Wheat water use and yield under different salinity of irrigation water

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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 S₁, S₂, S₃ and S₄ with three replications. The results revealed that the water consumed by plants during the different crop growth stages follows the order of FW > S₁ > S₂ > S₃ > S₄ 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 (Ψᵣ), therefore, the average values of water stress coefficient (Ks) follows this order; FW(1.0) = S₁(1.0) > S₂(1.0) > S₃(0.93) > S₄(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 have been released by researchers concerned 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 [ARAÚJO et al. 2011; CAVALLANTE 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 from 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.

**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%) super-phosphate (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 1. Some chemical properties of the experimental soil**

| Depth (cm) | pH  | ECₑ (dS·m⁻¹) | Anions, meq·dm⁻³ | Cations, meq·dm⁻³ |
|------------|-----|--------------|------------------|------------------|
|            |     |              | Cl⁻ | HCO₃⁻ | SO₄²⁻ | Ca²⁺ | Mg²⁺ | 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: ECₑ = electrical conductivity of saturated soil extracts. Source: own study.

**Table 2. Some chemical characteristics of the used irrigation water**

| Treatment | pH  | ECₘ (dS·m⁻¹) | Soluble anions, meq·dm⁻³ | Soluble cations, meq·dm⁻³ |
|-----------|-----|--------------|--------------------------|--------------------------|
|           |     |              | Cl⁻ | HCO₃⁻ | SO₄²⁻ | Ca²⁺ | Mg²⁺ | Na⁺ | K⁺ |
| Fresh water | 7.52 | 0.5 | 1.43 | 1.25 | 0.03 | 1.12 | 1.23 | 0.27 | 0.09 |
| S₁        | 8.23 | 4   | 28.8 | 3.4  | 4.78 | 4.25 | 8.4  | 22.8 | 1.02 |
| S₂        | 8.38 | 6   | 40.1 | 3.2  | 8.9  | 3.68 | 17.6 | 30.7 | 1.28 |
| S₃        | 8.42 | 8   | 61.5 | 2.8  | 11.2 | 4.79 | 22.3 | 45.6 | 1.48 |
| S₄        | 8.27 | 10  | 88.3 | 3.1  | 10.8 | 6.27 | 27.5 | 66.3 | 1.74 |

Explanations: ECₘ = electrical conductivity of water, S₁, S₂, S₃, S₄ = 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 S1, S2, S3 and S4, respectively, were used for this research. The saline water was made by blending fresh water with sodium chloride salt at a certain ratio. 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 (ET\(0\))**

Reference crop evapotranspiration (ET\(0\)) was predicted by Penman–Monteith equation as follows using eq. (1):

\[
ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \left( \frac{900}{T + 273} \right) U_2 (e_t - e_a)}{\Delta + \gamma (1 + 0.34 U_2)}
\]

Where: \(ET_0\) = reference crop evapotranspiration, mm·day\(^{-1}\); \(\Delta\) = slope vapor pressure curve, kPa·°C\(^{-1}\); \(R_n\) = 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; \(e_t - e_a\) = saturation vapor pressure deficit, kPa; \(U_2\) = wind speed at 2 m above the ground surface, m·s\(^{-1}\); \(\gamma\) = psychrometric constant, kPa·°C\(^{-1}\).

Therefore, CROPWAT v.8.0 software was used to calculate the mean 10-day values for ET\(0\).

**CALCULATION OF CROP EVAPOTRANSPIRATION (ET\(C\))**

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

\[
ETC = ET_0 \times KC
\]

Where: \(ETC\) = crop evapotranspiration, mm·day\(^{-1}\); \(KC\) = crop coefficient; \(ET_0\) = reference crop evapotranspiration, mm·day\(^{-1}\).

Furthermore, the ET\(C\) 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 evapotranspiration, is given by eq. (3):

\[
ETC_{adj} = ET_0 \times KC \times KS
\]

Where: \(ETC_{adj}\) = crop evapotranspiration under non-standard conditions, mm·day\(^{-1}\); \(KS\) = water stress coefficient; \(KC\) = single crop coefficient, \(ET_0\) = 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\(t\)) 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\(t\) > EC\(e\) threshold), readily available soil water is more than soil water depletion (MAD < RAW), the KS calculated by eq. (4):

\[
KS = 1 - \frac{b}{100K_y} (EC_e - EC_t)
\]

Where: \(EC_e\) = the electrical conductivity of a saturated soil extract, dS·m\(^{-1}\); \(EC_t\) = electrical conductivity at the threshold point, dS·m\(^{-1}\); \(b\) = slope 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 (ET\(a\))**

Crop consumptive use (Cu) or actual crop evapotranspiration (ET\(a\)) 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.

\[
Cu = ETa = \left( \frac{\Theta_f - \Theta_i}{100} \right) D_r
\]

Where: \(Cu\) = the seasonal water consumptive use, cm·period\(^{-1}\); \(ETa\) = the crop evapotranspiration, cm·period\(^{-1}\); \(\Theta_f\) = 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 (ET\(0\))**

Table 3 shows values of reference crop evapotranspiration through the growth stages of wheat season. The values of ET\(0\) 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 \( \text{ETO} \) value during the growth period of wheat was 514 mm.

### Table 3. Values of \( \text{ETO} \) for all growth stages of wheat season in 2015–2016

| Stage  | Duration \( \text{day} \) | \( \text{ETO} \) \( \text{mm} \cdot \text{stage}^{-1} \) | \( \text{ETO} \) \( \text{m}^3 \cdot \text{ha}^{-1} \) |
|--------|-----------------|-----------------|-----------------|
| 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 (\( \text{ETa} \))

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 (\( \text{ETa} \)). It is obvious that the total amount of the actual evapotranspiration (\( \text{ETa} \)) 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 (\( \text{ETa} \)) of wheat varied with the variation of irrigation water salinity, plant growth stage and the changing in climatic conditions. At the initial stage, the average daily \( \text{ETa} \) 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, \( \text{ETa} \) 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 \( \text{ETa} \) values of wheat plants grown under different irrigation water salinity

| Treatment | \( \text{ETa} \) in growth stages |
|-----------|---------------------------------|
|           | initial \( \text{mm day}^{-1} \) | development \( \text{mm} \) | mid-season \( \text{mm day}^{-1} \) | late \( \text{mm day}^{-1} \) | total \( \text{mm} \) |
| 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 \( \text{ETO} \) and \( \text{ETC} \) or \( \text{ETa} \) (eq. 2). At the initial stage of the plant (at the beginning to 22 days after sowing), \( KC \) values were 0.59, 0.58, 0.57, 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             |

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 (ECe) in the root zone of wheat plants

| Treatment        | ECe (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          |
| S1               | 1.40             | 1.38                  | 2.10                  | 3.18          |
| S2               | 3.05             | 3.55                  | 4.14                  | 4.57          |
| S3               | 4.53             | 5.65                  | 6.48                  | 6.71          |
| S4               | 6.47             | 6.91                  | 7.31                  | 7.56          |

Explanations: S1, S2, S3, S4 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          |
| S1         | 1.00             | 1.00                  | 0.93                  | 0.81          |
| S2         | 1.00             | 1.00                  | 1.00                  | 1.00          |
| S3         | 1.00             | 1.00                  | 0.93                  | 0.81          |
| S4         | 0.83             | 0.88                  | 0.81                  | 0.78          |

Explanations: S1, S2, S3, S4 as under the Table 2.
Source: own study.

During the initial stage, the Ks values close to 1.00 for FW, S1, S2, and S3, that is mean that the root zone salinity (ECe) did not reach to ECw, threshold value for wheat (6 dS∙m⁻¹) [Allen et al. 1998]. But a moderate effect appears for S4 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, S1, S2 and S3 but the Ks value was amounting of 0.88 for S4.

However, during the mid-season stage the influence of soil salinity (ECw) in the root zone were obtained especially for S2, S1 and S4 with Ks 1.00, 0.93 and 0.81, respectively. At the end stage, the Ks values were 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) = S1 (1.0) > S2 (1.0) > S3 (0.93) > S4 (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 S4 treatment. The obtained yield follows the descending order of: FW > S1 > S2 > S3 > S4. There are significant differences were obtained between FW yield (control) and other salinity treatments. On the other hand, S1, S2, and S3 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 S4, whenever significant differences between S1 and S4 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 S1 up to S4 but sharply decreased occurred with S4. The highest WUE value was obtained by (FW) and the lowest one was obtained by S4. Values of WUE were 1.03, 0.93, 0.92, 0.87, and 0.78 kg∙m⁻³ for FW, S1, S2, S3 and S4, 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 | 5060a | 12767.4a | 1.03a | 0.75a | 0.40a |
| S1         | 4380ab| 10428.6ab| 0.91ab| 0.66ab| 0.42ab|
| S2         | 4350a | 10408.9a | 0.92a | 0.67a | 0.42a |
| S3         | 4020 | 9348.7 | 0.87 | 0.63 | 0.43 |
| S4         | 3540 | 8620.5 | 0.78 | 0.54 | 0.41 |
| LSD0.05 | 265.4 | 752.6 | 0.14 | 0.12 | 0.10 |

Explanations: WUE = water use efficiency, IWUE = irrigation water use efficiency, HI = harvest index, S1, S2, S3, S4 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 ETo, depends on the soil physical characteristics, soil moisture and crop canopy [Rushston et al. 2006]. Crop evaportranspiration for middle season growth stage was higher than the other growth stage which agreed with [Er-Raki et al. 2010] remote sensing estimates of ETo 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

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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 (ETo) 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 Bandypadhyay 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], $K_s$ 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 $S_2$ 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∙m⁻¹ (woda słodka FW jako kontrola) oraz 4, 6, 8 i 10 dS∙m⁻¹ odpowiednio dla wariantów S₁, S₂, S₃ i S₄, każdy w trzech powtarzaniach. Wyniki wskazują, że woda pobierana przez rośliny w różnych stadiach ich rozwoju układała się w malejącym porządku zasolenia FW > S₁ > S₂ > S₃ > S₄. 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 (Ψt). Z tego powodu średnie wartości współczynnika stresu (KS) małasy w porządku FW(1,0) = S₁(1,0) > S₂(1,0) > S₃(0,93) > S₄(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