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Saline Irrigation-Water Management Strategy in Wheat Cultivation for Higher Yield and Water Productivity

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Abstract- **Salt stress is one of the most important abiotic stresses that adversely affect crop productivity and causes significant crop loss worldwide. The objective of this field study was to investigate the effect of different saline irrigation regimes and amelioratives on the yield performance of two wheat cultivars. Irrigation treatments were comprised of medium saline irrigation (6-7 dS/m) combinations at different growth stages along with excess gypsum and potash application, medium saline irrigation with intermittent fresh water applications, and high saline irrigation (9-12 dS/m) along with excess gypsum and potash application. The results revealed that the interactions between treatments and varieties were not significant for yield attributes, although there were distinct varietal differences in some cases. It is also evident that medium saline irrigation (7-8 dS/m) couple with intermittent fresh-water irrigation produce good yield (4.0-4.4 t/ha) of wheat cultivars. Saline irrigation at flowering - sot-dough stage of growth does not bring any benefit to grain yield. High saline irrigation (9-12 dS/m) at CRI, late-tillering, and booting-heading stages along with excess gypsum and K-application produced reasonable yield. Medium saline irrigation (7-8 dS/m) at CRI, late-tillering, and booting-heading stages along with excess gypsum and K-application produces reasonable yield.**

Keywords: Irrigation, saline water, gypsum, wheat, water productivity

I. Introduction

Around the world, 100 million ha, or 5% of arable land, is adversely affected by high salt concentrations, which reduce crop growth and yield (Gunes *et al.,* 2007). Salt and drought stresses have toxic effects on plants and lead to metabolic changes, like loss of chloroplast activity, decreased photosynthetic rate and increased photorespiration rate which then lead to an increased reactive oxygen species production (Hoshida *et al.,* 2000).

About 53 % of net cultivable land of coastal region of Bangladesh is affected by different degrees of salinity (SRDI, 2016). Agricultural land use in these areas is very poor compared to the country's average cropping intensity of 192 % (BBS, 2016; Haque, 2006). Water is the main natural resource for crop production which is also affected by salinity during winter/dry season. Salinity in the river system of the southwest coastal region increases steadily from December through February, reaching maximum in the late March and early April (BINA, 2013).

Many researchers have reported substantial increases in crop yields as a result of proper irrigation and management technique (Kamar et al., 2015; Wang et al., 2015; Ali et al., 2014). Numerous investigators reported the effects of different saline irrigation practices and management options on the growth and yield of wheat (Hamdy et al., 1993; Bajwa and Josan, 1989; Ma et al., 2008; Jiang et al., 2012; BINA, 2013; Wang et al., 2015; Kumar et al., 2017). Kumar et al.(2017) reported that the grain yield of all tested varieties were significantly reduced along with increase in the irrigation water salinity (3 – 12 dS/m), but the magnitude of reduction was found minimum of 40.57% in K-8434 variety and maximum of 67.52% in HUW-468 variety from normal to 12 dS/m salinity of irrigation water. Similarly, the reduction in germination percentage of sown seeds from control to 12 dS/m EC salinity was also recorded with minimum of 20% in K-8434 and maximum of 38% in variety HUW-468. Jiang et al. (2012) conducted field experiment to study the effects of irrigation amount and water salinity (0.65, 3.2, and 6.1 dS/m) on water consumption and water productivity of spring wheat, and concluded that, for the purpose of highest yield and WUE, irrigation amount should be controlled at appropriate level under saline water irrigation.

But the final effect on harvestable yield depends on the on-set and withdrawal of saline irrigation, growth stage of wheat at which saline irrigation was applied, salinity level of the irrigation water, salinity of the crop root zone soil, soil moisture content, varietal resistant to salinity level, underground salinity, climate, etc. (Ali, 2011a; Ali, 2011b). As a result, the findings of a particular location and for a particular cultivar may not be directly applicable to other locations and cultivars.
The objective of this study was to investigate the effect of different irrigation regimes and amelioratives on the yield performance of two wheat cultivars in salt affected area of Bangladesh, and finally suggest the saline irrigation management strategy for better yield of wheat.

II. Materials and Methods

2.1 Location and experimental treatments

The experiment was conducted at farmer's field, Satkhira District (north-western region) of Bangladesh ($22^0 43''$ N, $890^0 5''$ E), during winter season (December-April) of 2015-16 and 2016-17, to determine irrigation management strategy for higher yield of wheat cultivars.
The experimental design was RCBD (with split-plot arrangement) having three replications. Details of irrigation and ameliorative treatments are given in Table 1.

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Table 1. Treatment details for the study

Treatment ID	DS of irri. water	Excess S, K	Organic	Irrigation at			
				Stage-1 CRI (20-25)	Stage-2 Late-tillering (40-45)	Stage-3 Booting-heading (55-65)	Stage-4 Flowering - soft-dough (65-80)
T_1	6 - 7	N	-	1	-	1	-
T_2	6 - 7	Y	Y	1 (S, K)	-	1 (S, K)	-
T_3	6 - 7	Y	Y	1	1 (S, K)	1	1 (S, K)
T_4	6 - 7	Y	Y	1	1(S, K)	1(S,K)	-
T_5	6 - 7	Y	-	1	1(S, K)	-	1 (S, K)
T_6	6 - 7	Y	-	1	-	1 (S, K)	1 (S, K)
T_7	6 - 7	Y	-	-	1 (S, K)	1 (S, K)	1
T_8	Multi -	Y	-	1(7-8 dS) (S, K)	1 (pond/canal) 2-3 dS	1(7 – 8 dS) (S, K)	1 (pond/canal) 2-3 dS
T_9	Multi -	Y	Y	1(7-8 dS) (S, K)	1(7-8 dS)	1 (pond/canal) 2-3 dS	1(7-8 dS) (S, K)
T_{10}	9 - 12	Y	Y	1(S, K)	1	1 (S, K)	1
T_{11}	9 - 12	Y	Y	1(S, K)	1	1 (S, K)	-

Organic matter: Cowdung @ 5.0 t/ha

N = No, Y = Yes,
'1' means one irrigation at this stage with mentioned water salinity
S = Excess gypsum @ 50% of normal dose, in 2 equal splits (as specified)
K = Excess MP@ 30% of normal dose, in 2 equal splits (as specified)

The treatment T11 was initiated/added in 2016-17.

The cultivars were: V_1 = Binaghom-1, and V_2 = BARIghom-25. These cultivars are considered as salt tolerant (medium salinity level).

The seeds of wheat were sown on 7th December in 2015, and 30 November in 2016 [the land in this coastal region becomes available for cultivation (field capacity) at later days compared to other parts of the country]. The recommended fertilizers were: Urea, Triple Super Phosphate (TSP), Muriate of Potash (MP), and Gypsum at the rate of 200, 180, 115, and 130 kg/ha; respectively.

Treatments were imposed accordingly. The varieties were harvested on 13 March in 2016, and 14 March in 2017. At the harvest time, yield and yield attributing characters were collected. Other necessary data (e.g. amount of water applied at each irrigation, EC of soil and irrigation water) were recorded. The grain weight was adjusted to 12% moisture following Ali (2010).

2.3 Irrigation Water Productivity

Irrigation water productivity (IWP) was calculated as:

$$IWP = \frac{Y_{grain}}{I} \quad (1)$$

Where I is the irrigation amount.

2.3 Analysis of experimental data

The analysis of variance technique (ANOVA) was carried out on the data for each parameter as applicable to the design. The significance of the treatment effect was determined using F-test, and to determine the significant difference among the means of the treatments, least significant difference (LSD) were estimated at 5% probability level (using statistical software, "STAR").

3 Results and Discussion

3.1 Year 2015-16

During soft-dough stage of the variety V1, a heavy wind together with rainfall partially damage it (and thus the yield is low), whereas the variety V2 was in hardening stage and was not affected.

Yield attributing characters

The interaction effects of treatments and cultivars on different yield attributes are reported in Table 2.1. The interaction effects are not significant at 5% probability level for all parameters, although there are differences in spike length, seed per spike, and 1000 seed weight.

The mean Varietal effects are significant for number of tiller, spike length, and 1000 seed weight (not shown). The mean treatment effects are statistically significant for 1000 seed weight (not shown).

Grain yield

The effect of treatments under each level of variety is presented in Table 2.2. For cultivar V2, the highest grain yield was recorded in treatment T8, where intermittent freshwater (pond water) irrigation was applied (at late-tillering and flowering- soft-dough stage) along with excess gypsum and MP. The second height yield was recorded in T_9, followed by T6. When compared among T3 and T4, the yields are statistically identical, but in magnitude, the yield in T4 is higher than that of T3.

3.2 Year 2016-17

Yield attributing characters

The interaction effects of treatments and cultivars on different yield attributes are presented in Table 3.1. The interaction effects are not significant at 5% probability level for all parameters, although there are distinct varietal differences in plant height, seed per spike, and 1000 seed weight. In case of seed per spike, the variety V1 produced higher value than that of V2; while in case of 1000 seed weight, the V2 showed higher value.

The mean Varietal effects are significant for seed/spike, 1000 seed wt., and plant height. Although the treatment effects are not statistically significant, still there are some differences among the treatments (not shown).

Grain yield

The effect of treatments under each level of variety is reported in Table 3.2. The highest grain yield was recorded in treatment T8 for both the varieties, where intermittent freshwater (pond water) irrigation was applied (at late-tillering and flowering- soft-dough stage) along with excess gypsum and MP. This treatment was statistically similar with all except T1 for variety V1, and all except T1, T2, and T5 for variety V2. In T4 and T9, organic matter (OM) was applied in addition to S and K; but the OM did not have any remarkable influence on grain yield. When considering among T3 and T4, they produced almost similar yield in case of V1; but in V2, a bit higher in T4, indicating that saline irrigation at flowering – soft-dough stage did not bring any benefit, rather reduce yield.

When considered among T5, T6, and T7 (where one irrigation was omitted at different stages), they are statistically similar. The treatment T5 produced the lowest yield for V2 cultivar, in which irrigation was omitted at booting-heading stage.

When compared among T10 and T11 (high saline irrigation, 12 dS/m), they are statistically similar, but the T11 produced a little higher grain yield, indicating that high saline irrigation at flowering – soft-dough stage (in T10) may affect yield adversely (which is also evident from T3 for both the years).

The yield variations among the years may be due to variations in micro-climate (including rainfall) (Fig.1), soil condition (EC and nutrient) (Fig.2.1 and Fig.2.2), and their interactions.

The results revealed that substituting a part or all (except pre-sowing irrigation) with saline water having an electrical conductivity (EC_{iw}) of 6-7 dS/m is possible for cultivation of wheat. Similarly, saline water with EC_{iw} ranging between 9-12 dS/m could be used to supplement 3 irrigations to obtain reasonable yield (~ 80% of optimum).

Chauhan et al. (2008) concluded from field trials (Agora, India) that saline water (EC: 8~12 dS/m) could be used to supplement at least two irrigations to obtain 90% or more of the optimum yield. Ghan et al. (2009) investigated 4, 8 and 12 dS/m saline irrigation with different planting method and suggested 8 & 12 dS/m saline irrigation with 'furrow irrigated raised wavy beds with 60 cm'. Xiu-wei et al. (2016) recommended that to avoid the negative effects of saline irrigation, sufficient fresh water irrigation during next crop of wheat (in the low plain of North China). But in Bangladesh, having a monsoonal rainfall, the accumulated salt during wheat cultivation washes out during rainy season, and thus no fear of such salt-accumulated adverse effect after the wheat crop.

3.3 Rainfall, Irrigation amount and irrigation water productivity

The amount of rainfall and its distribution during crop period are depicted in Fig.1. The irrigation amount under each treatment, irrigation water productivity (IWP), and yield reduction compared to T8 are presented in Table 3. During 2016-16, the highest IWP was associated with T2 treatment, which received lowest irrigation water coupled with lower yield. Higher IWP values itself does not bring any benefit if it is not associated with higher or reasonable yield.
The groups T3- T8 and T8 – T9 showed moderate IWP couple with moderate yield. ……..
Among the group T10 – T11, the T11 produced 2nd highest IWP for V1 and highest for V2.

3.4 Discussions and conclusions

Wheat is an increasingly important commodity with rising rates of consumption throughout in Asia and specifically in Bangladesh. Two major approaches to improving and sustaining high agricultural productivity in a saline environment involve: (i) modifying the environment to suit the available plants; and (ii) modifying the plants to suit the existing environment. They could be used separately or together to make possible the productive utilization of available saline water without compromising the sustainability of the production at different management levels.
From the study, the following conclusions can be made:

(1) Medium saline irrigation (7-8 dS/m) couple with intermittent fresh-water irrigation produce good yield (4.0-4.4 t/ha) of wheat cultivars.
(2) High saline irrigation (9-12 dS/m) at CRI, late-tillering, and booting-heading stages along with excess gypsum and K-application produces reasonable yield.
(3) Medium saline irrigation (7-8 dS/m) at CRI, late-tillering, and booting-heading stages along with excess gypsum and K-application produces reasonable yield.
(4) Saline irrigation at flowering - sot-dough stage of growth does not bring any benefit to grain yield.

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Table 1.1. Interaction effects of irrigation treatments and cultivars on yield parameters during 2015-16

1) Treat-2) ment	*3)*	*4) tiller/plant*	*5) Spike length*	*6) No. of spikelets/ spike*	*7) seed /spike*	*8) 1000 grain wt. (gm)*
T_1	V_1	3.9	8.03	13.1	31.46	13.0
	V_2	4.1	9.06	14.1	29.53	20.4
T_2	V_1	4.7	8.16	14.0	32.33	13.9
	V_2	3.7	9.00	13.5	36.13	20.7
T_3	V_1	5.1	8.26	13.3	32.46	11.3
	V_2	4.2	8.66	12.3	29.60	19.5
T_4	V_1	4.1	8.06	13.1	31.06	12.4
	V_2	3.9	9.33	13.8	33.20	18.7
T_5	V_1	4.7	8.60	14.0	37.86	10.8
	V_2	4.4	9.13	14.2	34.46	19.3
T_6	V_1	4.4	8.43	12.7	32.53	11.9
	V_2	3.7	9.03	13.2	33.40	18.7
T_7	V_1	4.9	8.16	12.9	33.13	11.1
	V_2	4.4	8.36	13.5	32.06	19.0
T_8	V_1	4.2	8.30	13.0	33.00	10.1
	V_2	3.7	9.13	14.0	32.46	19.7
T_9	V_1	4.1	8.43	13.7	33.33	10.0
	V_2	3.5	8.76	13.5	33.00	19.5
T_{10}	V_1	4.7	8.36	13.3	28.80	9.4
	V_2	3.5	8.56	13.5	35.93	20.8
THSD (0.05)		*NS*	*NS*	*NS*	*NS*	*NS*

Note: THSD = Tukeys's Honest Significant Difference. Means with the same letter are not significantly (statistically) different at 5% probability level by THSD test.

Table 2.1 . Interaction effects of irrigation treatments and cultivars on yield parameters during 2016-17

9) Treat-10) ment	*11)*	*12) Tiller/ plant*	*13) Spike length (cm)*	*14) No. of spikelets/ spike*	*15) Seed/spike*	*16) 1000 grain wt. (gm)*
T_1	V_1	3.66	8.43	15.66	40.40	34.35
	V_2	3.73	8.86	15.86	37.20	46.96
T_2	V_1	3.93	8.77	15.86	48.26	33.02
	V_2	4.26	8.40	14.00	32.93	46.92
T_3	V_1	4.13	8.70	15.53	44.13	31.07
	V_2	3.93	9.26	16.26	38.00	47.79
T_4	V_1	4.20	8.13	15.20	47.06	32.09
	V_2	3.73	8.06	13.60	35.80	46.08

T_5	V_1	5.06	8.36	15.06	41.06	36.24
	V_2	4.60	8.96	15.40	34.86	48.38
T_6	V_1	4.33	8.70	16.20	43.60	33.76
	V_2	4.40	8.93	15.60	36.00	46.01
T_7	V_1	4.53	8.73	16.13	48.73	34.10
	V_2	4.60	8.63	15.13	35.46	44.33
T_8	V_1	4.93	8.66	15.86	43.13	34.46
	V_2	5.60	8.73	15.33	34.61	43.91
T_9	V_1	5.00	8.20	14.80	43.60	34.13
	V_2	5.40	8.70	14.8	32.46	48.61
T_{10}	V_1	4.33	7.83	13.80	42.20	32.37
	V_2	5.26	8.86	15.06	34.60	41.86
T_{11}	V_1	4.86	8.30	15.13	43.40	31.17
	V_2	4.80	8.96	14.93	35.40	47.26
THSD (0.05)		*NS*	*NS*	*NS*	*NS*	*NS*

Note: THSD = Tukeys's Honest Significant Difference. Means with the same letter are not significantly (statistically) different at 5% probability level by THSD test.

Table 1.2. Mean effects of irrigation treatments and cultivars on grain yield of wheat during 2015-16

17) Treatment	**Grain yield (t. ha^{-1})**	
	V_1= Binaghom-1*	V_2= BARI ghom-25
T_1	1.60	2.99 abc
T_2	1.63	3.05 abc
T_3	1.75	3.51 abc
T_4	1.66	3.66 abc
T_5	1.59	3.10 abc
T_6	1.32	4.16 ab
T_7	1.50	2.90 bc
T_8	1.35	4.45 a
T_9	1.11	3.68 abc
T_{10}	0.87	2.82 bc
THSD $_{(0.05)}$	NS	

Note: THSD = Tukeys's Honest Significant Difference. Means with the same letter are not significantly (statistically) different at 5% probability level by THSD test.

* The yield was very low due to damage by heavy storm during its soft-dough stage

Table 2.2. Mean effects of irrigation treatments and cultivars on yield of wheat during 2016-17

18) Treat ment	**Grain yield (t. ha^{-1})**	
	V_1= Binaghom-1	V_2= BARI ghom-25
T_1	1.97 b	2.55 c
T_2	3.21 ab	2.71 bc
T_3	3.47 a	3.49 abc
T_4	3.44 a	3.73 abc

T_5	3.65 a	2.96 bc
T_6	3.81 a	3.65 abc
T_7	3.68 a	3.90 ab
T_8	4.02 a	4.09 a
T_9	3.41 a	3.70 abc
T_{10}	3.14 ab	3.29 abc
T_{11}	3.15 ab	3.33 abc
THSD$_{(0.05)}$		

Note: THSD = Tukeys's Honest Significant Difference. Means with the same letter are not significantly (statistically) different at 5% probability level by THSD test.

Table 3. Irrigation water, and water productivity under different irrigation treatments

19) reatments	**2015-16 (V1)**			**2016-17 (V1)**		
	Irri.water (cm)	IWP(kg/ ha-cm)	yield reduction (%)	Irri.water (cm)	IWP (kg/ ha-cm)	yield reduction (%)
T_1	8	0.374	33	8	0.246	51
T_2	8	0.381	31	8	0.401	20
T_3	16	0.219	21	16	0.217	14
T_4	12	0.305	18	12	0.287	14
T_5	12	0.258	30	12	0.304	9
T_6	12	0.307	17	12	0.318	5
T_7	12	0.242	35	12	0.301	10
T_8	16	0.278	-	16	0.251	-
T_9	16	0.260	7	16	0.230	8
T_{10}	16	0.176	37	16	0.196	22
T_{11}	-	-	-	12	0.263	22

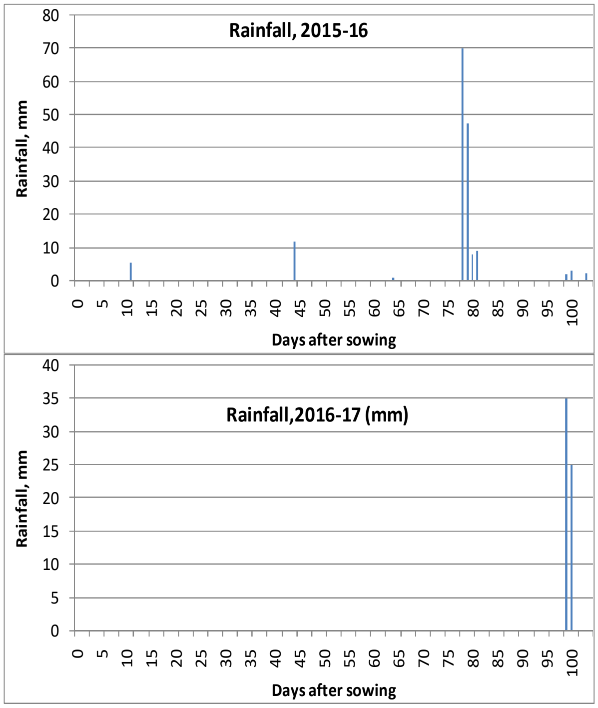

Fig.1. Rainfall during growing period

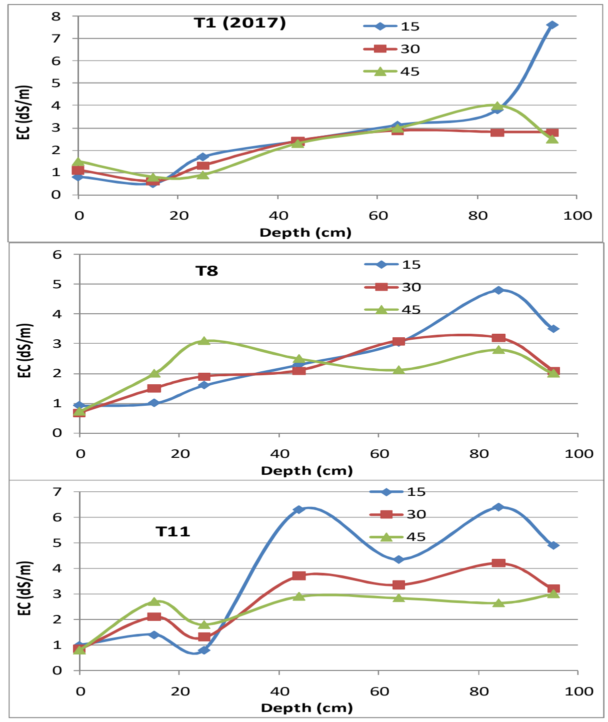

Fig.2.2. Variation of soil EC with depth under different treatments during 2016-17

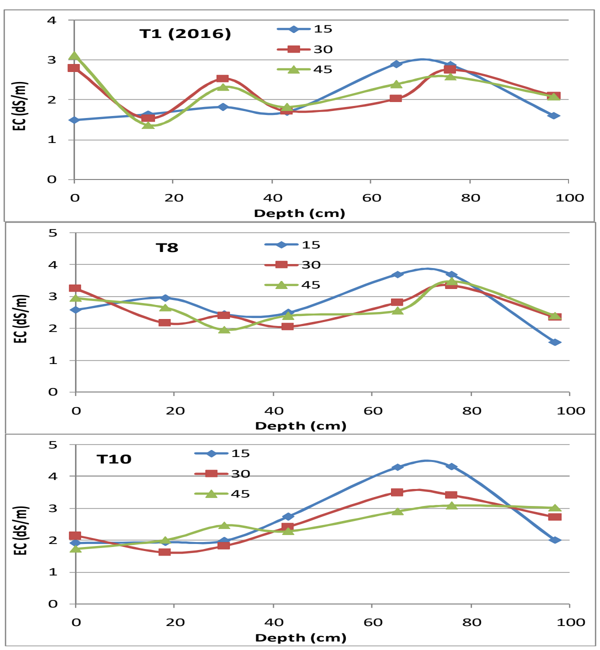

Fig.2.1. Variation of soil EC with depth under different treatments during 2015-16

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