0.80[a]	190.8[a]	239.6[ab]
I_3	7.75[c]	4.73[c]	3.683[a]	4.220[bc]	7.903[abc]	0.87[a]	184.0[a]	210.8[bc]
I_4	1.77[d]	4.86[d]	3.257[ab]	4.060[bcd]	7.317[bc]	0.80[a]	162.7[ab]	202.8[c]
I_5	1.57[e]	3.33[e]	2.947[b]	3.991[cd]	6.938[c]	0.74[a]	147.2[b]	199.4[c]
$LSD_{0.05}$	0.026	0.02	0.690	0.735	1.250	0.16	34.49	36.71

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

Yields and water productivity

Irrigation by fresh water (I_1) helped producing paramount grain, straw and biomass yields and that by high saline water (13 dS m^{-1}; I_5) suppressed them to the lowest values followed by T_4 (Table 2). Under I_2– I_5, the grain yield decreased by 0.7, 4.3, 15.3 and 23.4%, respectively compared to I_1. These results are in agreement with the findings of Chauhan *et al*. (1991), but in contradiction, to some extent, with Phogat *et al*. (2001), who obtained 32 and 63% reduced grain yield of wheat under 8 and 12 dS m^{-1} salinity, respectively compared to the non-saline treatment. Flagella *et al*. (2000), on the contrary, found significant damages of wheat only with irrigation water salinity of 12 dS m^{-1} or more. Salinity level ≤7 dS m^{-1} exerted insignificant impact on the grain yield of wheat. I_1–I_4 produced statistically similar grain yields, but I_5 produced a significantly reduced grain yield. The grain yields under I_4 and I_5 were similar. These results are in partial agreement with that of Yazar *et al*. (2003), who obtained similar grain yields of wheat under 0.5, 3.0, 6.0, 9.0 and 12.0 dS m^{-1} irrigation water salinity levels. Chauhan *et al*. (1991) reported obtaining 90% or more of the optimum yield of wheat under two supplemental irrigations with water salinity 8–12 dS m^{-1}. It is therefore contemplated that if saline water is used only for supplemental irrigations, wheat might provide acceptable yield under higher salinity level. The straw yield of wheat reduced by 3.5, 11.5, 18.0 and 22.3% under I_2, I_3, I_4 and I_5, respectively compared to I_1. I_1 and I_2 produced invariant straw yields, while I_3 – I_5 produced similar but significantly lower straw yields than I_1. Although Behrouz *et al*. (2009) obtained significantly different grain and straw yields under irrigation water salinity of 2, 8 and 12 dS m^{-1}, significantly different values of these yields for irrigation water salinities 4 and 13 dS m^{-1} were obtained in this study. The biomass yield decreased by 5.7, 17.0, 20.2 and 21.6% under I_2, I_3, I_4 and I_5, respectively compared to I_1. It is noted that although irrigation water salinity of 4 dS m^{-1} augmented most of the growth and yield attributes of wheat, it suppressed tillering and hence spike density, which, consequently, reduced the grain, straw and biomass yields of the crop. The ratios of the grain to straw yields were similar in all treatments (Table 2). The highest value (0.87) was under I_3 and the lowest (0.74) was under I_5. The grain-straw ratios revealed that irrigation water salinity of 13 dS m^{-1} retarded the grain yield more than the straw yield. The production function of wheat, estimated under conditions of the imposed irrigation water salinities (0.385, 4, 7, 10 and 13 dS m^{-1}), followed a quadratic form. This function depicted that as salinity level of irrigation water increased, the yield level of wheat decreased. This result is in full agreement with that of Data *et al*. (1998). Water productivity for grain production under the treatments synchronized with grain yield of the corresponding treatments. For biomass production, water productivities under I_1 and I_2 were similar but significantly higher than that under I_4 and I_5, which provided similar water productivities.

Conclusion

Irrigation by saline water of electrical conductivity 10 and 13 dS m^{-1} (at 25°C) significantly ($p = 0.05$) suppressed most growth and yield attributes, and yield of wheat compared to irrigation by fresh water of background salinity 0.385 dS m^{-1}. Irrigation water of 7 dS m^{-1} salinity exerted insignificant negative impact on the crop attributes except for leaf area index, above ground dry matter, straw yield and water productivity for straw production. Irrigation water salinity of 4 dS m^{-1} improved leaf area index, spike length, spikelets and grains per spike, 1000-grain weight and above-ground dry matter compared to irrigation by fresh water. Because of the largest spike density arising from the highest tiller density, irrigation by fresh water provided higher, although statistically alike, grain, straw and biomass yields than irrigation by saline water of 4 dS m^{-1}. It is, nevertheless, speculated that there might be some advantageous level of irrigation water salinity for wheat cultivation. Further study is needed to verify this supposition and establish the fact taking into account the ensuing salt dynamics in the irrigated soil.

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