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Water Productivity of Winter Wheat in Different Irrigation/ Planting Methods using Saline Irrigation Water

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ABSTRACT

A field study was conducted to optimize an irrigation/planting method for higher wheat yield and water productivity (WP). The experiment comprised planting winter wheat with three irrigation water salinities as main plots, including: 4, 8 and 12 dS m^{-1}. Three irrigation/planting methods as sub-plots, namely: furrow irrigated raised wavy beds with 60 cm ($FIRWB_{60}$) and 80 cm ($FIRWB_{80}$) furrow to furrow width and conventional flat planting (FP). Finally, two irrigation depths as sub-sub plots, embodies 0.9 and 1.1 times the evapotranspiration. Results indicated that $FIRWB_{60}$ had lower soil salinity than FP in the topsoil. As a result, wheat yield components (1000-grain weight, spike length & grain yield) enhanced. When irrigated with the saline irrigation water of 8 and 12 dS m^{-1} the $FIRWB_{60}$ method produced higher grain yield with less irrigation, so WP increased by, respectively, 14.9 and 18.4% in comparison with the FP method. Based on the low water consumption, and high grain yield and WP of $FIRWB_{60}$, it could be concluded that $FIRWB_{60}$ is a suitable irrigation/planting method for providing sustainable agriculture in salt prone regions with water shortages.

Key Words: Wheat yield; Water consumption; Salinity; Conventional flat planting; Furrow irrigated raised wavy bed planting

INTRODUCTION

There are parts of the world that have limited supplies of good quality water and so it is desirable to irrigate with water that contains higher salt concentrations; these areas are often in the arid and semi arid zones, for example the Roudaht region of Isfahan, Iran. The yield of crops irrigated with saline water could be enhanced substantially, if an additional source of good quality water is available for use at critical times during the season. An alternative approach for enhancing crop yield can be to use a mixture of saline and non-saline water (water blending). The use of saline drainage water for irrigation has the environmental advantages of reducing the fresh water requirement for salt-tolerant crops and decreasing the volume of drainage water disposal. When water resources are limited and the cost of fresh water becomes prohibitive, crops of moderate to high salt tolerance can be irrigated with saline water especially at later growth stages. This can be achieved provided that appropriate irrigation methods and management practices are used (Flowers *et al.*, 2005).

Ghassami *et al.* (1995) reviewed various estimates of the global extent of salinization of land and water resources. They concluded that, of the total 230 million ha of irrigated land around the world, some 45 million ha suffer from severe irrigation induced salinity problems. Around about 15% of lands, that is about 25 million ha, are suffering from different degrees of salinity and sodicity in Iran, including 320 000 ha of lands in Isfahan province (Feizi, 1993). The Roudasht region with about 50 000 ha of salt affected soils, is located southeast of Isfahan city, central part of Iran. Due to high evapotranspiration demand, low annual rainfall, limitation of fresh water and use of saline underground and drainage water of irrigation, the soils have lost their productivity. This problem is not only reducing the agricultural productivity, but is also putting far-reaching impacts on the livelihood strategies of small farmers (Tanwir *et al.*, 2003). This presents a serious environmental problem for sustainable agricultural development in the region (Mostafazadeh-Fard *et al.*, 2007).

Bed planting systems have been used in cultivation for centuries. The origin of raised-bed cultivation has traditionally been associated with water management issues, either by providing opportunities to reduce the impact of excess water in rainfed conditions, or to more efficiently deliver irrigation water in high production irrigated systems (Sayre, 2006). Over the past 20 years, farmers in the irrigated areas in the northwest state of Sonora in Mexico have adopted an innovative system by which wheat is planted in defined rows on top of beds with irrigation supplied in furrows between the beds. With more than 95% farmer acceptance of this planting method for wheat as well as all other crops in the cropping systems, dramatic improvements have occurred in productivity of irrigation

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water. Farmers are also taking advantage of the field access provided by this planting method to improve N management (Sayre & Moreno Ramos, 1997; Limon-Ortega *et al*., 2000). Farmers have adopted this system for growing both rice and wheat crops in India and Pakistan. These farmers were also growing mustard, other oilseed and pulse crops (Ockerby & Fukai, 2001; Choudhury *et al*., 2007). Abdelhadi *et al.* (2006) stated that bed-planting can be considered as one of the methods for wheat production provided that suitable seeding machines are available. Knowing that water productivity is the crop production per unit of agricultural water use, Aggarwal and Goswami (2003) also reported that under sandy loam soil with three rows of wheat per bed, bed-planting wheat yield and water productivity (WP) increased, respectively, by 0.22 and 0.03 ton ha^{-1} cm^{-1} compared to flood irrigation in conventional flat planting. Fahong *et al.* (2004) found that nitrogen use efficiency (NUE) could be improved by 10% or more in furrow irrigated bed-planting systems, because of improved N placement possibilities. Also, the microclimate within the field was changed to the orientation of the wheat plants in rows on the beds, which reduced crop lodging and decreased the incidence of some wheat diseases. These advantages were found to improve grain quality and increase grain yield by more than 10%. Zhang *et al.* (2007) also reported that FIRB had higher WP than FP due to lower water consumption and higher yields. In conclusion, Furrow irrigated raised-bed planting has been suggested to be one of the most effective measures to reduce the cost of cultivation and to increase WP as well as to optimize yield.

The objective of the research reported here was to evaluate the effects of different irrigation/planting methods with high and moderately saline water on yield and water productivity of winter wheat.

MATERIALS AND METHODS

Description of roudasht experimental station. The experiment was conducted during December, 2006 to June, 2007 at the Roudasht experimental station of Isfahan Agricultural and Natural Resources Research Center, southeast Isfahan city, Iran (latitude 32°29′N, longitude 52°11′E), at an elevation of 1504 m above sea level. The climate of the Roudasht is widely classified as semi-arid with hot-dry summers and cold winters. Rainfall ranges from 70 to 100 mm every year in the Roudasht region. Mean annual temperature is 13.9°C. The physical and chemical properties of the experimental soil are summarized in Table I.

Treatments and experimental design. The winter wheat (Roshan cultivar) was planted on December 9, 2006 on an area of 1300 m^2 and was harvested on June 26, 2007. The experimental design consisted of a split-split-plot on a randomized complete block with three replications. The experiment comprised planting winter wheat with three irrigation water salinities as main plots, including: 4, 8 and 12 dS m^{-1}. Three irrigation/planting methods as sub-plots, namely: furrow irrigated raised wavy beds with 60 cm ($FIRWB_{60}$) and 80 cm ($FIRWB_{80}$) furrow to furrow width and conventional flat planting (FP). Finally, two irrigation depths as sub-sub plots, embodies 0.9 and 1.1 times the evapotranspiration ($0.9ET_c$ & $1.1ET_c$), where ET_c is wheat water requirement, which was calculated using the class A evaporation pan. In this study we compare the characteristics of FP with $1.1ET_c$ and FIRWB with $0.9ET_c$ irrigation depth.

Each individual plot was 4 m × 4 m. The distance from the top of the bed to the bottom of the furrow in the two FIRWB planting methods was 25 cm. For the $FIRWB_{60}$ and $FIRWB_{80}$, the width of the ridges was, respectively 45 and 65 cm. For $FIRWB_{60}$ and $FIRWB_{80}$, the two rows per bed configuration were spaced 25 and 35 cm apart, respectively. The sowing location of the seeds in the FIRWB planting method was on the sides of the wavy beds to study the salinity effects on wheat production (Fig. 1). The FP method had a row spacing of 20 cm. Seeding rate of 115 seed m^{-1} was used for all the treatments.

Irrigation was applied eight times during the growing season. During this period the measured volume of water was applied according to crop requirement with the help of class A evaporation pan and the irrigation intervals were assessed by soil and plant visual appearance. Mean composition of the irrigation waters are given in Table II. The crops were fertilized at a rate of 400 kg N ha^{-1} using urea, with N applied to the plots before fourth, fifth and seventh irrigations in three equal splits of 133 kg N ha^{-1}. The fertilizer for FIRWB was applied in the furrow and uniformly applied over the surface for flood irrigated, flat planting method. Furthermore, 20% additional irrigation water was applied with each irrigation to all the plots for leaching requirement. This amount was the typical amount used by the local farmers in this region. This requirement was included to take care of saline soil conditions. Groundwater (EC=13 dS m^{-1}) and canal water (EC=0.5 dS m^{-1}) supplies were blended to achieve the required irrigation water salinities.

Measurements. Soil samples from each plot were collected from 0-30 cm soil depth at four stages, including: before planting, two in the middle of the season and after harvest. It should be pointed out that soil samples in the FIRWB method were drawn from the wheat rows to have the maximum representation of rooting zone. Finally, the electrical conductivity (EC_e) of the soil samples were measured from their saturated paste extract using EC meter.

The amount of the applied irrigation water was measured with a flow meter installed on the flexible hoses. Precipitation was measured using a standard rain gauge from the weather station at the experimental site. Soil water content from 0-30, 30-60 and 60-90 cm depths was measured by the gravimetric method for each plot before sowing, straight after harvest and just before and after irrigation numbers four to eight. Soil moisture measured by gravimetric method (weight basis) was converted into volumetric proportion by multiplying with bulk density.

The crop growth components (1000-grain weight, spike length, spike number per square meter) were recorded at the end of the season. Grain yield was measured by manually harvesting 15 m and 11.25 m of $FIRWB_{60}$ and $FIRWB_{80}$, respectively, and an area of 3 m × 3 m of FP.

The evapotranspiration (ET) of individual plots of winter wheat for the entire growing season was estimated by the standard water balance equation (Huang *et al.*, 2005):

$$ET = \pm\Delta S + (P + I + C) - (RO + DP) \quad (1)$$

Where ΔS is the change in soil water storage before sowing and after harvest measured in the soil profile (mm), P is the precipitation (mm), I is the irrigation (mm), C is the upward flow into the soil profile (mm), RO is the surface runoff from each plot (mm), and DP is the deep percolation out of the soil profile (mm). Soil moisture measurements in the soil profile were taken down to 90 cm (i.e., between the soil surface & maximum root depth). The groundwater table remained at a depth of about 2 m below the surface according to the peizometers installed in the field, so the upward flow into the soil profile was negligible. Surface runoff was assumed to be zero as irrigation water was protected by 40 cm high bunds. Deep percolation was approximated as:

$$DP_i = D_i - SMD \quad (2)$$

Where D_i is the irrigation depth (mm) and SMD is the soil moisture deficit (mm), which is calculated as:

$$SMD = (\theta_{FC} - \theta_i) \times RD$$

Where θ_{FC}, θ_i are, respectively volumetric soil moisture content at field capacity and right before irrigation, and RD is the wheat maximum root depth (mm). Regarding the information mentioned above, Eq. (1) reduces to the following form (Walker & Skogerboe, 1987):

$$ET = \pm\Delta S + P + I - DP \quad (3)$$

Water productivity was determined by dividing grain yield by evapotranspiration as follows (Ali *et al*., 2007):

$$WP = \frac{GY}{ET} \quad (4)$$

Where WP is water productivity (kg m^{-3}), GY is grain yield (kg ha^{-1}) and ET is wheat total water consumption of the growing season (m^3 ha^{-1}).

Productivity of irrigation water was calculated as (Ali *et al*., 2007):

$$PIW = \frac{GY}{I} \quad (5)$$

Where I is the irrigation water applied (m^3 ha^{-1}).

Statistical evaluation and analysis of variance (ANOVA) were performed using MSTAT-C software. System means were compared using the Duncan's multiple range test (DMRT), which were statistically significant when $p \leq 0.05$.

RESULTS AND DISCUSSION

Soil salinity. For practical purposes, the salinity (EC_e) of surface soil where most of the roots reside is required for suitability of water for irrigation. Thus, the effect of irrigation/planting method on periodic build up of salinity in the agriculturally most important soil layer (surface 0.3 m) is presented in Fig. 2. Irrigation/planting method had a significant effect on soil salinity at the 0-30 cm depth. Results illustrated in Fig. 2 indicate that in the saline irrigation water of 4 dS m^{-1}, FP had the highest soil salinity throughout the season. This difference in soil salinity is of no importance to influencing wheat yield, since the average values of EC_e (without the pre-sowing EC_e) in the three planting methods were less than the soil salinity tolerance level for wheat (6 dS m^{-1}) (Ayers & Westcot, 1976).

With saline irrigation water (8 & 12 dS m^{-1}) FP had significantly higher EC_e in comparison with the FIRWB methods. EC_e was lower in the FIRWB methods throughout the season, since soil samples were taken from the wheat rows on the shoulder of the raised wavy beds (Fig. 1) and away from the area of greatest salt accumulation (center of the bed). However, this difference is more evident in the earlier growth stages of wheat, which can provide better growth conditions to wheat in the seedling stage. We can conclude that with the furrow irrigation method, salinity at the root zone was lower than that in the flood irrigation method. Therefore, with the FIRWB methods, yield reduction due to salinity is lower than FP. The $FIRWB_{80}$ method had slightly lower but not significant soil salinity in comparison to the $FIRWB_{60}$ method. This can be explained by the extra distance from the salt concentrations on top of the bed to the plant and root zone.

Also, these figures show that seasonal average of the EC of the soil solution was completely associated with salinity of irrigation water. The soil salinity caused by flood and furrow irrigation systems are in accordance with the findings of Ashraf and Saeed (2006), who reported that the EC_e increased more in the field with basin irrigation as compared to the field with bed-furrow irrigation under wheat crop. The EC_e of all the irrigation/planting methods increased at the end of the season due to high evaporation from the topsoil.

Grain yield and yield components. Planting method had a significant effect on yield components (Table III). The 1000-grain weight for $FIRWB_{60}$ was 13.3, 17.3 and 20.7% higher than FP in EC_{iw}=4, 8 and 12 dS m^{-1} irrigation water, respectively. Similarly, spike length for $FIRWB_{60}$ and $FIRWB_{60}$ was higher than FP for the irrigation water salinities of 4, 8 and 12 dS m^{-1}. For $FIRWB_{80}$, 1000-grain weight and spike length did not have any significant

Table I. Physical and chemical properties of soil under consideration

(a) Physical properties

Depth (cm)	Particle size distribution (%)			Texture	Field capacity (%)	Permanent wilting point (%)	Bulk density ($g\ cm^{-3}$)
	Sand	Silt	Clay				
0-30	15.0	49.9	35.1	Silty clay loam	28	17	1.39
30-60	12.9	47.5	39.6	Silty clay loam	28	17	1.39
60-90	11.2	47.6	41.2	Silty clay	28	18	1.40

(b) Chemical properties

Depth (cm)	EC ($dS\ m^{-1}$)	pH	Soil soluble ions ($meq\ L^{-1}$)					SAR
			$Ca^{2+}+Mg^{2+}$	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	
0-30	7.36	7.66	40.67	37.6	2.4	36	40.5	8.34
30-60	6.64	7.67	40.00	38.1	2.8	38	37.6	8.5

Table II. Chemical composition of the saline water used for irrigation

	EC ($dS\ m^{-1}$)	pH	Cations and anions ($meq\ L^{-1}$)					SAR
			Na^+	$Ca^{2+}+Mg^{2+}$	SO_4^{2-}	Cl^-	HCO_3^-	
Saline water 1	3.9	6.7	27.6	11	7.6	26	5.0	11.8
Saline water 2	8.2	7.6	59.0	24	26.5	54	4.1	17.0
Saline water 3	12.3	6.8	100.2	40	33.7	102	5.5	22.4

Table III. Effect of water quality and planting methods on yield components

Treatments		1000-grain weight (g)	Spike length (cm)	Number of Spikes (m^{-2})	Grain yield ($kg\ ha^{-1}$)
	FP	41.47 b[a]	9.57 b	543 a	6403 a
4 $dS\ m^{-1}$	$FIRWB_{60}$	47.00 a	9.87 a	377 b	5925 b
	$FIRWB_{80}$	46.80 a	9.73 a	289 c	5061 c
	FP	36.20 b	8.23 b	458 a	4647 b
8 $dS\ m^{-1}$	$FIRWB_{60}$	42.47 a	8.93 a	335 b	4895 a
	$FIRWB_{80}$	42.83 a	8.97 a	247 c	4099 c
	FP	33.63 b	7.33 b	377 a	2741 b
12 $dS\ m^{-1}$	$FIRWB_{60}$	40.60 a	8.23 a	301 b	3084 a
	$FIRWB_{80}$	41.10 a	8.30 a	216 c	2375 c
C.V. (%)		3.03	2.24	3.34	2.36

[a]Means in a column with the same letter are not significantly different at the 5% level

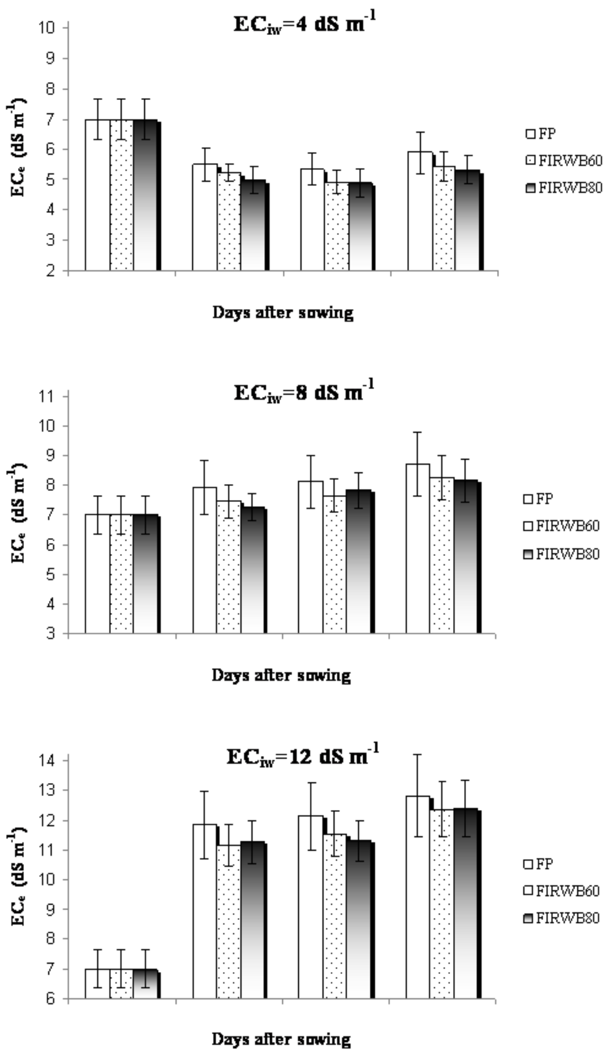
Table IV. Total water consumption (ET) for different irrigation/planting methods

Treatments		Initial soil moisture content (mm)	Final soil moisture content (mm)	Rainfall (mm)	Irrigation water (mm)	Deep percolation (mm)	ET (mm)
4 $dS\ m^{-1}$	FP	206.5	167.4	112.7	646.3	5.6	792.5 a[a]
	$FIRWB_{60}$	211.8	154.9	112.7	525.0	0	694.6 b
	$FIRWB_{80}$	209.0	152.7	112.7	530.0	0	699.0 b
8 $dS\ m^{-1}$	FP	211.5	198.9	112.7	645.3	64.1	706.5 a
	$FIRWB_{60}$	209.7	191.0	112.7	525.3	9.3	647.4 b
	$FIRWB_{80}$	207.8	191.5	112.7	527.0	7.5	648.5 b
12 $dS\ m^{-1}$	FP	208.9	205.6	112.7	644.7	96.1	664.6 a
	$FIRWB_{60}$	211.6	199.5	112.7	526.7	19.0	632.6 b
	$FIRWB_{80}$	207.6	200.1	112.7	528.7	19.3	629.6 b
C.V. (%)							0.57

[a]Means in a column with the same letter are not significantly different at the 5% level

difference compared to the ones in $FIRWB_{60}$. The higher spike length may result in higher seed number per spike for $FIRWB_{60}$ and $FIRWB_{80}$. An explanation should be given at this stage to justify the fact that yield components were higher for $FIRWB_{60}$ and $FIRWB_{80}$. First of all, seeds were placed on the shoulder of the raised wavy beds (Fig. 1) and away from the area of greatest salt accumulation (center of the bed), so wheat seedling growth was less exposed to salt concentrations. This can also be due to enhanced field access and higher sunlight absorption resulting in stronger, healthier wheat as a result of improved photosynthesis (Sayre & Moreno Ramos, 1997). Finally, fertilizer absorption efficiency increased, because of improved placement (Fahong *et al*., 2004). In addition to the extra

Fig. 2. Diagram of the soil salinity variation throughout the season at 0-30 cm soil depth, a) saline irrigation water of 4 dS m^{-1}, b) saline irrigation water of 8 dS m^{-1}, c) saline irrigation water of 12 dS m^{-1} (error bars represent standard deviation)



field access and light penetration, the extra distance from the salt concentrations on top of the bed to the plant and root zone can explain the slightly higher but not significant yield components for FIRWB$_{80}$ compared to FIRWB$_{60}$. This is more evident in the saline irrigation water of 12 dS m^{-1}.

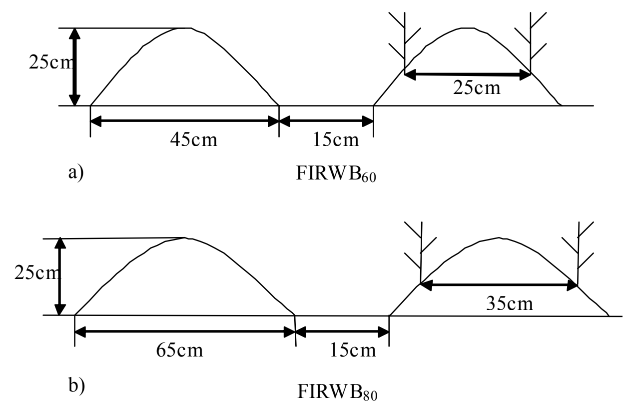
It can also be concluded that with the increase in salinity of irrigation water, the difference between the 1000-grain weight of FP and the FIRWB methods increased, since the lower salinity in the FIRWB methods caused a greater advantage over FP. In the irrigation water salinity of 4 dS m^{-1}, the 1000-grain weight was not influenced by salinity, but as the salinity of irrigation water increased, the influence on 1000-grain weight increased. Therefore, the difference of 1000-grain weight for FP and FIRWB increased.

Table V. Water productivity (WP) and productivity of irrigation water (PIW) for different irrigation/planting methods

Treatments		WP (kg m^{-3})	PIW (kg m^{-3})
4 dS m^{-1}	FP	0.808 b[a]	0.991 b
	FIRWB$_{60}$	0.853 a	1.128 a
	FIRWB$_{80}$	0.724 c	0.955 c
8 dS m^{-1}	FP	0.658 b	0.720 c
	FIRWB$_{60}$	0.756 a	0.932 a
	FIRWB$_{80}$	0.632 b	0.778 b
12 dS m^{-1}	FP	0.412 b	0.425 b
	FIRWB$_{60}$	0.488 a	0.586 a
	FIRWB$_{80}$	0.377 c	0.449 b
C.V. (%)		2.51	2.70

[a]Means in a column with the same letter are not significantly different at the 5% level

Fig. 1. A diagram of the two FIRWB planting systems



In contrast, in the irrigation water salinities of 4, 8 and 12 dS m^{-1}, spike number per square meter for FP was higher than FIRWB$_{60}$ and FIRWB$_{80}$. The lower spikes per square meter for the FIRWB methods were due to the increase of row spacing in these treatments. The FIRWB$_{80}$ method had the lowest spikes number per square meter, since it had the widest beds. It can also be concluded that with the increase of salinity of irrigation water, spike number per square meter for FP decreased more rapidly than the FIRWB methods. This was due to the severe salinity effects in the FP method, which will affect grain yield in this method.

Table III also indicates that grain yield was significantly affected by planting method. In the saline irrigation water of 4 dS m^{-1}, grain yield for FP was higher than FIRWB$_{60}$ and FIRWB$_{80}$. Although, the FIRWB methods had higher 1000-grain weight and spike length than FP, but these advantages could not compensate for the loss of spike number per square meter. The lower grain yield mentioned above was due to planting two rows of wheat on each bed instead of three. In addition to using two rows, soil salinity was lower than the tolerance level of 6 dS m^{-1} for wheat (Ayers & Westcot, 1976), so soil salinity did not cause yield reduction in any of the treatments. Therefore, the salinity reducing effects of the FIRWB methods in the root zone did not influence grain yield in these treatments. Several earlier studies (Fahong *et al.*, 2004; Zhang *et al.*, 2007) have indicated that furrow irrigated raised-bed planting with three rows on each bed can improve wheat grain yield by 5-10% in comparison with flat planting.

On the other hand, the grain yield for $FIRWB_{60}$ was 5.3 and 12.5% higher than FP in EC_{iw}=8 and 12 dS m^{-1} irrigation water, respectively. This could be related to the higher 1000-grain weight, spike length, and lower soil salinity for $FIRWB_{60}$ in comparison with FP, which compensated for the lower spike number per square meter. In relation to this, in the irrigation water salinities of 8 and 12 dS m^{-1} soil salinity for FP was higher than the FIRWB methods at 0-30 cm root zone throughout the season.

This difference in soil salinity has caused grain yield to reduce more in FP than the FIRWB methods. In addition, $FIRWB_{80}$ had slightly higher 1000-grain weight and spike length in comparison to $FIRWB_{60}$, but it could not compensate for the loss of spike number per square meter due to wider beds. Thus, $FIRWB_{80}$ had the lowest grain yield in all of the treatments, since it had the minimum number of seed lines. In this experiment, the increase of wheat grain yield in the FIRWB method was, lower than those of previous studies mainly due to having two rows per bed instead of three, saline irrigation water and may be relative to different wheat varieties.

Water productivity. The total water consumption (ET) throughout the season was significantly affected by irrigation/planting method. In addition, ET was calculated using Eq. (3) and is reported in Table IV. Mean irrigation water applied for $FIRWB_{60}$ and $FIRWB_{80}$ methods was respectively, 525.3 and 528.6 mm, 18.6 and 18.1% lower than that of the FP method. This was because less irrigation water is sufficient for furrow irrigation as compared with flood irrigation. Thus, the less amount of water applied induced less amounts of salts to the field in the FIRWB method. These results corroborated the earlier findings of Fahong *et al.* (2004) and Zhang *et al.* (2007), which mentioned the water saving characteristics of the furrow irrigated raised-bed planting method.

The increase of deep percolation with the boost of salinity of irrigation water was due to the higher soil moisture content before irrigation, which reduced soil moisture deficit (SMD). Therefore, the excess water was leached out of the soil profile, so deep percolation increased. In this case, the higher soil moisture is related to the higher salinity of the soil solution. In addition, the FP method in comparison with the FIRWB method had higher deep percolation, since it had higher irrigation water applied and higher soil moisture before irrigation. Fahong *et al.* (2004) reported that the humidity within the wheat canopy for raised-bed planting was consistently lower (for both the top of the bed & in the furrow) than the humidity within the crop canopy for flat planting. In this study, the lower moisture content at 0 to 30 cm soil depth in the $FIRWB_{60}$ and $FIRWB_{80}$ planting methods could be associated with the lower crop humidity mentioned before.

WP and PIW for each treatment were determined using Eq. (4), and Eq. (5), respectively and are summarized in Table V. The analysis of variance showed a significant difference of WP between different planting methods. Table V indicates that FIRWB effectively boosted WP and PIW. The highest WP and PIW were obtained under $FIRWB_{60}$, indicating that irrigation water was most efficiently used in this treatment.

Table V also indicates that WP and PIW of $FIRWB_{60}$ were higher than those of $FIRWB_{80}$ and FP for the saline irrigation water of 4 dS m^{-1}. It should be stated that the irrigation water savings of furrow irrigation in the $FIRWB_{60}$ method compensated for the lower grain yield and in turn increased WP and PIW. The yield per unit of water or irrigation depth consumed is a good indicator for assessing the performance of different irrigation/planting methods. However, the high value of productivity is of little interest if they are not associated with high (or acceptable) yields, particularly in water scarce areas (Ali *et al.*, 2007). Therefore, the $FIRWB_{60}$ and $FIRWB_{80}$ methods with two rows of wheat on each bed are not suitable in the saline irrigation water of 4 dS m^{-1}. However, the FIRWB method can be used with three rows of wheat on each bed, since salinity does not have any effect in the saline irrigation water of 4 dS m^{-1}. Previous researchers working with wheat reported the increase of WP under furrow irrigated raised-bed planting method with three rows of wheat on each bed (Fahong *et al.*, 2004; Zhang *et al.*, 2007).

In case of the saline irrigation water of 8 and 12 dS m^{-1}, WP of the $FIRWB_{60}$ method reached 0.756 and 0.488 kg m^{-3}. This indicates a relative increase in WP of 14.9 and 18.4% for $FIRWB_{60}$ compared to FP, respectively for the saline irrigation water of 8 and 12 dS m^{-1}. The higher WP and PIW for $FIRWB_{60}$ are obviously due to higher yields accompanied by saving of irrigation water as compared to FP. Although $FIRWB_{80}$ consumed less water than FP, but it could not compensate for the loss of grain yield due to wider beds and this resulted in a decrease of WP and PIW for the $FIRWB_{80}$ method. WP was lower than the findings of Fahong *et al.* (2004) and Zhang *et al.* (2007). This was due to growing wheat in saline conditions, which consumed more irrigation water for leaching requirements.

CONCLUSION

The use of $FIRWB_{60}$ can increase WP in a saline soil and water condition. Furthermore, the increase of salinity of irrigation water from 4 to 12 dS m^{-1}, decreased grain yield and water productivity, but this decrease was lower in $FIRWB_{60}$ than FP. Thus, the $FIRWB_{60}$ method is suitable for growing winter wheat in a harsh saline condition.

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