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Research Article

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Effect of fertilizer management and the application of zeolite on agronomic traits and grain yield of maize (*Zea mays* L.) hybrids under deficit irrigation conditions

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ABSTRACT- Drought stress is considered as the most important limiting factor for growing of crops such as maize. Under low irrigation conditions, proper nutrition of plants can improve the effects of drought stress. This experiment was carried out in order to investigate the effect of nutrition management along with application of zeolite on agronomic traits of two hybrids of maize under deficit irrigation conditions in a field research in Soil and Water Research Institute in Karaj, Iran in 2015 and 2016 via a factorial split-plot plan based on a randomized complete block design with three replications. Experimental treatments included two levels of irrigation; full irrigation (I1) and deficit irrigation (70% of full irrigation) (I2) as the main factor and factorial combination of fertilizer application at five levels; application of fertilizer in the conventional method (F1), fertilization application in conventional method + 10 tons of zeolite.ha^{-1} (F2), fertilizer application based on local recommendation (F3), fertilizer application based on local recommendation + 10 tons of zeolite.ha^{-1} (F4) and control (without fertilizer) (F5). Besides, maize hybrids including a late hybrid (SC704) (H1) and an early maturity hybrid (260 = Fajr) (H2) were considered as sub-factors. The results of analysis of variance showed that deficit irrigation had a significant effect on grain yield, number of grain.ear^{-1}, ear weight, number of ear.m^{-2}, and fertility of florets, while under deficit irrigation condition the values of these traits decreased. Under deficit irrigation treatment, the highest grain yield of maize hybrids (7934.3 and 7793.8 kg.ha^{-1} for 704 and 260 hybrids, respectively) was obtained from recommended fertilizer application + zeolite, which were 7% and 15% less than grain yield of corresponding maize hybrids (8180 and 9170.29 kg.ha^{-1} for 704 and 260 hybrids, respectively) where recommended application of fertilizer + zeolite were used under full irrigation condition. In general, the appropriate fertilizer management with the application of 10 tons of zeolite.ha^{-1} led to a higher grain yield of both late and early hybrids of maize and saving 30% water consumption (up to 2100 m^3.ha^{-1}).

INTRODUCTION

Maize (*Zea mays* L.) with harvest area of 184 million hectares and annual production of 7.16 million tons and with an average yield of 5520 kg of grain.ha^{-1}, is the world's first major cereal crop in terms of production and the second-largest crop in terms of the harvest area (FAO, 2017). In Iran, maize production reported to be 2,540,000 tons with an average yield of 5970 kg.ha^{-1} and a harvest area of 425000 hectares in 2015 (FAO, 2017). Early and late maturity maize cultivars (with growing period of 80-115 days and 120 to 140 days, respectively) can be cultivated in different regions of Iran, but late maturity cultivars are more profitable (Ashofteh Birgi *et al.,* 2011).

Water stress negatively affects the growth and productivity of plants that may respond to water shortage using different and complex mechanisms.
Drought tolerance or compensatory growth of plants may be influenced by stress intensity, phenology of plant and soil fertility (Ertek and Kara, 2013). Water stress affects growth, development and physiological processes of maize and reduces grain yield and biomass via reduced seed number.ear^{-1} and grain weight. Soil moisture content which is important in maintaining the optimum yield can be achieved by irrigation. It was reported that farmers with limited water sources face several options: full irrigation of smaller areas of the field, irrigation of a larger area, and the selection of

plants that require less water or develop in more efficient irrigation systems (English et al., 2002). The main goal of deficit irrigation is to increase the water use efficiency of a plant by eliminating those irrigations which are less effective on yield. It is necessary to consider the amount of allowable reduction of transpiration without significantly reducing plant performance. The reduction of performance due to deficit irrigation should be less than the benefits of stored water that can be used for other crops with traditional irrigation practices (Ertek and Kara, 2013).

Although chemical fertilizers play a major role in increasing the productivity of agricultural products, the negative effects of excessive application of chemical fertilizers have gradually become evident. Actually, using new management methods based on increasing nitrogen and water efficiency would promote a healthy community and choosing the type, amount, and time of proper application of fertilizer can improve the efficiency of fertilizers (Malekoty, 2008). Salehi et al. (2012) reported that different rates of potassium had a significant effect on all studied traits in maize and increasing potassium application from zero to 75 and 150 $kg.ha^{-1}$ increased grain yield, 100-grain weight, number of $grain.ear^{-1}$ and harvest index.

Negative effects of drought can be alleviated by potassium application through the preservation of turgor pressure, reduction of transpiration, and increase water use efficiency of plants (Bukvice et al., 2003). It was reported that application of zeolite reduced the exchange rate of ammonium to nitrate, which resulted in reduction of nitrogen leaching (Mumpton, 1999). Clinoptilolite, with high Cation Exchange Capacity (CEC) and a high ability to preserve ammonium (NH4+) in the soil, is one of the natural forms of zeolite which is often used in agriculture. It was shown that natural zeolite, by maintaining some of the cations in its structure and gradually releasing them in the medium, increased the growth and production of plants and reduced required nutrients costs (Esfandiari, 2008). Mahrokh and Azizi (2012) indicated that under normal irrigation conditions, the application of natural zeolite does not affect grain yield of maize, but under water stress conditions, the application of zeolite was recommended to maintain moisture in the root zone and to save irrigation water consumption. Results of experiments have shown that the use of zeolite with chemical fertilizers increases the yield of many crops. In wheat, the application of 4 to 8 tons of zeolite, increased grain yield by 20 percent (Mumpton, 1999). It was indicated that the use of zeolite increased fertilizer productivity through their slow release to the soil, which reduced the loss of fertilizer to the air and water and increased the uptake of fertilizers (Brian, 2008). Zeolite can potentially act as a water modifier by maintaining water and gradually releasing it, which is a factor in modulating the drought cycle (Kojic et al., 2012). It has been reported that the application of 10 tons of zeolite increased the yield of forage of maize and improved the morphological traits and leaf chlorophyll content (Alfi and Azizi, 2014). According to the above statements, reducing water consumption lessens the yield of crops and it has been proved that the use of zeolite can reduce the adverse effects of dehydration and in this case, the plants with adequate nutrients performed better under drought stress conditions, therefore the objective of the present study was to identify a suitable combination of nutrition management and application of zeolite in two maize hybrids, with late and early maturity, under deficit irrigation conditions in Karaj, Iran.

MATERIALS AND METHODS

The experiment of this study was conducted in a field of the Soil and Water Research Institute in Karaj, Iran with geographical coordinates of N35°45′ and E50°57′ and 1248 meters above sea level in the spring of 2015 and 2016. Karaj is located in a semi-arid region and according to the meteorological data, its average rainfall is 244.3 mm and its average annual temperature is 14.4°C. The amount of rainfall during the growing season is presented in Table 1. The experiment was performed in a split-plot plan based on the factorial arrangement in a randomized complete block design with three replications. Two levels of irrigation including full irrigation (I1) and deficit irrigation (70% of full irrigation, I2) were used as the main factors and factorial combination of fertilizer application at five levels including application of fertilizer in the conventional method of local farmers (F1, see below), fertilizer application in conventional method + 10 tons of $zeolite.ha^{-1}$ (F2), fertilizer application based on a recommendation (F3, see below), fertilizer application based on recommendation + 10 tons of $zeolite.ha^{-1}$ (F4) and control treatment (no fertilizer) (F5). Besides, maize hybrids including a late (SC704) (H1) hybrid and an early maturity (Fajr) (H2) hybrid were considered as sub-factors.

Table 1. Meteorological information recorded in Karaj Synoptic Station during the period 1994-1995 (monthly average) (agro.irimo.ir)

Months of the year	Temperature (centigrade)	Rainfall (millimeter)
December21- January19	2.76	32.16
January20 –February18	5.15	27.96
February19- March19	10.19	39.69
March20 – April19	15.78	44.73
April20 – May20	20.85	18.35
May21- June20	26.22	3.06
June21 – July21	28.42	4.07
July22 – August21	3.59	28.34
August22- September21	1.98	24.05
September22- October21	19.49	17.90
October22- November20	33.74	9.91
November21 – December20	31.37	4.77
Annual average	16.19	260.2

In the conventional fertilization treatment, 150 $kg.ha^{-1}$ of nitrogen (in urea form) in three stages and evenly was applied at sowing date, at 5-6-leaf stage and before the emergence time of tassels. Also, 50 $kg.ha^{-1}$ of phosphorus (in triple superphosphate form) and 100 $kg.ha^{-1}$ of potassium (in potassium sulfate form) was applied before seed sowing (Dehghanpour, 2013). The recommended application of fertilizers was performed according to the Soil and Water Research Institute recommendations (Gheibi et al., 2014) in such a way that nitrogen fertilizer was applied in furrows in four equal ratios at four stages including the second irrigation stage, 4-6-leaf stage, 10-leaf stage (before tassel emergence time) and at the emergence time of tassels, respectively. Half of phosphorous and potash fertilizers were applied to the planting lines at the same time as sowing and half of these fertilizers in the form of highly soluble fertilizers (mono ammonium phosphate and potassium superoxide) were applied in four equal ratios at the second irrigation time, 10-leaf, anthesis and milk stages, respectively. According to Alfi and Azizi (2014), 10 ton.ha^{-1} zeolite in the form of clinoptilolite was applied at the soil preparation time. In full irrigation treatment, the plants were irrigated completely and in deficit irrigation treatment plants were irrigated with 70% of the water of full irrigation treatment each time (Ertek and Kara, 2013; Jonghan and Giovanni, 2009). The deficit irrigation treatment began after the seedling establishment (4-leaf stage, V4).

The soil texture of the field was a loam texture with a bulk density of 1.68 g.cm^{-3}, pH 7.49, the electrical conductivity of 1.45 ds.m^{-1}, and field capacity of 26%. The sowing dates were May 20th, 2015 and May 25th, 2016 when the temperature of the soil at the depth of 5 centimeters was about 25°C according to local meteorological information. The soil was plowed in the previous fall and spring. Fertilizers, and zeolites were broadcasted according to each treatment and mixed with soil and then the ridges and furrows were constructed. The spacing between two adjacent furrows was 75 centimeters. The size of each plot was 22.5 m^2 (5 m long and 4.5 m wide) and the seeds were sowed on the ridges in 6 lines with a 16.7 cm space between two seeds (80 plants/m^{-2}). The first and last rows were considered as boarders and samples were collected from two mid rows. Weeds were controlled by hand weeding at the 4-6-leaf stage. The irrigation water rate was calculated by determining the soil water content at the root zone by weighing the water and using the soil moisture curve (Fig. 1). To determine the next irrigation time for each treatment, 48 hours after the irrigation, daily sampling was performed at the depth of root to determine the soil moisture content. The amount of irrigation water for each treatment was calculated as follows (Alizadeh, 1995): (Eq. 1)

$$V = (\mathrm{FC} - \Theta\mathrm{m}) \times \rho\mathrm{b} \times \mathrm{D\,Root} \times \mathrm{AEi} \quad (1)$$

where V is the volume of irrigation water (m^3), FC is the percentage of soil moisture content at the field capacity, Ɵm is moisture weight percentage of the soil before irrigation, ρb is soil bulk density (g.m^3), A is irrigated area (m²), DRoot is depth of root development (m) and Ei is irrigation efficiency.

Drip irrigation was performed using tapes with an inner diameter of 16 mm and a droplet spacing of 20 cm. The output of the strips was 0.9 liters per hour for each drop at 0.8 atmospheres pressure. One tape was placed on the top of each stack and was fixed. All rows were equipped with faucet. The main pipe that distributed water in the main terraces was equipped with a gate valve. In the main terrace of deficit irrigation, at the end of irrigation, the valve was closed again by lowering the water flow through the main gate. In the first irrigation, all droppers of the strips were adjusted to 0.9 ml. To ensure the correct operation of the droplets, the amount of water used for each irrigation was recorded using a volume meter installed at the beginning of the route.

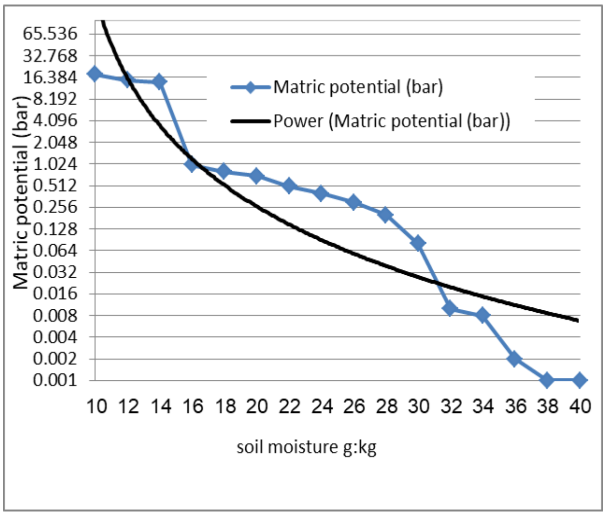

Fig. 1. Soil moisture curve graph of experiment field

Before harvesting and from the main rows of each plot by considering the marginal effect, eight plants were randomly selected from the competing plants in order to measure the yield components. Grain yield was measured by harvesting plants from three internal rows of each plot. The nondestructive method was used to measure the leaf area (Equation 2) (Elings, 2000) and to determine the leaf area index (LAI). In the silk stage, the average leaf rolling was calculated by using a caliper (Equation 3) (Saneoka and Agata, 1996). Eq. (2)

$$LA = 0.75 \times Lw \times Ll \quad (2)$$

where *LA* is leaf area, *LW* is leaf width and *LI* is leaf length. Eq. (3)

$$LS = 1 - \frac{LWn}{LWS} \times 100 \quad (3)$$

where *LS* is leaf rolling (%), LWn is maximum width of leaf lamina of the rolled leaf and *LWs* is maximum width of normal leaf lamina (not twisted).

Relative water content (RWC) of the leaves was measured in three fully developed leaves (Dopte and Manuel, 2002). Eq. (4)

$$RWC = \{\frac{Ldw - Lsw}{Lfw - Ldw}\} \times 100 \quad (4)$$

where *RWC* is relative water content (%), *Ldw* leaf dry weight, *Lsw* is leaf turgid weight and *Lfw* is leaf fresh weight.

To calculate the relative water loss (RWL) at the emergence of tassels, five fully developed leaves were randomly selected from each plot and immediately weighed. To calculate the wilting weight, the weighed samples were placed at 30 $^{\circ}$C for two hours, then samples were placed in an oven at 100 $^{\circ}$C for 24 hours to determine dry weight. The amount of water loss was calculated in terms of water loss from leaf dry weight in two hours. The amount of water loss (g g-1 h-1) was calculated (Equation 5) (Yang et al., 1991). Eq. (5)

$$RWL = \frac{\frac{w1-w2}{w3}}{(t1-t2)/60} \quad (5)$$

where $t1$ and $t2$ are times needed for wilting weight and dry weight, respectively. $W1$, $W2$ and $W3$ are fresh, wilt, and dry weight of leaves, respectively (g).

To measure the canopy temperature, an infrared thermometer (Infrared camera 800, Infratac, USA) was used with a pass filter for wavelengths of 8000 to 14000 nm. The canopy temperature was measured between 13 and 14 pm in the afternoon. Before that, the temperature of the atmosphere was measured using a thermometer and the difference in temperature (ΔT) was calculated. Eq. (6)

ΔT (°C) = Temperature of the canopy - Temperature of atmosphere (6)

Water productivity was estimated using Eq. 6 (Oktem et al., 2003). (Eq. 7)

$$WP = \frac{Y}{I} \quad (7)$$

where WP is water productivity (kg of grain yield per m^3 irrigation water), Y is Grain yield ($kg.ha^{-1}$) and I is Irrigation water ($m^3.ha^{-1}$).

The data were independently analyzed in the form of uniformity of the variance of the error by using SAS software, version 1.9. The mean comparison was performed using the least significant difference test (LSD) at the probability levels of 1 and 5%. Correlation between plant traits was evaluated using SPSS software and graphs were generated using the EXCEL software.

RESULTS AND DISCUSSION

The results showed that deficit irrigation had a significant effect on grain yield and some yield attributes such as number of rows of grain.ear-1, ear weight and ear number of ears per m^2 (Table 2). Grain yield and all the related yield attributes decreased due to water deficit stress in deficit irrigation treatment, although that was not significant for some traits (Table 3). Chapman *et al.* (1997) also reported a 17% reduction in maize grain yield under medium drought stresses and an 80% reduction in yield as a result of severe drought stress. Fertilizer application had a significant effect on grain yield and yield components, except for the cob diameter (Table 3). The highest grain yield was observed in recommended fertilizer + zeolite treatment, however, no significant difference was observed with recommended fertilization and conventional fertilizer + zeolite treatments. The lowest grain yield was obtained from control treatment and conventional fertilizer application that significantly differed from other treatments (Table 3). In an experiment, Osborne et al. (2002) reported a positive effect of nitrogen fertilizer on grain yield, the number of $grain.ear^{-1}$, and grain weight on some maize hybrids. Nitrogen increases vegetative growth, which provides the sinks needed to accumulate storage products and increases the grain yield through the transfer of storage materials to the grains. Also, in the presence of nitrogen at the flowering stage, fertilization of the flowers improves that it itself increases grain yield (Ahmadi et al., 2004). Because the difference in the treatment of conventional and recommendation fertilizer method was only in terms of the availability of fertilizers, while the amount of fertilizer did not differ, it can be concluded that in the conventional fertilization method, all the provided fertilizers were not used by the plants. Therefore, it is possible to improve performance and yield components by fertilizer management without altering fertilizer use for maize. Furthermore, the use of zeolite in both fertilizer application methods improved the yield components and yield, which indicated the capabilities of this material in preserving the nutrients and gradually delivering to the plants (Table 3). In addition to increasing soil moisture, zeolite can improve the growth and increase the grain yield of the plant by increasing the efficiency of fertilizers, absorbing and releasing nutrients needed by plants, stabilizing heavy metals, and improving soil conditions (Mumpton, 1999). Others reported an increase in grain yield and forage maize yield and sorghum by using zeolite application (Naseri et al., 2012).

Grain yield was significantly different in two maize hybrids, however, the differences in yield components were only significant for the number of rows per ear, the number of ears per m^2, and ear weight. The yield of the 704 maize hybrid was more than that of the 260 maize hybrid which can be related to longer growing duration of the 704 maize hybrid (Oluwaranti et al., 2011). It was reprted that higher grain yield of the 704 hybrids related to the higher number of ears per m^2 and 100-grain weight compared to other maize hybrids (Abendroth et al., 2011). Reduction in the yield of both hybrids were similar in deficit irrigation conditions. However, grain yield reduced less in 704 hybrid (21%) compared to 260 hybrid (23%), which means that the late maturity hybrid can withstand deficit irrigation conditions better than the early one. Shirinzadeh et al. (2009) in an experiment for selecting late, medium, and early maturity maize hybrids under drought stress conditions found that hybrid the 704 hybrid (a late maturity maize hybrid) had higher yield in both stress and normal conditions. It was concluded that hybrid this hybrid was the most tolerant maize hybrid in three conditions of deficit irrigation conditions including water deficit at vegetative stage, water deficit at flowering stage and water deficit at grain filling stage and the behavior of both hybrids in this experiment under its fertilizer treatments was almost similar.

The interaction effects of irrigation and fertilizer treatments on grain yield of maize hybrids showed that the highest grain yield (8870 $kg.ha^{-1}$) was obtained from the recommended fertilizer + zeolite treatments under full irrigation condition, that did not significantly differ with that obtained in recommended fertilization method under full irrigation condition. The lowest grain yield (5207 $kg.ha^{-1}$) was obtained in deficit irrigation condition without fertilizer application which did not significantly differ with conventional fertilizer application under deficit irrigation condition. The grain yields obtained from conventional fertilization and conventional fertilizer + zeolite treatments under full irrigation condition were not significantly different from the grain yield of conventional fertilizer + zeolite and the recommended fertilizer + zeolite treatments under deficit irrigation conditions (Fig. 2).

Table 2. Data analysis of variance for plant traits of maize hybrids in deficit irrigation, fertilizer management, and zeolite application treatments

		Mean Square													
Source of variation	df	Grain yield	No. Rowear^{-1}	No. Grain grain-.row^{1}	Ear diameter	Cob diameter	Cob weight	Ear length	100 grain weight	LAI	RWC	ΔT	Leaf rolling	Relative water loss	Water productivity
Year (Y)	1	31.8**	1.2^{ns}	777.8*	0.4^{ns}	28.5**	115.1*	36.2**	227.4**	42.01**	1980.1**	33.18**	36.4^{ns}	0.001^{ns}	1.17**
Block×Year	4	1.3**	0.61^{ns}	90.3**	6.9^{ns}	1.2^{ns}	7.4^{ns}	1.1^{ns}	11.6**	0.22^{ns}	44.9**	20.03**	6.86^{ns}	0.09**	0.05**
Irrigation (I)	1	95.3**	19.8**	989^{ns}	407.7^{ns}	3.2^{ns}	672.1^{ns}	83.2^{ns}	665.5^{ns}	25.21*	815.89^{ns}	532.57^{ns}	1316.7**	0.101*	0.87^{ns}
Y× I	1	9.1**	0.0001^{ns}	34^{ns}	22.9^{ns}	0.2^{ns}	115.1**	0.95^{ns}	177.1**	0.08^{ns}	19.76*	8.43**	0.08^{ns}	0.001^{ns}	0.91*
Block×Y×I	4	1.1*	0.25^{ns}	34.3**	14.5^{ns}	1.3^{ns}	4.9^{ns}	1.2^{ns}	0.3^{ns}	0.17^{ns}	35.04**	3.2**	6.27^{ns}	0.02*	0.05^{ns}
Fertilizer (F)	4	13.1**	17.1**	665.9**	244.8**	4.1^{ns}	116**	25.4*	82.7**	8.08**	402.24**	62.49**	38.74*	0.19**	0.45**
Y×F	1	0.36^{ns}	0.8^{ns}	25.5*	10.4^{ns}	1.8^{ns}	4.3^{ns}	2.2*	2.4^{ns}	0.18^{ns}	4.29^{ns}	0.22^{ns}	20.75^{ns}	0.03*	0.01^{ns}
Hybrids (H)	4	12.2**	15.8*	844.3^{ns}	77.4^{ns}	31.5^{ns}	411.6^{ns}	40.7^{ns}	6.9^{ns}	0.21^{ns}	42.36**	85.18**	46.82*	0.009^{ns}	0.34^{ns}
Y×H	1	4.5**	0.04^{ns}	283.1**	25^{ns}	7.4**	87.1**	14.1**	1.4^{ns}	2.4**	3.25^{ns}	1.66*	32.34^{ns}	0.008^{ns}	0.06*
I×F	4	1.8*	1.2**	19.4^{ns}	52.7**	0.37^{ns}	7^{ns}	2.1^{ns}	18.2**	0.96**	0.27^{ns}	8.22**	50.05**	0.009^{ns}	0.07^{ns}
Y×I×F	4	1.1 *	0.05^{ns}	30*	61.3**	0.29^{ns}	1.1^{ns}	2.5**	0.41^{ns}	0.08^{ns}	3.2^{ns}	3.7**	28.52*	0.001^{ns}	0.04**
I×H	1	0.87^{ns}	4.2^{ns}	7.3^{ns}	1.6^{ns}	2.5^{ns}	31.8*	0.6^{ns}	5.4^{ns}	0.41^{ns}	5.94^{ns}	0.99^{ns}	0.87*	0.004^{ns}	0.01^{ns}
Y×I×H	4	11.2**	0.34^{ns}	3.1^{ns}	1.2^{ns}	0.1^{ns}	78.8**	1.3^{ns}	59.1**	0.41^{ns}	0.05^{ns}	0.004^{ns}	0.52^{ns}	0.008^{ns}	0.32**
F×H	4	0.3ns	1.2^{ns}	12.7^{ns}	4^{ns}	0.49$_{ns}$	5.6^{ns}	0.1^{ns}	4.1^{ns}	0.04^{ns}	4.25^{ns}	1.36^{ns}	1.04^{ns}	0.006^{ns}	0.01^{ns}
Y×F×H	1	0.1^{ns}	0.22^{ns}	21.8^{ns}	3^{ns}	0.36^{ns}	0.95^{ns}	0.19^{ns}	0.002^{ns}	0.08^{ns}	16.41*	0.06^{ns}	0.1^{ns}	0.014^{ns}	0.003^{ns}
I×F×H	4	0.23^{ns}	0.04^{ns}	5.9^{ns}	1.7^{ns}	0.42^{ns}	5.4^{ns}	0.2^{ns}	0.44**	0.24^{ns}	9.48^{ns}	0.13^{ns}	0.4^{ns}	0.003^{ns}	0.004^{ns}
Y× I×F×H	4	0.36^{ns}	0.19^{ns}	11.4^{ns}	3.3^{ns}	0.44^{ns}	2.7^{ns}	0.6^{ns}	0.0008**	0.16^{ns}	14.03^{ns}	0.04^{ns}	0.33^{ns}	0.008^{ns}	0.01^{ns}
Error	72	0.3	0.5	9.5	7.5	0.95	9	0.61	0.26	0.11	5.95	0.62	881.02	0.49	0.009
CV (%)		7.7	4.7	7.4	6.1	4.1	8.3	4.1	2	6.34	3.16	14.11	20.84	18.9	7.45

ns * and **: Not significant and significant at 5 and 1% probability levels, respectively

Table 3. Mean comparison of plant traits of maize hybrids in deficit irrigation, fertilizer management, and zeolite application treatments

Treatments	Grain yield (kg.h^{-1})	No. Row.ear^{-1}	No. Grain.row^{-1}	Ear diamete (mm)	Cob diamete (mm)	Cob weigh (g)	Ear length (cm)	100 grain weight (	LAI	RWC (%)	ΔT (°C)	Leaf rolling (%)	RWL (%	WP (kg.m^{-3})
I1	8810a	15.7a	44.5a	46.5a	23.6a	24.9a	19.8a	1.4b	5.93a	79.75a	-7.7a	18.22a	48a	1.18a
I2	6313b	14.9b	38.7a	42.8a	23.3a	20.2b	18.2a	1.8a	5.02b	74.54a	-3.5b	20.1a	40b	1.35a
F1	6947c	15.2b	39.4c	44.1b	23.6ab	21.6b	18.8b	1.7b	5.25c	75.16c	-4.5b	16.88b	52a	1.22b
F2	7499a	15.6ab	42.9bc	46.2ab	23.3ab	23.3b	19.2ab	1.4c	5.75ab	78.97b	-7.6a	17/29ab	37b	1.33ab
F3	7580a	15.9ab	45.1ab	46.ab	23.7a	23.2b	19.6ab	1.5bc	5.71b	77.94bc	-4.3b	14.76c	42c	1.32ab
F4	7947a	16.1ab	47.0a	47.5a	23.9a	25.2a	20.a	1.2c	6.08a	82.25a	-7.1a	16.75b	36c	1.4a
F5	6047d	14c	33.7cd	39.3c	22.8b	19.3c	17.3a	2.3a	4.58d	71.4d	-4.5b	18.22a	56a	1.05c
H1	7524a	15.7a	39a	43.8a	23a	20.7a	18.4a	1.8a	5.43a	76.95a	-5.5a	16.37a	46a	1.21a
H2	6885b	15b	44.3a	45.4a	24a	24.4a	19.6a	1.5a	5.52a	77.33a	-5.6a	17.2a	42a	1.32a

Mean in each column followed by similar letter(s) are not significantly different at 5% probability level, using LSD Test
Treatments; I1. Full irrigation, I2. Deficit irrigation, F1. Conventional fertilization, F2. Recommended fertilization, F3. Conventional fertilization + Zeolite, F4. Recommended fertilization + Zeolite, F5. No fertilizer (Control),
H1. SC704, H2= SC260; a late and an early maturity maize hybrids, respectively.

In conclusion, fertilization makes the plant to be less affected by the adverse effect of deficit irrigation because one of the main factors influencing the physiological response of plants is water shortages and the availability of nutrients. In an experiment, Tariq al-Islami et al. (2012), reported that increasing nitrogen fertilizers from 80 to 180 kg.ha^{-1} significantly increased the leaf area index and plant growth rate. They concluded that preserving grain yield by nitrogen fertilizers under drought stress conditions may improve the physiological indices of the plant. The important role of nitrogen in determining plant response to water stress in some plant species has been also investigated. It has been reported that high nitrogen fertilization increased the susceptibility of maize to drought (Bennet et al. 1986), while others reported that this susceptibility was lower (Alizadeh et al.,2007).

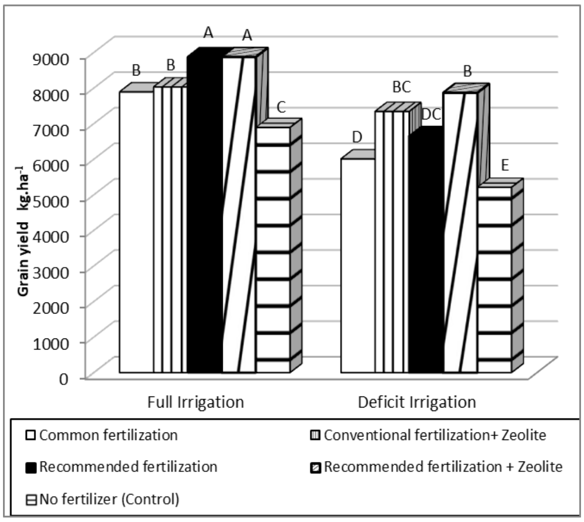

Fig. 2. Interaction of irrigation and fertilizer on corn grain yield (2015, 2016)

It was reported that nitrogen fertilizer application had positive effects on the yield of plants under dehydrated conditions as it improved the growth indices such as leaf area index, crop growth rate, relative growth rate, and uptake of nutrients (Sajedi and Ardakani, 2008). Potassium fertilizer also reduces the adverse effects of drought stress. Salehi et al. (2012) reported that zinc and potassium uptake compensated yield reduction of maize under drought stress conditions. Increase of potassium from zero to 75 and 150 $kg.ha^{-1}$ increased grain yield, 100-grain weight, number of grains per ear, and harvest index of maize. The application of potassium would reduce the negative effects of drought on maize plants through the preservation of turgor pressure, reduced transpiration, and increased water use efficiency (Bukvice et al., 2003). Moreover, the positive effect of zeolite on the maintenance of maize grain yield under deficit irrigation conditions should be considered. Under deficit irrigation conditions, the highest grain yield of maize hybrids (7934.3 and 7793.8 $kg.ha^{-1}$ for 704 and 260 hybrids, respectively) was obtained from recommended fertilizer + zeolite, that was 7% and 15% lower than those of 704 and 260 hybrids, respectively, when recommended fertilizer + zeolite was used under full irrigation conditions. Reduction of grain yield in recommended fertilizer treatments without the application of zeolite in deficit irrigation treatment compared with zeolite treatment was about 26 and 23%, indicated that zeolite preserved water and nutrients, which makes the plant use water more efficiently in dehydrated conditions. The results of this study are consistent with the results of Mahrokh and Aziz (2012) that recommended the application of 12 tons of $zeolite.ha^{-1}$ maintained moisture in root zone and saved water consumption by 12.9 percent in maize.

The application of zeolite increases water use efficiency and grain yield increases consequently. Khashei Siuki et al. (2008) reported that zeolite had a significant effect on all traits of forage maize, SC704, including plant height, the protein content of leaf and stem, and water use efficiency. They stated that the application of 8 g of $zeolite.kg^{-1}$ of soil with 85% moisture discharge had the highest water use efficiency in maize. On the other hand, zeolite can prevent the elements from being leached by retaining and gradually releasing some water-soluble nutrients (Esfandiari, 2008; Mumpton, 1999). Youssefi and Sepaskhah (2004) evaluated the effect of calcium and magnesium zeolite application on nitrogen and ammonium in soil and reported that total amount of nitrate ion extracted from the soil in zeolite treatments of 0, 2, 4 and 8 $g.kg^{-1}$ of soil were 90, 87.7, 74.7 and 63 percent of the amount added to the soil. Zeolite contains potassium, calcium, aluminum, magnesium, silicon, phosphorus, sulfur, iron, and manganese that solely can be used as a fertilizer additive (Abedi Kupai et al., 2010). It is worth noting that the presence of zeolite is ineffective in full irrigation (similar to the results of the experiment of Mahrokh, and Azizi, 2012). Although zeolite was expected to have a positive effect on yield by preserving positive charge nutrient elements (cations), apparently the effect of zeolite on water conservation is more evident than maintaining nutritive elements. As shown in Fig 2, the application of zeolite in both conventional and recommended methods of fertilization in full irrigation increased grain yield, but the difference was not significant. Considering to high efficiency of the drip irrigation method, it seems that water-soluble nutrients were not leached and were maintained around the root zone of the maize plant. Azari et al., (2007) reported that drip irrigation resulted in salt accumulation in the root zone of maize plants.

The number of grains per ear and the number of ears per m^2 were significantly affected by deficit irrigation and reduced. Although the deficit irrigation was applied throughout the plant growth period, the plants showed more sensitivity at the flowering and fertilization stages. The effect of deficit irrigation on some yield components was not significant because the intensity of the water stress was not due to irrigation and only 30% of the plant's water requirement was reduced. Ardalan et al (2012), Imam and Ranjbar (2000), Ortak and Kara (2013), Jungan and Giovanni (2009) have reported similar results. Ahmadi et al., (2000) also stated that drought stress has negative effects on most plant traits in maize, among which grain yield affected worst. It caused by a sharp decrease in the number of $grain.ear^{-1}$, ear length and thousand-grain weight.

Positive effects of fertilizer management and application of zeolite on grain yield under deficit irrigation were due to some of the components of yield, such as the number of grain rows of the ear (Fig. 3), ear diameter (Fig. 4), test weight (Hectoliters; Hl) (Fig. 5) and 100-grain weight (Fig. 6). Deficit irrigation increased the non-fertile $flower.ear^{-1}$, but it was reduced by nutrition management. The application of zeolite mitigated the adverse effect of deficit irrigation and reduced the number of non-fertile flowers. The shortest (1.25 cm) unfilled (empty) part of the ear was obtained under deficit irrigation in recommended fertilizer application + zeolite treatment, which was not significantly different from that obtained in the recommended application of fertilizer + zeolite treatment under deficit irrigation and conventional fertilizer + zeolite treatment under full irrigation conditions, while it was less than 50% in control treatment under deficit irrigated condition. Moser et al. (2006) showed that drought stress before pollination reduced the number of rows of grain and the number of grains per row, so the number of grains decreased. They also reported a reduction in the weight of 1000 grain under water stress conditions.

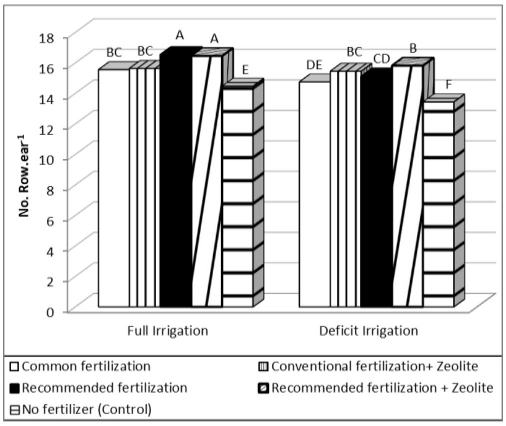

Fig. 3. Interaction of irrigation and fertilizer on number of rows per corn ear (2015, 2016)

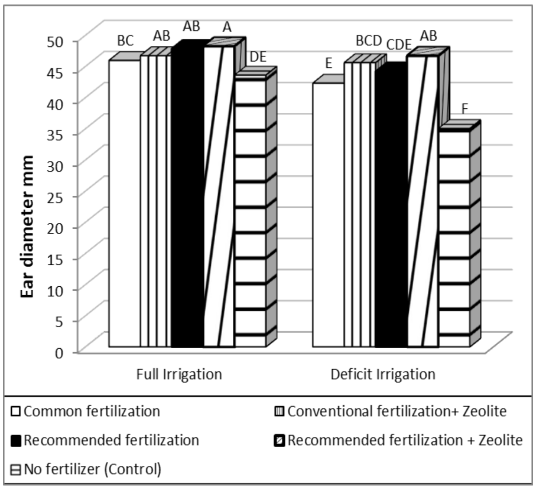

Fig. 4. Interaction of irrigation and fertilizer on corn ear diameter (2015, 2016)

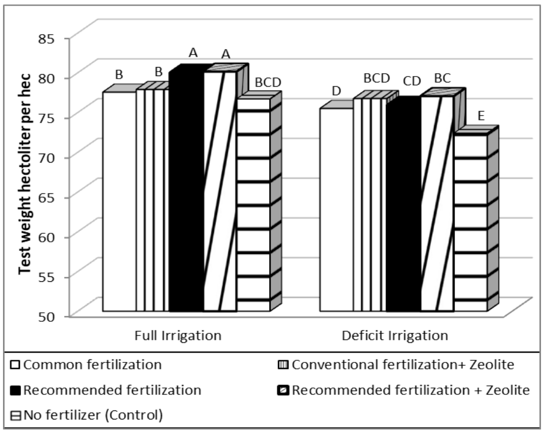

Fig.5. Interaction of irrigation and fertilizer on corn test weight (2015, 2016).

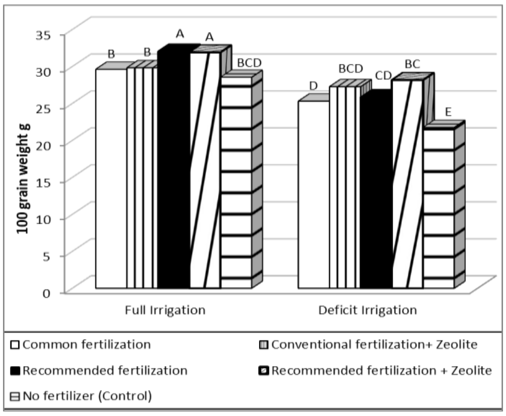

Fig. 6. Interaction of irrigation and fertilizer on corn 100 grain weight (2015, 2016)

Abandrout et al. (2011) stated that dehydration stress during vegetative growth affected the number of grains because the size of the ear and the number of egg cells are determined at this stage. Reduction in maize grain yield components has been reported in several experiments, they included reduction in the number of grains per m^2 (Uhart and Andrade. 1995), grains per plant (Andrea et al., 2007), and grains per ear (Evans et al., 2003). While the number of rows in the ear was often not affected (Moser et al., 2006; Costa et al., 2002). Results of the Moser et al., (2006) study have shown that the increase in grain yield was the result of nitrogen application. However, Costa et al. (2002) suggested that a change in grain yield was not achieved by nitrogen application. Most researchers reported that increasing in maize grain weight related to the increase in nitrogen rates (Moser et al., 2006, Roth et al., 2013).

Results of analysis of variance showed that the effect of irrigation regime on leaf area index and relative water loss by leaves and leaf rolling percentage were significant. However, there was no significant difference between canopy temperature, ambient temperature and relative water content. All fertilizer treatments had significant effects on leaf relative water content, leaf area index, leaf rolling percentage, and the difference between canopy and ambient temperature. The maize tested hybrids did not differ in the leaf area index and the water loss, but there were significant differences in the relative water content of the leaves and the difference in the canopy temperature with ambient temperature and leaf rolling (Table 2).

Mean comparison showed that the leaf area index (5.93) of maize tested hybrids in full irrigation treatment was greater than that (5.02) in deficit irrigation (Table 2). The results of this study showed that the plants benefited better water supply which resulted in improving growth and increasing leaf area. It seems that deficit irrigation treatment and water shortage accelerated leaf aging, reduced leaf development, and increased leaf senescence, which decreased the leaf area index. Marashi et al. (2016) reported that the stress of water deficit decreased growth and leaf area index, while increased aging in leaves of maize plants.

Moreover, Nouri Azhar and Ehsanzadeh (2007) reported changes in growth indices of five maize hybrids in two irrigation regimes, which showed that dehydration had a significant effect on the leaf area index. They also reported that there was a significant positive correlation between leaf area index and dry matter performance. The results of this study showed that the highest leaf area index (6.08) was obtained in recommended fertilizer application + zeolite, treatment but there was no significant difference between this treatment and the conventional fertilizer + zeolite treatment. The lowest leaf area index (4.58) was obtained from the control treatment (without fertilizer) (Table 2). The highest leaf area index (LAI) was obtained from the recommended fertilizer + zeolite treatment under deficit irrigation condition which showed no significant difference with recommended fertilization treatment under deficit irrigation condition. The lowest leaf area index (4.19) was obtained non-fertilization treatment under deficit irrigation condition which showed no significant differences from control treatment under full irrigation condition. Maybe zeolite improved the adverse effects of deficit irrigation and therefore causing the leaf area index to be increased (Fig. 7). It was reported that nitrogen enhanced the leaf area development and consequently the development of the leaf of the canopy which affected the leaf size, leaf longevity and increased the leaf area index and might cause changes in the physiological characteristics of the plant during flowering and grain development and filling (Tariq Al-Islami et al., 2012).

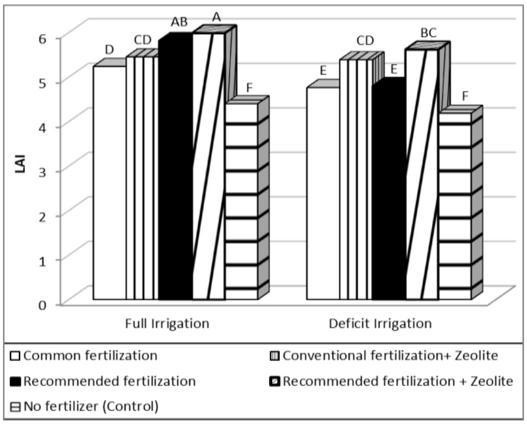

Fig. 7. Interaction of irrigation and fertilizer on corn LAI (2015, 2016)

Sajidi and Ardakani (2008) showed that physiological indices; leaf area index, crop growth rate, relative growth rate, and net assimilation rate were affected by nitrogen fertilizer rates. It was also shown that both phosphorus deficiency and dehydration were factors influencing the development of leaf area and under stress conditions, the effect of phosphorus deficiency on leaf development wa exacerbated (Gutirrez-Boem and Thomas, 2001). In this study, the leaf area index of maize tested hybrids was not significantly different.

Leaf rolling difference was not significant according to irrigation treatments. However, the leaves were less rolled in full irrigation treatment than that in deficit irrigation. The highest (18.22%) leaf rolling was observed in the control treatment (without fertilizer), while the lowest (14.76%) leaf rolling was observed in the recommended fertilizer + zeolite treatment. Under deficit irrigation condition the highest percentage of leaf rolling was observed in control (without fertilizer application) treatment. Zeolite had a significant effect on water deficit. It has been reported that plants may cope with the stress of water scarcity by twisting or rolling of leaves (Lak, 2013). It is a mechanism to reduce the turgor pressure of the bulliform cells which are located along the main vein of the leaf bundle; under drought conditions, these cells lose less water which causes the leaves to twist and become vertical, resulting in the reduction of light incidence (Lak, 2013).

Irrigation treatments influenced the relative water loss of leaves which was greater (48%) under deficit irrigation conditions than that (40%) under the full irrigation conditions. The greatest (52%) relative water loss of leaves was observed in control treatment without fertilizer application, which did not have a significant difference with that obtained in conventional fertilizer treatments. The lowest (36%) relative water loss was observed in plants grown under recommended fertilizer + zeolite treatment, which did not differ significantly with that obtained in recommended fertilizer treatment. Similar to the results of Wang and Clarke (1993) on wheat, there was no significant difference in relative loss of leaf water between the maize tested hybrids in this study.

At the beginning of the day, leaves start to absorb the light energy, leaf stomata begin to open and the transpiration of the plant starts. During transpiration, the plant absorbs water from the soil and the water reaches the stomata through which the water evaporates. Each gram of water to be evaporated requires 585 calories of energy at 20 degrees Celsius. Therefore, during transpiration, the water inside the stomata absorbs energy from the surrounding environment and transpirate, and as a result, the temperature of the leaves decreases. The greater the amount of transpiration, the lower the leaf temperature is obtained (Peters and Evett, 2004). Although the tested plants under deficit irrigation conditions in this study had a higher canopy temperature (3.5°C cooler than atmosphere temperature), there was not a significant difference in canopy temperature under deficit irrigation and full irrigation conditions (7.69°C lower than atmosphere temperature) (Table 2) indicated the deficit irrigation method did not cause plants to suffer from severe dehydration. The first response of plants to water shortage is to close the stomata in order to reduce the loss of water through transpiration. Although the closure of stomata is a compromise response to the maintenance of water in dehydrated conditions, it can also reduce the photosynthetic gas exchange. Generally, there is an inverse relationship between the conductance of the stomata and the cooling of the leaves due to transpiration. The highest (-7.1°C) difference between canopy temperature and atmosphere temperature observed in recommended fertilizer +

zeolite treatment, which was significantly different with that obtained in conventional fertilizer application + zeolite treatment (-4.3°C). The lowest (-4.5°C) difference in temperature of canopy temperature and atmosphere temperature observed in no fertilizer treatment which was not significantly different with those obtained in recommended and conventional fertilizer treatments (Table 2). These results indicated that the fertilization management did not significantly affect the canopy temperature, and the only difference may be due to zeolite, in a such way that when zeolite was applied, the effects of water deficit were eliminated (Fig. 8). In an experiment carried out by Carroll et al., (2017), it was reported that the presence of nitrogen alone did not change the canopy temperature, but under drought stress, nitrogen could prevent canopy warming because it reduced the effects of drought stress. In this study, the canopy temperature of maize hybrids was not significantly different.

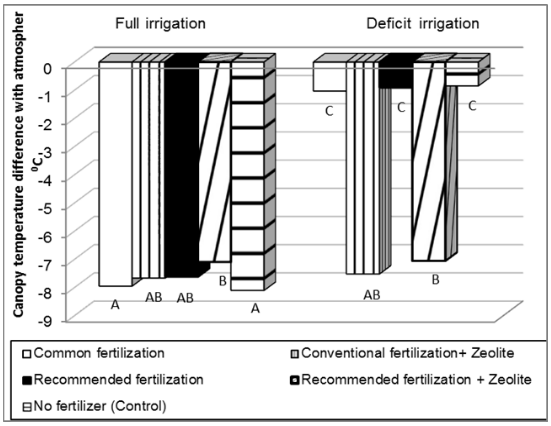

Fig. 8. Interaction of irrigation and fertilizer on corn Canopy temperature difference with atmospher (2015, 2016)

Changes in leaf relative water content and leaf chlorophyll content is a short term reaction to stress and it could be source adapting in drought stress condition (Ahmadi et al., 2004). In fact, there is a positive relationship between reduction of the relative water content of leaf and the relative water content of soil and it has been shown that with decreasing available water in soil, the leaf RWC in maize reduced as well (Khadem et al., 2010).

In the present study, although plants that had grown under full irrigation conditions had higher relative water contents, the lack of water due to deficit irrigation treatment was not enough to put the plants in severe stress conditions and could make a significant difference in the RWC of corn cultivars. Results of the mean comparison of the effect of fertilizer treatments on RWC showed that the highest (82.25%) relative water content of maize hybrids was obtained in recommended fertilizer + zeolite treatment and the lowest one (71.4%) was in control treatment (no fertilizer) (Table 2). In an experiment performed on *Agrostis palustris*, it was found that the osmotic potential of the leaf decreased simultaneously with nitrogen nutrition as a result of RWC increase in leaf (Saneoka et al., 2004). It has also been reported that the application of potassium in soybean under drought stress condition, increased RWC of leaves (Azizi and Rashed Mohasel, 1998). In this study, there was no significant difference between maize hybrids tested for RWC in terms of this property.

Results showed that water productivity was not significantly different between full irrigation and deficit irrigation treatments, although it was higher (13%) in deficit irrigation treatment. Abbasi et al. (2012) reported that the highest water productivity of maize obtained at 80% of water requirement supply treatment in maize. It has been also reported that the highest water productivity of maize obtained in 80% of water requirement supply treatment (Azari et al., 2007). Although the results of the present study were not significant among water productivity data of different treatments but generally were consistent with the results of previous reports. In recommended fertilizer + zeolite treatments, the highest water productivity (25 and 13% higher than those obtained in control and conventional fertilization, respectively) were achieved. The results of this study showed a simultaneous increase in water productivity and fertilizer application and this increase continued under deficit irrigation condition in the presence of zeolite. The adverse effect of deficit irrigation was mitigated by zeolite. Results of another study have also shown that the application of zeolite could ameliorate the adverse effect of irrigation water shortage in maize (Mohamadi et al., 2013).

Based on the results of the mean comparison of the interaction effect of year on maize tested hybrids, it can be concluded that the grain yield of 704 hybrid was higher than that of 260 hybrid in both years, although this increase was not significantly different in the first year. It can also be concluded that the yield reduction because of water loss was similar for both maize hybrids, but the difference between grain yields of the two hybrids in different treatments was not the same.

CONCLUSIONS

The results of this study showed that deficit irrigation and maize nutrition management can be considered as alternative approaches to full irrigation because only with a 30% reduction in irrigation water (average 2100 $m^3.ha^{-1}$), there was not a significant reduction (by only 12%) in grain yield. In addition, the application of zeolite reduced the effects of water shortage in deficit irrigation by preserving water and nutrients and consequently improving the yield of maize. However, if the amount of water is sufficient for the plant and the nutrient leaching is not high, there is no need to use zeolite. These results were similar for both maize early and late maturity hybrids. The late maturity hybrid (SC704) had a higher grain yield than that of the early maturity hybrid (SC260) and under deficit irrigation conditions, the superiority was maintained. However, none of maize hybrids was superior to the other one in terms of traits in irrigation and fertilization management treatments.

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تأثیر مدیریت کود و کاربرد زئولیت بر صفات زراعی و عملکرد دانه ارقام ذرت (*Zea mays* L.) در شرایط کم آبیاری

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چکیده- تنش خشکی به عنوان مهمترین عامل محدود کننده برای رشد محصولاتی مانند ذرت در نظر گرفته می شود. در شرایط کم آبیاری ، تغذیه مناسب گیاهان می تواند اثر تنش خشکی را بهبود بخشد. این تحقیق به منظور بررسی اثر مدیریت تغذیه و مصرف زئولیت بر صفات زراعی دو رقم ذرت در شرایط کم‌آبیاری در سال‌های ۱۳۹۴ و ۱۳۹۵ در موسسه تحقیقات خاک و آب ایران به صورت کرت‌های خرد شده فاکتوریل در قالب طرح بلوک‌های کامل تصادفی با سه تکرار اجرا شد. تیمارهای آزمایشی شامل دو سطح آبیاری، آبیاری کامل (I1) و کم‌آبیاری (۷۰٪ آبیاری کامل) (I2) بعنوان عامل اصلی و ترکیب فاکتوریل سطوح مصرف کود: به شیوه رایج زارعین منطقه (F1)، شیوه رایج + ۱۰ تن در هکتار زئولیت (F2)، شیوه توصیه شده (F3)، شیوه توصیه شده + ۱۰ تن در هکتار زئولیت (F4) و شاهد (بدون مصرف کود) (F5) و ارقام ذرت: دیررس (۷۰۴) (H1) و زودرس (فجر=۲۶۰) (H2) بعنوان عامل فرعی در نظر گرفته شدند. نتایج حاصل از تجزیه واریانس نشان داد که کم‌آبیاری بر عملکرد دانه، تعداد ردیف دانه در بلال، وزن بلال، تعداد بلال در مترمربع و باروری گل‌ها تاثیر معنی دار داشت و در مقایسه با شرایط آبیاری کامل کلیه این صفات کاهش نشان دادند. در شرایط کم آبیاری بیشترین عملکرد دانه ارقام ذرت از تیمار مصرف کود توصیه شده + زئولیت حاصل شد (ارقام ۷۰۴ و ۲۶۰ به ترتیب: ۷۹۳۴/۳ و ۷۷۹۳/۸ کیلوگرم در هکتار) که نسبت به تیمار کودی توصیه شده + زئولیت در شرایط آبیاری کامل (۸۱۸۰ و ۹۱۷۰.۲۹ کیلوگرم در هکتار به ترتیب برای ۷۰۴ ارقام و ۲۶۰) به ترتیب ۷ و ۱۵ درصد کاهش داشتند. به طور کلی با مدیریت مناسب کود و مصرف ۱۰ تن در هکتار زئولیت، با صرفه‌جویی ۳۰ درصد در مصرف آب (۲۱۰۰ مترمکعب در هکتار)، می‌توان عملکرد دانه مناسبی از هر دو رقم زودرس و دیر رس ذرت بدست آورد.