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Wheat water use and yield under different salinity of irrigation water

Meysam ABEDINPOUR ABCDEF ✉

Kashmar Higher Education Institute, Water Science and Engineering Division, 998145784 Kashmar, Iran;
e-mail: abedinpour_meysam@yahoo.com

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Abstract

A field experiment was conducted for determination of crop coefficient (*KC*) and water stress coefficient (*Ks*) for wheat crop under different salinity levels, during 2015–2016. Complete randomized block design of five treatments were considered, i.e., 0.51 dS·m^{-1} (fresh water, FW) as a control treatment and other four saline water treatments (4, 6, 8 and 10 dS·m^{-1}), for S_1, S_2, S_3 and S_4 with three replications. The results revealed that the water consumed by plants during the different crop growth stages follows the order of FW > S_1 > S_2 > S_3 > S_4 salinity levels. According to the obtained results, the calculated values of *KC* significantly differed from values released by FAO paper No 56 for the crops. The *Ks* values clearly differ from one stage to another because the salt accumulation in the root zone causes to reduction of total soil water potential (Ψ_t), therefore, the average values of water stress coefficient (*Ks*) follows this order; FW(1.0) = S_1(1.0) > S_2(1.0) > S_3(0.93) > S_4(0.82). Precise data of crop coefficient, which is required for regional scale irrigation management is lacking in developing countries. Thus, the estimated values of crop coefficient under different variables are essential to achieve the best management practice (BMP) in agriculture.

Key words: *crop coefficient, saline water, stress, wheat crop*

INTRODUCTION

Iran is an agricultural country, and the agricultural sector plays an important role in the national economy. Almost 27% of the gross national product (GNP) and 23% of the labour force belong to agriculture. The agricultural sector is the major user of water in Iran, consuming more than 87% of the country's water resources. Agricultural water productivity is one of the most important issues in economic development. The dry, high desert climate in Iran forced farmers to develop special methods of using their limited natural resources. For years precipitation has been of the declining (less than 250 mm) order while consumption, evaporation and waste have increased. Apart from this, salinity is one of the biggest problems in Iran. The total area affected by salinity and water logging is estimated to be about 15.5 million ha or 9.4% of the total country area. About 7.32 million ha have saline affected soils [FAO 2013].

Therefore, a complementary and more permanent approach to minimizing deleterious effects of soil and water salinity is to develop crops that can grow and produce economically sufficient yields under saline conditions. The crop evapotranspiration (*ETC*) can be affected by soil salinity since the soil water uptake by plant can be drastically reduced due to higher osmotic potential of the saline water. Poor crop growth may be due to adverse physical characteristics of saline soils. Therefore, it is necessary to estimate crop water needs in order to calculate deficiencies in the crop water requirement caused by shortage in precipitation or soil moisture storage capacities. One of the most accurate methods for determination of crop water requirement and crop coefficient is the lysimeter method. Due to different properties of cultivars, seasonal diversity in crop growth stages and local climatic variability, accurate estimation of crop parameters such as, crop coefficient (*KC*) and water stress coefficient (*Ks*) for determination of crop evapotranspiration (*ETC*) is very important to increase the water use efficiency and crop yield. Different reports around the globe has been released by researchers concern to *KC*, *Ks* and *ETC*. Values of *KC* varies over the crop growth stages and increases from a minimum value at sowing until a maximum *KC* reaches full canopy cover, the *KC* tends to decline at a point after a full cover is reached in the crop season [ALLEN *et al.* 2006; KO *et al.* 2009]. The comparison between local *KC* and the existent FAO values is always performed to ensure the quality of the new values [ARAUJO *et al.* 2011; CAVALCANTE *et al.* 2011; FILHO *et al.* 2015; KISI 2016; RÁCZ *et al.* 2013]. ABEDINPOUR [2015] evaluated maize growth coefficients by weighing lysimeter in New Delhi, India. The results revealed that, the observed *KC* values were different with the FAO values. A research performed in Texas (USA) found coefficient of Pearson of 0.87 for the local values of crop coefficient for wheat as compared to the FAO value [KO *et al.* 2009].

Overall, estimation of crop coefficient in the regions of salt affected soils can assist to improve the agricultural management. In this respect, a field experiment was conducted for determination of water stress coefficient (*Ks*) and *KC* for wheat under different salinity in the semi-arid environment. Thus, the goals of study were:

1. Determination of the actual water consumptive use of wheat crop under tape irrigation system saline and non-saline water.
2. Estimation of crop coefficient (*KC*) and water stress coefficient (*Ks*) for wheat plant through the plant growth stages under different salinity levels.
3. Determination of wheat growth and yield under different irrigation water salinity.

MATERIALS AND METHODS

SITE DESCRIPTION

A field experiment was performed in the Farm of Soil and Water Research Department, Kashmar Higher Education Institute, located at Kashmar city in the north-east of Iran. The latitude and longitude of the experiment site are 30°24′ N, 31°35′ E, respectively, while the altitude is 1180 m above sea level. The meteorological data recorded by the synoptic weather station which located 300 m away from the experimental site. The measured weather parameters used in this study were the maximum and minimum of the air temperature and air humidity, rainfall, wind speed, solar radiation and sun shine hours. Some chemical properties of the soil are presented in Table 1.

Table 1. Some chemical properties of the experimental soil

Depth cm	pH	EC_e dS·m^{-1}	Anions, meq·dm^{-3}			Cations, meq·dm^{-3}			
			Cl^-	HCO_3^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
0–20	8.46	0.58	2.20	2.88	0.12	1.51	0.87	2.62	0.25
20–40	8.41	0.55	2.25	2.83	0.25	1.47	0.94	2.47	0.55
40–60	8.57	0.52	2.01	2.89	0.15	1.54	1.14	1.91	0.47
60–80	8.62	0.52	2.00	2.87	0.28	1.40	1.38	1.84	0.33

Explanations: EC_e = electrical conductivity of saturated soil extracts.
Source: own study.

AGRONOMY PRACTICES

Complete randomized block design (CRBD) of five treatments with three replications were used for wheat crop. The experimental plot area was 2 × 1.5 m under T-Tape irrigation system. Wheat crop (*Triticum aestivum* L.) 'Pishtaz' variety was cultivated on December 18, 2015 and harvested at May 26, 2016. The amount of seeds required was 160 kg·ha^{-1}. The seeds planted with space of 5 cm within rows and 15 cm between rows. The experiment plots were fertilized before sowing with potassium sulphate (48%) superphosphate (15%) and at the rate of 80 and 100 kg·ha^{-1}, respectively. The nitrogen fertilizer was applied to the soil with three split doses with one-third given as basal, one-third at 30 days after sowing (DAS) and the remaining at 90 DAS of the crop.

Table 2. Some chemical characteristics of the used irrigation water

Treatment	pH	EC_W	Soluble anions, meq·dm^{-3}			Soluble cations, meq·dm^{-3}			
			Cl	HCO_3	SO_4	Ca	Mg	Na	K
Fresh water	7.52	0.5	1.43	1.25	0.03	1.12	1.23	0.27	0.09
S_1	8.23	4	28.8	3.4	4.78	4.25	8.4	22.8	1.02
S_2	8.38	6	40.1	3.2	8.9	3.68	17.6	30.7	1.28
S_3	8.42	8	61.5	2.8	11.2	4.79	22.3	45.6	1.48
S_4	8.27	10	88.3	3.1	10.8	6.27	27.5	66.3	1.74

Explanations: EC_W = electrical conductivity of water, S_1, S_2, S_3, S_4 = saline water treatments, 6, 6, 8 and 10 dS·m^{-1}, respectively.
Source: own study.

Five different irrigation water salinities, i.e., 0.51 dS·m^{-1} (fresh water) as a control treatment and other four saline water treatments (4, 6, 8 and 10 dS·m^{-1}), for S_1, S_2, S_3 and S_4, respectively, were used for this research. The saline water was made by blending fresh water with sodium chloride salt at a certain ratios. Chemical characteristics of the applied irrigation water through wheat season are presented in Table 2.

Irrigation water was applied based on the 50% moisture depletion (*MAD* 50%) of field capacity (FC) for all irrigation treatments. This amount was scheduled throughout the growth season and calculated according to the values of the recommended (*KC*) as well as the period of each stage.

ESTIMATION OF REFERENCE EVAPOTRANSPIRATION (*ETo*)

Reference crop evapotranspiration (*ETo*) was predicted by Penman–Monteith equation as follows using eq. (1):

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma\left(\frac{900}{T + 273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (1)$$

Where: *ETo* = reference crop evapotranspiration, mm·day^{-1}; Δ = slope vapour pressure curve, kPa·°C^{-1}; *Rn* = net solar radiation at the surface, MJ·m^{-2}·day^{-1}; *G* = heat flux density of soil, MJ·m^{-2}·day^{-1}; *T* = mean air temperature at crop height, °C; $e_s - e_a$ = saturation vapor pressure deficit, kPa; U_2 = wind speed at 2 m above the ground surface, m·s^{-1}, γ = psychrometric constant, kPa·°C^{-1}.

Therefore, CROPWAT v.8.0 software was used to calculate the mean 10-day values for *ETo*.

CALCULATION OF CROP EVAPOTRANSPIRATION (*ETC*)

There are two methods to estimate *ETC*, one under standard conditions (fresh water) and the other for nonstandard conditions (saline water). *ETC* under non-stress conditions, is given by eq. (2):

$$ETC = ETo \cdot KC \qquad (2)$$

Where: *ETC* = crop evapotranspiration, mm·day^{-1}; *KC* = crop coefficient; *ETo* = reference crop evapotranspiration, mm·day^{-1}.

Furthermore, the *ETC* under non-standard environment and management conditions i.e. salinity and deficit irrigation is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. So, the adjusted crop evapotrranspiration, is given by eq. (3):

$$ETC_{adj} = ETo \cdot KC \cdot Ks \qquad (3)$$

Where: ETC_{adj} = crop evapotranspiration under non-standard conditions, mm·day^{-1}, *Ks* = water stress coefficient; *KC* = single crop coefficient, *ETo* = reference crop evapotranspiration, mm·day^{-1}.

WATER STRESS COEFFICIENT (Ks)

Water stress coefficient (*Ks*) shows the crop transpiration affects due to the water stress or irrigation water deficit. The wheat threshold is the electrical conductivity of saturated extract (EC_e) above which yield starts to decline; is 6 dS·m^{-1} and the reduction in the total grain yield with increasing the soil salinity is 7.1% per dS·m^{-1} above threshold [MASS, HOFFMAN 1977]. When salinity stress occurs without water stress, for these conditions (EC_e > EC_t threshold), readily available soil water is more than soil water depletion (*MAD* < *RAW*), the *Ks* calculated by eq. (4):

$$Ks = 1 - \frac{b}{100K_y}(EC_e - EC_t) \qquad (4)$$

Where: EC_e = the electrical conductivity of a saturated soil extract, dS·m^{-1}; EC_t = electrical conductivity at the threshold point, dS·m^{-1}; *b* = slop of yield reduction per increase in soil salinity, K_y = yield response factor; *MAD* = management allow depletion, mm; *RAW* = the readily available soil water, mm.

ACTUAL EVAPOTRANSPIRATION (*ETa*)

Crop consumptive use (*Cu*) or actual crop evapotranspiration (*ETa*) is calculated by measuring changes of soil water contents during time interval considered and using the eq. (5). Soil moisture content through the soil profile was determined using TDR (time domain reflector meter). Measures were determined immediately before irrigation and one hour after irrigation. The soil moisture reading using TDR was recorded every 20 cm from soil surface up to 80 cm depth. The daily and seasonal evapotranspiration of wheat plant were calculated under all irrigation water treatments.

$$Cu = ETa = \left(\frac{\Theta_{fc} - \Theta_i}{100}\right)D_r \qquad (5)$$

Where: *Cu* = the seasonal water consumptive use, cm·period^{-1}; *ETa* = the crop evapotranspiration, cm·period^{-1}; Θ_{fc} = the percent of soil moisture contents at field capacity and before next irrigation during a specific time on volume basis; D_r = rooting depth, cm.

RESULTS

REFERENCE EVAPOTRANSPIRATION (*ETo*)

Table 3 shows values of reference crop evapotranspiration through the growth stages of wheat season. The values of *ETo* through growth season indicate that it is lowest with the beginning of season and increased till harvesting time. This may be due to the changes in the length of the crop growth stage, climatologically norms of the area, as the cultivation starts with both relatively low temperature and solar radiation and ended by high of it was. The total *ETo* value during the growth period of wheat was 514 mm.

Table 3. Values of *ETo* for all growth stages of wheat season in 2015–2016

Stage	Duration day	*ETo*	
		$mm·stage^{-1}$	$m^3·ha^{-1}$
Initial	20	42	420
Development	57	137	1370
Mid-season	58	230	2300
Late	25	105	1050
Total	160	514	5140

Source: own study.

ACTUAL EVAPOTRANSPIRATION (*ETa*)

Data in Table 4 show the actual evapotranspiration values for wheat crop. The obtained results indicate that the irrigation water salinity affects mainly the plant consumptive use i.e. the actual evapotranspiration (*ETa*). It is obvious that the total amount of the actual evapotranspiration (*ETa*) of plants irrigated with fresh water (FW) is higher (491 mm per season) compared with that of saline water irrigated once, where it was 483, 470.5, 460 and 451 $mm·season^{-1}$ for S_1, S_2, S_3 and S_4 salinity levels, respectively.

Referring to the effect of irrigation water salinity on the water consumptive use, reveal that the water consumed by plants during the different periods of plant growth follows the order of FW > S_1 > S_2 > S_3 > S_4 salinity levels. From the data presented in Table 4, it could be found that the mean values of seasonal actual crop evapotranspiration (*ETa*) of wheat crop varied with the variation of irrigation water salinity, plant growth stage and the changing in climatic conditions. At the initial stage, the average daily *ETa* was lower than other growth stages; it was 1.25, 1.23, 1.20, 1.18 and 1.14 $mm·day^{-1}$ for FW, S_1, S_2, S_3 and S_4, respectively. Subsequently, *ETa* was increased to reach maximum value at mid-season stage, where it was 4.20, 4.21, 4.18, 4.10 and 4.08 $mm·day^{-1}$ for FW, S_1, S_2, S_3 and S_4, respectively. Then, at the end of season it was decreased.

Table 4. The average seasonal *ETa* values of wheat plants grown under different irrigation water salinity

Treatment	*ETa* in growth stages								
	initial		development		mid-season		late		total
	$mm·day^{-1}$	mm	$mm·day^{-1}$	mm	$mm·day^{-1}$	mm	$mm·day^{-1}$	mm	mm
Fresh water	1.25	25.0	2.32	132.3	4.20	243.6	3.60	90.0	490.9
S_1	1.23	24.6	2.24	127.7	4.21	244.2	3.45	86.3	482.8
S_2	1.20	24.0	2.10	119.8	4.18	242.4	3.37	84.3	470.5
S_3	1.18	23.6	2.03	115.7	4.10	237.8	3.32	83.0	460.1
S_4	1.14	22.8	1.95	111.2	4.08	236.6	3.21	80.3	450.9

Explanations: S_1, S_2, S_3, S_4 as under the Table 2.
Source: own study.

CROP COEFFICIENT (*KC*)

The estimated (*KC*), derived from *ETo* and *ETC* or *ETa* (eq. 2). At the initial stage of the plant (at the beginning to 22 days after sowing), *KC* values were 0.59, 0.58, 0.0.57, 0.56 and 0.54 for FW, S_1, S_2, S_3 and S_4, respectively. Also *KC* values at the vegetative growth stage (development: 57 days after end of initial stage) which is a kinetic growth cycle the *KC* increased to 0.96, 0.93, 0.87, 0.84 and 0.81 for FW, S_1, S_2, S_3 and S_4, respectively. Subsequently, at the start of the mid-season period (flowering and seed filling period: 58 days after end of development stage) the *KC* values increased to a maximum of about 1.06, 1.06, 1.05, 1.03 and 1.03 for FW, S_1, S_2, S_3 and S_4, respectively (Tab. 5). The meaning of low *KC* data is reduced crop water need than that occurred from evapotranspiration of wheat, generally, less than that of cereals. Finally, during the late season (from end of mild-stage till harvest: 60 days), the *KC* decreased and reached a value of 0.86, 0.82, 0.80, 0.79 and 0.76 for FW, S_1, S_2, S_3 and S_4, respectively.

The average calculated *KC* values clearly differ from the mean *KC* values of FAO No. 56 during all stages, in the initial and development stage the average calculated *KC* values for FW, S_1, S_2, S_3 and S_4, were more than the average *KC* values released by FAO No.56; the opposite observations were found in mid and late stages, the average calculated *KC* values for FW, S_1, S_2, S_3 and S_4 lower and more than the mean *KC* values released by FAO No. 56, respectively.

Table 5. Crop coefficient (*KC*) of the four growth stages of wheat plants as affected by irrigation water salinity compared with *KC* values suggested by the FAO No. 56

Treatment	*KC* in growth stages			
	initial (20 days)	development (57 days)	mid-season (58 days)	late (25 days)
Fresh water	0.59	0.96	1.06	0.86
S_1	0.58	0.93	1.06	0.82
S_2	0.57	0.87	1.05	0.80
S_3	0.56	0.84	1.03	0.79
S_4	0.54	0.81	1.03	0.76
Acc. to FAO No. 56	0.4	0.8	1.2	0.7

Explanations: S_1, S_2, S_3, S_4 as under the Table 2.
Source: own study.

WATER STRESS COEFFICIENT (*Ks*)

Table 6 indicates the mean values of soil electrical conductivity in the root zone from 0–30 cm; it was used to calculate the water stress coefficient (*Ks*). Table 7 illustrates water stress coefficient (*Ks*) of wheat for the four growth stages under irrigation treatments.

Table 6. Electrical conductivity (EC_e) in the root zone of wheat plants

Treatment	EC_e (dS·m^{-1}) in growth stages			
	initial (20 days)	development (57 days)	mid-season (58 days)	late (25 days)
Fresh water	0.56	0.48	0.62	0.88
S_1	1.40	1.38	2.10	3.18
S_2	3.05	3.55	4.14	4.57
S_3	4.53	5.65	6.48	6.71
S_4	6.47	6.91	7.31	7.56

Explanations: S_1, S_2, S_3, S_4 as under the Table 2.
Source: own study.

Table 7. Water stress coefficient (*Ks*) for the four growth stages of wheat under irrigation with saline water

Treatment	*Ks* in growth stages			
	initial (20 days)	development (57 days)	mid-season (58 days)	late (25 days)
Fresh water	1.00	1.00	1.00	1.00
S_1	1.00	1.00	1.00	1.00
S_2	1.00	1.00	1.00	1.00
S_3	1.00	1.00	0.93	0.81
S_4	0.83	0.88	0.81	0.78

Explanations: S_1, S_2, S_3, S_4 as under the Table 2.
Source: own study.

During the initial stage, the *Ks* values close to 1.00 for FW, S_1, S_2, and S_3 that is mean that the root zone salinity (EC_e) did not reach to EC_e threshold value for wheat (6 dS·m^{-1}) [ALLEN *et al.* 1998]. But a moderate effect appears for S_4 with *Ks* (0.83). It can be stated that, soil texture may play an important role in this respect beside the effect of salt accumulation in the root zone in this stage. Meanwhile, development stage, the data in Table 7 demonstrates the same values; the *Ks* values were identical (1.00) for FW, S_1, S_2 and S_3 but the *Ks* value was amounting of 0.88 for S_4.

However, during the mid-season stage the influence of soil salinity (EC_e) in the root zone were obtained especially for S_2, S_3 and S_4, with *Ks*, 1.00, 0.93 and 0.81, respectively. At the end stage, the *Ks* values were 1.00, 1.00, 1.00, 0.81 and 0.78 for FW, respectively; the direct increase in salt accumulation as well as the irrigation with saline water had reduced the *Ks* values. Generally, the average values of water stress coefficient (*Ks*) follows this order; FW (1.00) = S_1 (1.0) = S_2 (1.0) > S_3 (0.93) > S_4 (0.82).

WHEAT CROP PRODUCTION

As for the effect of irrigation water salinity on wheat yield, data indicate that with less stressed condition (FW) treatment, wheat yield increased compared with the other salinity treatments. Table 8 illustrates the yield of wheat plants cultivated under T-Tape irrigation system as affected by different irrigation water salinity. The total yield varied between 3.54 to 5.06 t·ha^{-1}. The highest yield was obtained, when using fresh water (FW) which represents nearly non-stressed conditions and the lowest one was obtained with using saline water S_4 treatment. The obtained yield follows the descending order of: FW > S_1 > S_2 > S_3 > S_4. There are significant differences were obtained between FW yield (control) and other salinity treatments. On the other hand, S_1, S_2 and S_3 treatments gave the same yield approximately; where no significant differences between them. Where, wheat was classified into the moderate salt tolerant crop [MAAS, HOFFMAN 1977]. But, there is significant different between all treatments and S_4, whenever significant differences between S_1 and S_4 treatments. The data Table 8 show water use efficiency (*WUE*) of wheat crop as a function of irrigation water salinity. The obtained data indicate that a slightly decrease in the *WUE* with increasing irrigation water salinity from S_1 up to S_3 but sharply decreased occurred with S_4. The highest *WUE* value was obtained by (FW) and the lowest one was obtained by S_4. Values of *WUE* were 1.03, 0.93, 0.92, 0.87, and 0.78 kg·m^{-3} for FW, S_1, S_2, S_3 and S_4, respectively.

Table 8. Means of five irrigation treatments for yield and yield components traits of wheat

Treatment	Yield	Biomass	*WUE*	*IWUE*	*HI*
	kg·ha^{-1}		kg·m^{-3}		
Fresh water	5060^{a}	12767.4^{a}	1.03^{a}	0.75^{a}	0.40^{b}
S_1	4380^{ab}	10428.6^{ab}	0.91^{ab}	0.66^{b}	0.42^{a}
S_2	4350^{ab}	10408.9^{ab}	0.92^{ab}	0.67^{b}	0.42^{a}
S_3	4020^{b}	9348.7^{b}	0.87^{b}	0.63^{b}	0.43^{a}
S_4	3540^{c}	8620.5^{c}	0.78^{c}	0.54^{c}	0.41^{b}
$LSD_{0.05}$	265.4	752.6	0.14	0.12	0.10

Explanations: *WUE* = water use efficiency, *IWUE* = irrigation water use efficiency, *HI* = harvest index, S_1, S_2, S_3, S_4 as under the Table 2; treatment means followed by the same letter indicate no significant difference according to the least significant difference (LSD) test at probability level 0.05.
Source: own study.

DISCUSSION

Irrigation water salinity affects the *ETa*, depends on the soil physical characteristics', soil moisture and crop canopy [RUSHTON *et al.* 2006]. Crop evapotranspiration for middle season growth stage was higher than the other growth stage which agreed with [ER-RAKI *et al.* 2010] remote sensing estimates of *ETc* that compare very satisfactorily with ground measurements, since the soil evaporation and plant water stress are negligible, and wheat water requirement was higher in the vegetative and mid-season stage and shows decreasing trend toward the maturity stage [GAURAV *et al.* 2010]. Crop coefficient value is a function of irrigation frequency and the evaporative power of atmosphere (*ETo*). *KC* values for mild stage in cereals are commonly more than measured values in development stage [ALLEN *et al.* 2005; TYAGI *et al.* 2004]. According to KUMARI *et al.* [2013] the *KC* values (based on fractional canopy cover, fc) of wheat crop varied from 0.2 to 0.5, 0.5 to 0.9, 0.5 to 1.3, 0.5 to 1.3 and <0.3 to 0.7 for different months of winter season December, January, February, March and April, respectively.

Also, a study was done on estimating the crop coefficient (*KC*) and crop evapotranspiration (*ETc*) using SPOT-4 satellite data integrated with the meteorological data and FAO-56 approach. Reference evapotranspiration (*ETo*) were determined using FAO Penman-Monteith equation. Multi linear regression analysis was applied to develop the crop coefficient (*KC*) prediction equations for the different growth stages from vegetation indices. The results showed R^2 were 0.82, 0.90 and 0.97 for developing, mid-season and late-season growth stage respectively [FARG *et al.* 2012]. According to BANDYOPADHYAY and MALLICK [2003] the estimated values of KC for wheat at four crop growth stages (initial, crop development, mid season and maturity) were 0.33, 0.82, 1.08 and 0.64, respectively which were identical to those suggested by the FAO indicating need for generating these values at the local/regional level. Thus, the calculated *KC* values in this study were in agreement with the above reported results by researchers in different location in the globe.

Furthermore, according to CRAMER [1997], *Ks* values clearly differ from one stage to another because the salt stress causes both osmotic stress, due to a decrease in the soil water potential and ionic stress, due to toxicity caused by high concentrations of certain ions within the plant. The accumulation of solutes may allow plants to maintain a positive pressure potential, which is required to keep stomata open and to sustain gas exchange and growth [WHITE *et al.* 2000].

CONCLUSIONS

The daily *ET* of wheat under saline irrigation water is lower than under non-saline irrigation. The total yield varied between 3540 to 5060 kg·ha^{-1}. The highest yield was obtained, when using fresh water (FW) which represents nearly non-stressed conditions and the lowest one was obtained with using saline water S_4 treatment. Also, crop water use efficiency was decreased by increasing salinity of irrigation water. Thus, future study of the antioxidants ingredients of these varieties under salt stress should be examined using well-controlled water and solutes flux experimental system.

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Meysam ABEDINPOUR

Zużycie wody i plon pszenicy w warunkach różnego zasolenia wody stosowanej do nawodnień

STRESZCZENIE

W latach 2015–2016 przeprowadzono polowy eksperyment w celu określenia współczynnika roślinnego (*KC*) i współczynnika stresu (*Ks*) dla pszenicy nawadnianej wodą o różnym zasoleniu. Eksperyment przeprowadzono metodą bloków losowych w pięciu wariantach zasolenia: 0,51 $dS \cdot m^{-1}$ (woda słodka FW jako kontrola) oraz 4, 6, 8 i 10 $dS \cdot m^{-1}$ odpowiednio dla wariantów S_1, S_2, S_3 i S_4, każdy w trzech powtórzeniach. Wyniki wskazują, że woda pobierana przez rośliny w różnych stadiach ich rozwoju układała się w malejącym porządku zasolenia FW > S_1 > S_2 > S_3 > S_4. Obliczone wartości współczynnika *KC* różniły się istotnie od wartości podanych dla upraw w biuletynie FAO nr 56. Wartości *Ks* różniły się znacząco między poszczególnymi stadiami, ponieważ kumulacja soli w strefie korzeniowej ograniczyła całkowity potencjał wody glebowej (Ψ_t). Z tego powodu średnie wartości współczynnika stresu (*Ks*) malały w porządku FW(1,0) = S_1(1,0) > S_2(1,0) > S_3(0,93) > S_4(0,82). W krajach rozwijających się brakuje dokładnych danych o współczynniku roślinnym, które są niezbędne w regionalnym zarządzaniu wodą do nawodnień. Dlatego wartości współczynnika oznaczone w różnych wariantach zasolenia są istotne dla osiągnięcia najlepszych praktyk w gospodarce rolnej.

Słowa kluczowe: *stres, uprawa pszenicy, woda słona, współczynnik roślinny*