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The Effect of Potassium and Zinc Foliar application time on Grain Yield, Qualitative Traits and water Use Efficiency (WUE) of Corn (*Zea Maize* L.; S.C704) under Deficit Irrigation Conditions

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ABSTRACT

In order to investigate the effect of potassium and zinc foliar application on grain yield and quality characteristics of corn under deficit irrigation conditions, a research was carried out in summer of 2015 and 2016as split-split plots based on completely randomized block design with three replications in Ahvaz, the southwest of Iran. The main factor included deficit irrigation operations including three stages (irrigation off at 12 leaf stage, irrigation off in the emergence stage and full irrigation), and the sub factor including three stages of potassium foliar application (8 leaf stage, 12+ 8 leaf stages and non-application) and sub-sub factor including three stages of zinc foliar application (8 leaf stage, 12+ 8 leaf stages and non-application).The results showed that simple effect and interaction effects of deficit irrigation stress and potassium and zinc foliar application on grain yield, chlorophyll a and b, proline, soluble sugars, relative water content, and economic and biological efficiency of water use were significant. The highest grain yields (1073.28 gr/m^2), chlorophyll a (4.47 ml/g), chlorophyll b (2.53 ml/g) and relative water content (92.4%) were obtained in optimum irrigation with two stages Potassium and zinc foliar application. In the case of irrigation off in the 12+8 leaves stage with two foliar application steps, the most effective water use efficiency (1.335 kg/m3) and biological water use efficiency (3.321 kg/m3) were also obtained. Also, two stages of potassium and zinc foliar application under deficit irrigation conditions, by improving all the measured traits, could greatly compensate for the damage caused by stress and increase grain yield.

Keywords: corn grain yield, chlorophyll a and b, proline, sugar, leaf relative water

1. INTRODUCTION

Corn cultivation has increased in recent years and its use in livestock and poultry nutrition and industrial use has been considered (Imanogor Patrick Aromuegbe et al. 2018). On the other hand, water supply is essential in the particular stages of vegetative and reproductive growth of maize (Salispour et al., 2009; Shrestha and Subedi, 2018). Plants respond to stress conditions when drought stress changes occur make some alterations in their physiological characteristics (Salman Saleem et al. 2017). Increasing the accumulation of solutes in response to drought stress conditions is a way to keep plant turgor. Also, the accumulation of proline in higher plants is a general reaction to stress. However, amount of several other amino acids also increase under drought stress, but the degree of these changes is not comparable to proline accumulation. Other substances that accumulate under stress in plants are soluble sugars, which under water stress can act in two ways: as an osmotic agent, or as an osmotic protector (Sanchez et al., 2003).

Cagnula et al. (2018) stated that water deficit stress during pollination and before pollination increased sugar content in corn plant. Moser et al. (2006) stated that the effect of water deficit in vegetative stage led to a decrease in corn grain yield compared to irrigation treatments, and significantly reduced the number of seeds per row, the number of rows in ear and 1000-grain weight. Ghoshchi et al. (2008) concluded that deficit irrigation stress in the pre-silk stage, silk stage and grain filling stage was significantly decreased yield by 12.5, 42 and 22.5 percent, respectively, than the desired conditions. Deficit irrigation reduced corn grain yield (Naem et al., 2018) and decreased chlorophyll a, b content (Hsong et al., 2018; Abdurrahman et al., 2018). Khaliq et al. (2016) stated that with increasing number of irrigation steps, the highest significant effect of water use efficiency on grain yield was obtained. Potassium and zinc are known as an important factor in controlling water shortages in plants. These elements play an important role in the growth of crop production, and important elements in the physiology of plant water relations (Voldabadi et al., 2009).

Potassium sulfate foliar application was not significantly different in drought stress conditions of one stage in the plant sowing and one stage in tasseling. However, the foliar application in two stages had a significant effect on corn grain yield (Forutan and Yarnia 2015). Merira et al. (2018) argued that potassium foliar application increased chlorophyll a and b content. Potassium foliar application had a significant effect on 1000-seed weight and grain yield before flowering and two weeks later (Kana'povsky et al., 2015). Zafar et al. (2018) stated that simultaneous application of potassium and zinc resulted in increased water use efficiency. Kumar et al. (2017) concluded that co-application of potassium and zinc increased the sugar content in plant. Monirah et al. (2015) stated that Znfoliar application increased the corn leaf relative water content and chlorophyll and Zn application increased the grain yield compared to control. Farnia and Khodabandehloo (2015) stated that the interaction of water deficit stress and zinc foliar application on 100 grain weight was significant. Irrigation stress without foliar application showed the lowest amount of SPAD chlorophyll, 100-grain weight and grain yield.

Due to the aggravation of water deficit in the southwestern part of Iran, there is no possibility of irrigation at some stages of corn growth and severe grain yield decrease occurs. On the other hand, nutrients can play an important role in improving the plant's status in counteracting different environmental stresses, and since zinc and potassium have important functions in plant metabolism for water stress tolerance, so the aim of the present study is to determine the effects of these two elements on the yield and important physiological traits of corn in water deficit conditions.

2. MATERIALS AND METHODS

This research was carried out for two years (2015 and 2016) as split plots in a randomized complete block design with three replications in southwest of Iran, Ahwaz (31° 20'N latitude and 48° 40'E longitude with altitude of 12 meters above sea level) and mean annual rainfall of 213 mm, based on the long-term average of 30 years and the average minimum and maximum temperature of 7°C and 54°C, respectively. The study area has dry climate, based on the criteria of the Domarten. The experimental factors included irrigation cut off in three stages (irrigation cut off at 12 leaf stage, irrigation cut off at the emergence stage and full irrigation), three stages of potassium foliar application (8 leaves and 12+8 leaves stages and non-foliar application) and three stages of zinc foliar application (8-leaf stage, 12+8-leaf stages and non-application).

Before planting, soil samples were taken randomly and in a zigzag manner from field soil depths of 0-30 and 60-30 cm and physical and chemical properties of soil were determined (Table 1). The land preparation operations consisted of a plow plunger at a depth of 30 cm, two discs, a trowel, arrow building at a distance of 75 cm. Following the preparation of the seedbed, fertilizers were added to the soil based on the soil test results. The sowing date was based on the climatic conditions of Ahwaz on July 25th of each year. The amount of potassium and zinc application was determined by the recommended amount by 2 and 3 unit per thousand, respectively. The source of the utilized elements was 40% potassium fertilizer, and zinc liquid fertilizer 7%, respectively. Elements foliar application was applied to the whole surface of the plant during early morning. After applying drought stress treatments, re-irrigation was performed when stress symptoms, including the curvature of the youngest leaves, were observed in samples under stress (Sediq et al., 2000). Each treatment was applied to each plot in plots containing six 5 meter lines at a distance of 75 cm between the rows and 18 cm spacing between the plants on the row and the sowing depth of 3-5 cm. The first irrigation was carried out immediately after planting and irrigation was performed based on depletion of 30% of field capacity moisture. According to formula proposed by Alizadeh (2008), after reaching the determined moisture content of the soil, the required volume of water was calculated as follows:

Moisture percent (w/w) = (moist soil weight- dry soil weight)/soil dry weight

$$V = \frac{(FC - \theta m) \times \rho b \times DRoot \times A}{Ei}$$

Where, V: volume of irrigation water (m^3), F_c: the percentage of moisture content at the field capacity, θ_m: Percentage of moisture content before irrigation, ρb: the soil bulk density (g/cm^3), A: Irrigated area (m^2), D_{root}: Root Depth (m) and E_i: Irrigation efficiency. Input water to the each plot was measured using a pump and a meter installed on irrigation pipes.

Table 1 Physical and chemical properties of soil in two years of study

	Depth	Organic Carbon (%)	Phosphorous	Potassium	Zinc	pH	EC (dS/m)	Texture
2015	0-30	0/74	11/4	195	0/28	7/1	3/44	Sandy-clay- loam
	30-60	0/28	6/3	154	0/17	7/1	3/32	Sandy-clay- loam
2016	0-30	0/72	11/1	183	0/26	7/2	3/36	Sandy-clay- loam
	30-60	0/25	6/9	122	0/19	7/3	3/1	Sandy-clay- loam

Grain yield was obtained from the total grain weight per unit area. In order to measure the chlorophyll a and b concentrations after applying stress in two stages (irrigation at stage 6 and 8 leaves and crown flower), the method recommended by Arnon (1975) and the spectrophotometer (Zeletex Zx 50 made in Germany) were utilized (Arnon, 1975).

$$mg\ Chlorophyll\ a\ per\ gr\ leaf = [12.7\ (D663) - 2.59(D645) \times \frac{V}{1000 \times W}$$

$$mg\ Chlorophyll\ b\ per\ gr\ leaf = [22.9\ (D645) - 469(D663) \times \frac{V}{1000 \times W}$$

Proline free index in leaf

The amount of proline accumulated in the plant at flowering stage (silk) measured using spectrophotometer at 520 nm and calculated according to the standard curve obtained from different concentrations of proline as g/g leaf weight (Bates et al., 1973).

Soluble Sugars

Soluble sugars content was measured using the Hendrix method (1993). Firstly, 0.5 g of leaves were thoroughly crushed in 5 ml of 95% ethanol in the masonry and shaken vigorously with vortex machine for 30 seconds. Then, the absorbance was measured by spectrophotometer at 625 nm.

RWC content measurement by Ritchie *et al.* (1990)

By placing the numbers derived from the weight of leaves with a scale of one ten thousandths, the following formula was obtained:

RWC:
$RWC=(FW-DW)/(SW-DW)\times 100$

Where, FW: fresh weight of the leaves after sampling, DW: dry weight after placement in oven and SW: the saturation of the leaves after putting in distilled water.

Biological Water Use Efficiency (kg/m^3)

The amount of dry matter produced (ton/hectare or kilogram/hectare) is obtained per unit (m^3) of water consumed by the plant.

$WUE= D/W$
Where, WUE = biological efficacy of water use, D= amount of dry matter produced, W = amount of water consumed,

Economic efficiency of water consumption (kg/m^3):

The economic yield generated by the plant is obtained for each unit of water consumed.

$WUEg = GY / W$
WUEg = Economic efficiency of water use, GY= economic yield, W = amount of water consumed (Karam et al., 2007).

The statistical analysis of the data was performed using SAS and MSTATC software and the mean comparisons were performed using Duncan Multiple Range Test.

3. RESULTS AND DISCUSSION

Chlorophyll

The results of analysis of variance showed that irrigation cut off stress ($P < 0.01$), potassium foliar application ($P<0.01$), zinc foliar application ($P < 0.01$) and interactions of zinc and potassium foliar application ($P < 0.01$), as well as triple interaction effects of irrigation cut off× Potassium× zinc foliar application significantly affected chlorophyll a and b content in corn ($P < 0.01$; Table 2). The lowest amount of chlorophyll a and b were obtained in irrigation cut off at tasseling stage and no zinc and potassium application by 1.79 and 0.99 mg/g, respectively, with the highest chlorophyll a and b content by 4.47 and 2.53 mg/g of leaves was obtained in optimal irrigation and two stages of zinc and potassium foliar application (Table 3). The photosynthesis rate is limited in response to dehydration due to the closure of the stomata and defects in metabolic processes, and the total amount of chlorophyll is reduced (Mafakheri et al., 2010). But it is possible to improve yield under stress conditions through foliar application to improve conditions to increase chlorophyll concentration and photosynthesis. Despite the increase in the level of water deficit stress, chlorophyll levels increased, and this was due to the protective role of potassium and zinc in increasing chlorophyll and preventing damage from water stress. The chlorophyll content in living plants is one of the important factors for preserving photosynthetic capacity (Jiang and Hang, 2001). The researchers concluded that possibly the deficient of micro-nutrients could prevent the activity of a number of antioxidant enzymes, resulting in oxidative damage to chlorophyll (Cakmak, 2000). Increasing the chlorophyll content is attributed to increasing the nutrients availability, especially zinc and potassium, and increasing the availability of other elements. Foliar application at different stages of plant growth may result in less nutrients loss and consequently increases nutrients availability for the plants which in turn increase the chlorophyll content. Zinc foliar application does not directly affect the formation of chlorophyll, but it can affect the concentration of nutrients involved in the chlorophyll formation or elements that are part of the chlorophyll molecule, such as iron and magnesium (Kaya and Higgs, 2002). Osman et al. (2017), Kumar & Singh (2018), Wajari et al. (2018), and Zafar et al. (2018) achieved similar results.

Proline and Soluble Sugars

According to the results of analysis of variance, irrigation cut off stress (P<0.01), potassium foliar application (P<0.01), zinc foliar application (P<0.01) and interactions of zinc and potassium foliar application (P<0.01) and triple interactions of irrigation cut off stress× zinc× potassium foliar application (P <0.01) had a significant effect on proline and sugar content of corn (Table 2). The highest values of these parameters were obtained by 111.7 and 148 µmol/g of leaf fresh weight in irrigation cut off stress at tasseling and potassium and zinc foliar application in two stages, respectively. The lowest amounts by 39.4 and 58.3 µmol/g of leaf fresh weight were obtained in optimum irrigation and non-application of zinc and potassium (control) (Table 3). Munns (1993) concluded that at the initial stages of maize exposure to the stress, the amount of soluble carbohydrates increases due to the conversion of sucrose to monosaccharide sugars. Ferdin et al. (1996) stated that in under water deficit stress condition, maintaining and preserving the pressure potential to actively photosynthesis and continuing to grow provides through increased solutes in the cell. Carbohydrates and proline are the most important compounds. Proline is also considered as an indicator for assessing resistance to stress. Proline acts as a reservoir of nitrogen or a solubilizing agent that reduces the osmotic potential of the cytoplasm and helps the plant to tolerate stress (Reedi et al., 2004; Shawu et al., 2006). Cavellier (1983) stated that increasing proline in plants under stress conditions is actually a response from the plant to reduce the water potential in the root environment. Meanwhile, proline reduces the osmotic potential of root cells provides the proper conditions for water and nutrients uptake. Therefore, foliar application can regulate the osmotic potential of the plant under stress conditions through increased proline and sugar content. Foliar addition of potassium also significantly increased proline content of Mungbean (Taloth et al., 2006), which was in consistent with the results obtained in this study. Hamza et al. (2018), Torabian et al. (2016), and Abdul Rahman et al. (2018) also found similar results.

Table 2 The results of combined analysis of variance of different stages of irrigation interruption, potassium spraying and zinc foliar application and their interaction on quantitative and qualitative traits of corn

		Mean Squares							
Source of Variance	df	Grain Yield	Chlorophyll a	Chlorophyll b	Proline	Soluble sugars	Leaf relative water content	Biologic water use efficiency	Economic water use efficiency
Year (Y)	1	69689ns	0/19ns	0/13ns	112/5ns	94/9ns	20/7ns	0/098ns	0/004ns
Replication (Year) (R(Y))	4	3718ns	0/17ns	0/008ns	6/32ns	2/50ns	4/61ns	0/008ns	0/0006ns
Irrigation interruption (I)	2	1251804**	25/85**	6/59**	21573/1**	43253/6**	641/9**	8/89**	2/49**
Year*Irrigation	2	1758ns	0/0009ns	0/0004ns	0/46ns	0/19ns	0/02ns	0/0004ns	0/0002ns
Replication (R(Y*I))	8	4236	0/03	0/02	4/01	32/7	6/37	0/005	0/003
Potassium Foliar Application (K)	2	109552**	7/88**	3/05**	2564/4**	5712/5**	607/9**	2/06**	0/300**
Y*K	2	1568ns	0/003ns	0/01ns	4/16ns	2/2ns	1/2ns	0/003ns	0/00008ns
I*K	4	48475**	1/01**	0/25ns	134/8ns	1174/8**	22/6ns	0/052ns	0/09ns
Y*I*K	4	1031ns	0/0006ns	0/002ns	0/46ns	0/56ns	0/02ns	0/0009ns	0/0002ns
R(Y*I*K)	24	8678	0/12	0/02	31/40	37/45	8/53	0/011	0/004
Zinc Foliar Application (Z)	2	114116**	5/30**	2/58**	2326/6**	3426/4**	293/4**	0/63**	0/17**
Y*Z	2	4530ns	0/06ns	0/001ns	14/35ns	23/4ns	0/76ns	0/009ns	0/0009ns
I*Z	4	8912ns	0/27ns	0/21ns	264/8**	344/8ns	20/03ns	0/12ns	0/02ns
Y*I*Z	4	794ns	0/01ns	0/007ns	0/92ns	4/6ns	0/24ns	0/004ns	0/0001ns
K*Z	4	156254**	1/10**	0/67**	640/9**	919/5**	158/3**	0/44**	0/16**
Y*Z*K	4	2383ns	0/004ns	0/021ns	8/1ns	4/2ns	1/87ns	0/008ns	0/0004ns
I*Z*K	8	110343**	0/86**	0/39**	238/4**	605/3**	69/3**	0/19**	0/077**
Y*I*Z*K	8	353ns	0/003ns	0/009ns	0/92ns	1/02ns	0/24ns	0/002ns	0/0002ns
Error	72	10217/9	0/12	0/054	37/57	84/43	9/89	0/019	0/011
Coefficient of Variation (%)	-	13/02	11/15	14/00	8/33	9/46	3/93	5/83	8/84

* and ** significant at 5 and 1 percent significant level, ns: non-significant.

Table 3 Mean comparison results of the interactions of different levels of irrigation interruption, potassium spraying and zinc foliar application on quantitative and qualitative traits of corn

	Grain Yield (gr/m2)	Chlorophyll a (mg/g leaf)	Chlorophyll b(mg/g leaf)	Proline (µg/gr leaf)	Soluble sugars (mg/g leaf)	Leaf relative water content (%)	Biologic water use efficiency	Economic water use efficiency
I ×K×Z								
$I_0K_0Z_0$	835/7d	3/42e	1/50d	39/4g	58/3f	79/5c	1/60g	0/72f
$I_0K_0Z_1$	883/6cd	3/95bc	1/59d	45/4g	63/7f	80/6c	1/80f	0/77f
$I_0K_0Z_2$	952/3c	4/07b	1/84d	52/2f	70/3 e	83/2c	1/85f	0/9e
$I_0K_1Z_0$	859/1d	3/19d	1/55d	43/3g	60/7f	80/0c	1/78f	0/86e
$I_0K_1Z_1$	878/6cd	3/70c	1/78d	53/3f	64/0f	84/9bc	1/90f	0/95e
$I_0K_1Z_2$	1006/8b	4/13b	2/23b	53/1f	68/4f	87/1b	2/22e	0/97e
$I_0K_2Z_0$	944/5c	4/02b	1/94c	50/7f	66/3f	86/1b	2/00f	0/98e
$I_0K_2Z_1$	1002/4b	4/10b	1/99c	61/7e	72/0f	83/3bc	2/16ef	1/17c
$I_0K_2Z_2$	1073/8a	4/47a	2/53a	68/6e	85/8e	92/4a	2/50d	1/27c
$I_1K_0Z_0$	755/2de	2/23f	1/16e	56/9e	80/3e	74/3cd	2/58d	1/26c
$I_1K_0Z_1$	759/9de	2/51e	1/57d	71/3d	85/2e	74/9cd	2/72d	1/34bc
$I_1K_0Z_2$	797/2d	2/48e	1/58d	72/4d	89/3d	75/4cd	2/79c	1/40ab
$I_1K_1Z_0$	718/6e	2/48e	1/68d	66/7e	92/1d	79/6c	2/54d	1/38b
$I_1K_1Z_1$	760/8de	3/41c	1/69d	72/9d	96/7d	80/5c	2/67d	1/39 ab
$I_1K_1Z_2$	816/7d	3/50c	2/27b	73/4d	99/0d	83/2c	2/83c	1/45 a
$I_1K_2Z_0$	813/3d	3/15c	2/01c	74/3d	93/2d	83/7c	2/81c	1/45a
$I_1K_2Z_1$	885/7cd	3/80b	2/12c	90/9c	129/5b	85/6b	2/86c	1/45a
$I_1K_2Z_2$	942/5c	4/28ab	2/43ab	100/9b	144/1a	89/1b	3/21a	1/51a
$I_2K_0Z_0$	579/7f	1/79g	0/99f	85/7d	106/3c	72/2d	2/21e	1/06d
$I_2K_0Z_1$	587/5f	2/30f	1/04e	94/4c	120/2b	73/6cd	2/36e	1/28c
$I_2K_0Z_2$	687/6e	2/56e	1/15e	92/0c	120/3b	79/9c	2/34e	1/35b
$I_2K_1Z_0$	589/3f	2/18f	1/00e	83/0d	113/5c	74/5cd	2/29e	1/13d
$I_2K_1Z_1$	611/8f	2/48f	1/19e	96/7bc	125/2b	74/9cd	2/34e	1/16 d
$I_2K_1Z_2$	721/0e	2/66e	1/45d	100/1b	136/1b	76/5c	2/74d	1/32 bc
$I_2K_2Z_0$	659/6e	2/53f	1/07e	90/9c	125/3b	74/9cd	2/36de	1/24c
$I_2K_2Z_1$	656/8e	2/93d	1/57d	99/8b	130/7b	82/6b	2/84c	1/32 bc
$I_2K_2Z_2$	763/6de	3/70c	2/06c	111/7a	148/0a	86/0b	3/05b	1/38b

I0: Optimum irrigation, I1: Stress at 12 leaf stage, I2: stress at Tassel stage, K0: no Potassium foliar application, K1: One stage potassium foliar application at 8 leaf stage, K2: Two steps of potassium foliar application in 8 Leaf and 12 leafs stage, Z0: no zinc foliar application, Z1: one stage of zinc foliar application at 8 leaf stage, Z2: two stages of zinc foliar application at 8 leaf and 12 leaf stages,

Means having similar letters do not have a significant difference in the 5% probability level.

Leaf Relative Water Content (RWC)

Analysis of variance showed that the relative water content of corn leaves was significantly affected by irrigation cut, potassium and zinc foliar application (P<0.01) and interactions of zinc and potassium foliar application as well as triple interactions irrigation interruption× Zn× potassium foliar application were significant (P <0.01; Table 2). The highest amount leaf RWC was obtained by 92.9% in normal irrigation and potassium and zinc spraying in two stages, and the least amount was observed in irrigation water stress treatment at tasseling stage and non-application of potassium and zinc by 72.2% and there was no significant difference among some treatments (Table 3).The RWC can be kept high through the foliar application in a timely manner, which stabilizes grain yield. Tarominkeng and Koto (2003) reported the reasons for decreasing the relative water content of the leaf as a delay in root growth and its activity, as well as increased evapotranspiration rate. Various studies have shown that potassium and zinc foliar application has increased the leaf area through maintaining relative water content of the leaves, which, by absorbing more solar radiation, increases the photosynthesis rate in the plant and eventually more dry matter will be produced. Foliar application by supplying macro- and micro-nutrients and balancing the micro- and macro-nutrients required by the plant by stimulating the production of growth promoters such as various growth regulating hormones and increasing the relative water content of leaf which causes resistance to various environmental stresses from like drought stress (Javanmard et al., 2015). Monirah et al. (2015) stated that foliar application increased the relative water content of the leaves. The results were consistent with the results of Abdul Rahman et al. (2018).

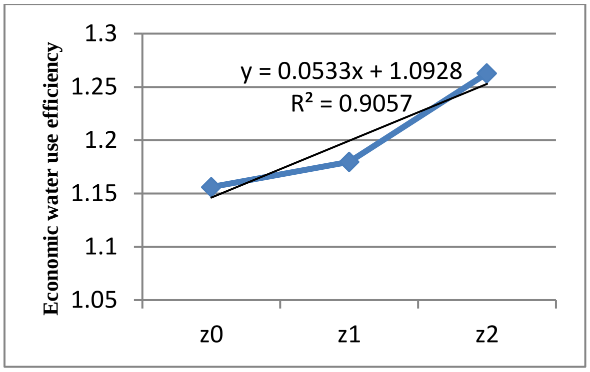

Figure 1 The effect of potassium foliar application on the economic water use efficiency

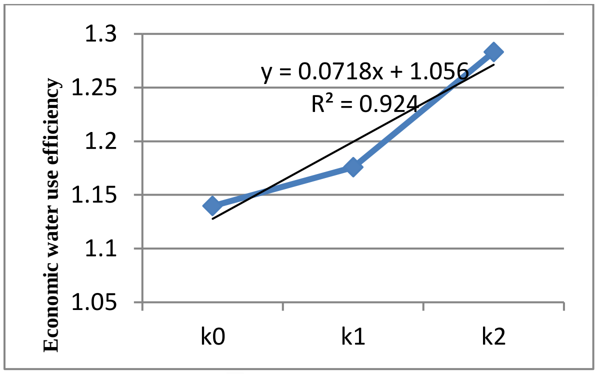

Figure 2 The effect of zinc foliar application on the economic water use efficiency

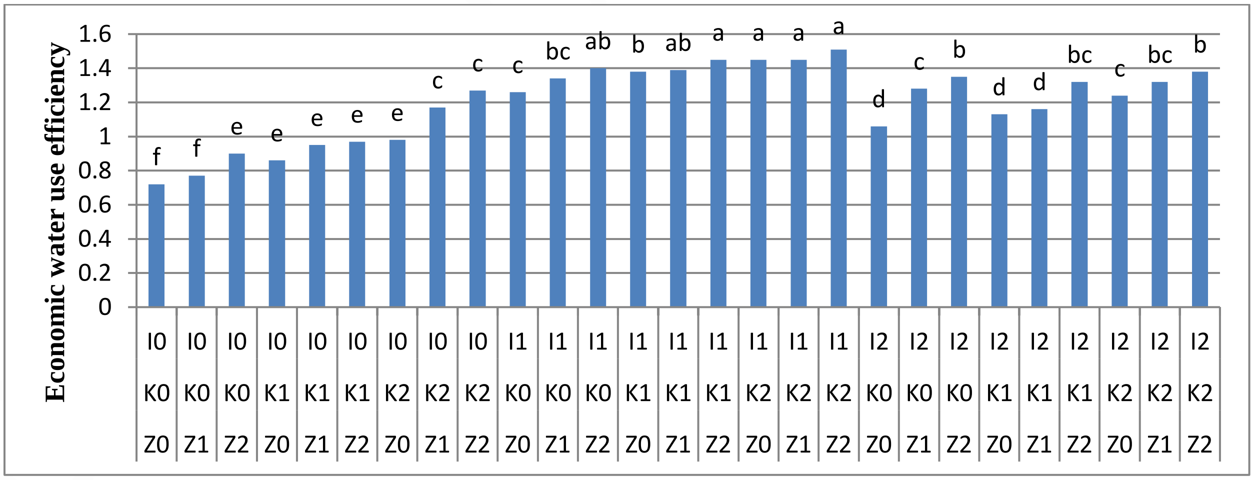

Figure 3 The interaction effect of deficient irrigation, potassium and zinc foliar application of economic water use efficiency

Biological and Economic Water Use Efficiency

The results of analysis of variance showed that among the studied factors, the effect of irrigation interruption stress, potassium and zinc foliar application and the interaction effect of potassium and zinc foliar application, and the interaction effect of irrigation interruption, potassium and zinc foliar application on biological and economic water use efficiency were significant (P<0.01) and other effects had no significant effect on these traits (Table 2). Potassium and zinc foliar application in two steps increased the amount of these parameters relative to the non-foliar application (control) and one application step. The highest biological water use efficiency and economic water use efficiency were obtained in irrigation interruption treatment at 12-leaf stage and two stages of potassium and zinc foliar application by 3.21 and 1.51, respectively, and the lowest values were equal to 1.60 and 0.72 were obtained in non-application of potassium and zinc and optimum irrigation, respectively (Table 3, Figures 1, 2 and 3).Foliar application under stress conditions increased water use efficiency through increasing yields. The reason for increase in water use efficiency is the increasing the amount of grain yield and biological yield per unit of consumed water under stress conditions. In corn, increasing water use efficiency in water stress due to decreased water loss through transpiration (Imam and Ranjbar, 2000). Potassium and zinc foliar application also increased grain yield and biological yield through plant water conservation, which resulted in increased biological and economic water use efficiency. Potassium reduced the effect of stress on plants under water deficit stress via affecting the opening and closure of stomata, maintaining cellular inflammation, decreasing water loss, water balance in plant tissues and increasing water use efficiency. The results were in consistent with Mourira et al. (2018), Jaklee et al. (2018).

Grain Yield

The results of analysis of variance showed that grain yield was significantly affected by irrigation interruption, potassium and zinc foliar application and interaction of potassium× zinc foliar application and triple effects of interaction irrigation interruptions× potassium× zinc foliar application ($P<0.01$; Table 2). The results mean comparisons showed that the highest grain yield was obtained in the co-application of zinc and potassium fertilizers in two stages of 8- and 12-leaf and in optimal irrigation conditions by 1073.8 g/m^2, which had a significant difference with other treatments. The lowest grain yield was obtained in irrigation cut off at the tasseling stage and the nn-application of zinc and potassium by 579.7 g/m^2 (Table 3). Deficit irrigation and foliar application operations increased the economic water use efficiency and, on the other hand, potassium application compensated the reduction of grain yield under dehydrated conditions in such a way that the presence of sufficient potassium due to the role which potassium plays in plant water potential and prevention water loss. And under the water stress conditions, preserves the activity of chlorophyll and prevents the great reduction of photosynthesis and the production of photosynthetic materials and increases grain yield (Daneshian et al., 2002). It seems that the foliar application of nutrients is effective in formation and activity of growth hormones, prolongation of internode intervals, formation of chloroplasts, synthesis of nucleotides, plant water status adjustment, and increasing the grain starch, thereby increased the grain yield (Brygenti and Castro, 2008). Yasin et al. (2017), Lee et al. (2018), Silva et al. (2018) had similar results.

4. CONCLUSION

According to the results of this study, irrigation interruption in 12-leaf stage, in addition to lowering of grain yield compared to irrigation cut off in the tasseling stage, increased water use efficiency and saved water, on the other hand, two stages of zinc and potassium foliar application largely compensated damages caused by deficit irrigation for all traits. Drought stress reduced the chlorophyll content and reduction photosynthesis by decreasing the relative water content of the leaves. As a result, grain yield declined. However, two stages of zinc and potassium foliar application played an important role in preventing the effects of water stress, and by preserving the relative water content of corn leaf, they could protect the chlorophyll degradation under stress conditions and, by producing photosynthetic materials, increased the plant's ability to produce grain yield and increase the water use efficiency.

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