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IMPACT OF LOW-ALTERNATE FURROW IRRIGIATION AND ZINC SULFATE FOLIAR APPLICATION ON GRAIN YIELD AND ENRICHMENT OF SWEET CORN HYBRIDS

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Abstract

These experiments were carried out at the IAU research farm, Arak, Iran, in 2014 and 2015. Treatments involved two sweet corn (*Zea mays* L. convar cv.Chase and Chalenger) hybrid varieties and low water irrigation methods arranged in the main plots and zinc foliar application levels as factoraial in sub-plots. Irrigation (I) levels were complete furrows irrigation (CFI), fixed furrows irrigation (FFI), and alternating furrows irrigation (AFI) arranged in sub-plots and non-foliar application (control), application of Drop® Zinc sulfate (0.2%), Fast® zinc sulfate (0.2%). The results demonstrated the impact of irrigation methods, zinc spraying, hybrid plants and their interaction on the grain yield and other parameters was significant at the 1% probability level. The interactive effects of treatment indicated the highest canable grain yield in the AFI treatment with an application of zinc fast in the Challenger hybrid of 8873 $kg.ha^{-1}$ had an increased yield of 45.03% compared to the least treatment. Most WUE (water use efficiency) in the AFI treatment with zinc fast application in the Challenger hybrid with a value of 0.62 $kg.m^{-3}$ had twice the increase than in the least treatment. The highest grain zinc content in AFI and application of zinc fast in the Challenger hybrid had a 64.83% increase compared to the least treatment with a value of 28.22 $mg.g^{-1}$. Based on the findings of this research, the application of zinc sulfate in the form of zinc fast with the AFI method decreased water consumption by 24% and caused the enrichment of grain zinc content of the Challenger hybrid by 64.83%, which is very necessary for fresh use, especially for the nutrition of children and teenagers.

Key words: Alternate irrigation, Hybrid, Sweet corn, Zinc.

Introduction

The optimal use of agricultural inputs, especially water, in dry and hot countries such as Iran, will create and develop sustainable agriculture and the production of safe food for a growing population (Adiloglu *et al.,* 2012). The use of low water irrigation methods can help farmers in increasing WUE and determining optimal cultivation methods (Ahmadi *et al.,* 2013). Moreover, it is very important to evaluate the ways to increase irrigation water and nutrient use efficiency. Research targeted at irrigated crops as affected by a combined supply of micro nutrients is very limited. The results irrigation and micro fertilizer studies indicate that irrigation improves the efficiency of fertilization. There is a strong correlation between fertilizer utilization and water supply to crops because irrigation water dissolves the fertilizers and makes them available to the crop for proper growth and development. Anderson *et al.,* (2012) reported that nutrient element supply, uptake, and transport were impaired without enough water irrigation. Ashraf *et al.,* (2012) also reported that water supply played an essential role in the utilization of fertilizer. A combination of irrigation and appropriate nutrient management could be an available economic alternative to arid and semi-arid area agricultural production (Cakmak *et al.,* 2008). Scientists have confirmed the effect of nutritional elements on the resistance of plants against low water irrigation (Ernest *et al.,* 2013). Sweet corn *(Zea mays con var. saccharata)* is a high water-demanding crop in all its physiological stages and can achieve high yields when water and nutrients are not in short supply (Evelin *et al.,* 2014). Researchers working on sweet corn have identified a better spatial coupling effect when using alternative furrow irrigation and fertilization in the same and different furrows by producing higher crop yield per unit of irrigation water and fertilizer, compared to the use of conventional irrigation-fertilization methods (Friedrick *et al.,* 2012). Ghatavi *et al.,* (2012) reported a greater yield response for corn with zinc application under enough soil water conditions (Kaman *et al.,* 2011).

Zinc availability or uptake may be modified by water supply. Furrow irrigation is commonly used in dry and arid zones to supply crops with water. Deep water percolation and chemical leaching is a recognized environmental problem with furrow irrigation (Layer *et al.,* 2003). Loongenecker *et al.,* (2009) reported that water application could be reduced by 20 to 30% through AFI, without much reduction in corn yield. Lutts *et al.,* (2012) also found that the use of AFI increased yields in corn compared to FFI. Therefore, less water is usually applied with the AFI method (Mathur *et al.,* 1996). He also reported that the AFI method could supply water in a manner that greatly reduced the amount of surface wetting, leading to less evapotranspiration and less deep percolation. Norden *et al.,* (2015) also showed a reduced deep percolation, when the FFI method was compared with the AFI method. AFI was proposed as a method to increase WUE and decrease chemical leaching compared to the FFI method and with small yield losses for different crops compared to the CFI system (Nouri Azhar *et al.,* 2015). The incidence of micronutrient deficiencies in crops has increased markedly in recent years due to intensive cropping, losses of micronutrients through leaching, decreased proportions of manure compared to chemical fertilizers (Payero *et al.,* 2014). Generally, dry matter production and its division into different parts of plant will be weakened by lack of micronutrients (Anderson *et al.,* 2012).When a plant has access to an element like zinc, the growth of roots increases, thus producing more carbohydrates and proteins, enabling the plant to utilize soil humidity more efficiently, specifically during periods of drought (Rabani *et al.*, 2012). Utilization of these elements increases the efficiency of plants in utilizing water (Reynold *et al.*, 2014). Among micronutrients, zinc plays a key role in pollination and seed set processes, so that its deficiency can cause a decrease in seed formation and subsequent yield reduction. Sanders *et al.*, (2014) stated that zinc played a key role in water and nutrient transportation from root to shoot. Similarly, zinc (Zn) supply is considered an important factor in the reproduction process (Scot *et al.*, 2009). Zn activates several enzymes and, hence, the metabolic activities, viz. nucleic acid and carbohydrate metabolism and utilization of nitrogen and phosphorus (Shahbaz *et al.*, 2015). Ghatavi *et al.*, (2012) indicated that lack of Zn was a major problem in the world and its shortage reduced crop yield. Zn and Fe can play useful and effective roles in plant growth and harvest increase (Soleymanifard *et al.*, 2015). Therefore, spraying plants with Zn increased the yields of many crops (Layer *et al.*, 2003). However, Zn is an essential micronutrient for plants, though its range between deficiency and toxicity is narrower than that of any other microelements (Loongenecker *et al.*, 2009).Reduction in water availability, along with an increase in agricultural production input cost, oblige producers to search for more efficient irrigation methods that reduce irrigation water losses and do not decrease yields. Therefore, the main aim of this research was to study the effects of various methods of low-water irrigation and the application of Zn in producing sweet corn by emphasizing the enrichment of Zn in grain and investigate the growing properties of this plant.

Materials and Methods

The study on the effects of low-water irrigation methods and the spraying of Zn on sweet corn hybrids was carried out for two years in 2014 and 2015 as a field experiment of split factorial type, based on randomized complete block design in three replications at the Agricultural Faculty of Islamic Azad University research farm, Arak (49°48'556"N and 34°3'022"E, height of 1711). Soil testing was done from fallows during the two farming years. Soil was plowed in the autumn of the previous year using moldboard and two perpendicular discs for leveling the land in spring (Nouri Azhar *et al.*, 2015). Before conducting the farm experiment to determine the physical and chemical properties of the soil, soil sampling was done and the samples were analyzed. The analysis results of the physical and chemical soil properties are shown in Table 1.

Zinc critical level in loamy soils was equal to 4 ppm, (Payero *et al.*, 2014). The experiment consisted of three irrigation methods applied through furrows in three ways and three different fertilizer combinations. Experimental treatments included irrigation methods (I): complete irrigation or whole furrows irrigation (CFI), fixed furrows irrigation (FFI), and alternate furrows irrigation (AFI) placed in the main plots. AFI means that one of the two neighboring furrowing was alternately irrigated during consecutive watering, FFI means that irrigation was fixed to one of the two neighboring furrows, and in CFI every furrow was irrigated during each watering. Different irrigation methods perform has been shown in figure 1. Spraying treatment with zinc included the following methods: no spraying, application of zinc sulfate drop and the application of fast zinc sulfate and, Chase and Challenger, sweet and super sweet corn hybrids with a viability of 97% were placed in sub plots. Zinc fast product of Sifu Company (Chifu) of Italy with the formula $ZnSO_4$ had a purity of 13.3 wt% of Zn and a solubility of 85%. Zinc drop was the product of the Darano Company of Spain with the $ZnSO_4$ formula having a purity of 6.22 wt% of zinc and solubility of 75% (Rabani *et al.*, 2012). Soil properties of the research field had been shown in table 1. Meteorological data of field research during the growing season in 2014 and 2015 also has been shown in table 2. The amount and frequencies of irrigation in different treatments and Day length in different months has been shown in tables 3 and 5 respectively.

Table 1. Soil properties of the research field.

	Soil texture	**Loam**	**Cu (ppm)**	**1.04**	**K (ppm)**	**400.00**	**SP (%)**	**31.00**
2014	Clay (%)	22.4	Mn (ppm)	6.72	P (ppm)	25.60	pH	7.70
	Silt (%)	35.0	Zn (ppm)	3.16	N (%)	0.15	EC (ds.m-1)	1.20
	Sand (%)	41.0	Fe (ppm)	2.98	O.C (%)	1.50		
2015	**Soil texture**	Loam	Cu (ppm)	1.04	K (ppm)	388.00	SP (%)	31.00
	Clay (%)	21.3	Mn (ppm)	6.66	P (ppm)	24.60	pH	7.63
	Silt (%)	34.2	Zn (ppm)	3.22	N (%)	0.25	EC (ds.m-1)	1.12
	Sand (%)	40.8	Fe (ppm)	2.89	O.C (%)	1.64		

OC: Organic carbon, SP: Soil porosity, pH: Potential hydrogen, EC: Electrical conductivity

Table 2. Meteorological data of field research during the growing season in 2014 and 2015.

Climatic factor	**May**		**June**		**July**		**Aug.**		**Sep.**		**Oct.**	
	2014	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Precipitation (mm)	9.3	9.4	0	0.2	0	0	0	0	0	0	1.1	1.2
Mean temperature (°C)	20.3	21.2	26.	24	31.1	30.45	29.7	28.4	24	23.2	19	18.8
Mean max. temp. (°C)	28.9	28.5	36.3	16.5	40.6	41.2	39.1	38.9	34.6	33.8	28.6	19.2
Mean min. temp. (°C)	11.3	11.6	15.62	15.61	20.2	21.3	19.5	18.19	12.7	12.9	9.9	8.91
RH (%)	40	39	22	21	20	21	22	23	23	22	28	29

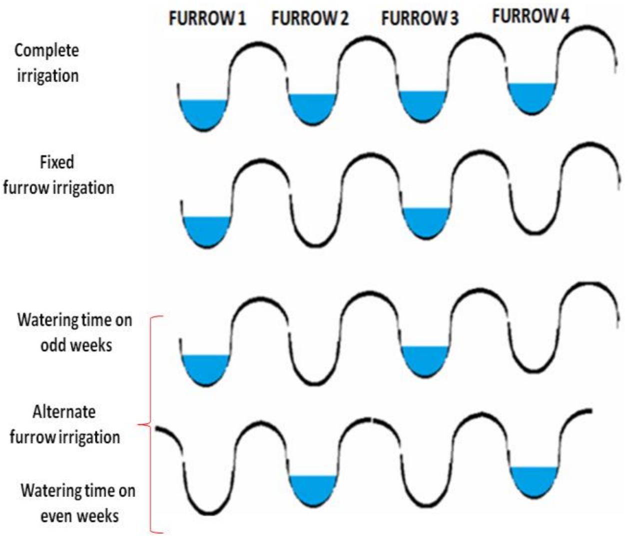

Fig. 1. Different irrigation methods perform.

Chase and Challenger hybrids were sweet corn and super sweet corn from hasty hybrids produced by Sminies Company that had uniform, long and suitable corns for fresh, canned, and frozen consumption with high sugar content and was suitable for cultivation in the Markazi province. They were the products of the Iran Falat Bazr Company (Reynold *et al.,* 2014). Soil moisture was measured by a tensiometer at a depth of 35 cm to determine the irrigation round, and the amount of irrigation water was measured with water meters installed in the water transfer pipe to the farm with an accuracy of 0.1 liter (Sanders *et al.,* 2014). The compounds containing zinc at a concentration of two per thousand liters at 7 and 12-leaf stage were used for spraying (Scot *et al.,* 2009). In both years, sowing of the seeds was done manually, on May 20. Each plot was 5 m wide, having five rows for cultivation with a space of 75 cm by 3.75 m. The distance between the blocks was 2 m. (Shahbaz *et al.,* 2015). Seventy five kilograms of urea fertilizer per hectare was used during the vegetative growth stage and weed control was done by hand picking, while pests and diseases were combated in accordance with the technical recommendations during the sweet corn growing season (Shahbaz *et al.,* 2015). A test was conducted to determine the rate of grain yield, the rate of grain zinc, the moisture rate, and oil content in grain at the harvested dough stage of corns with 10 samples from each plot. Then the grains were separated manually and the rate of zinc, moisture and grain oil was calculated by using standard methods (Soleymanifard *et al.,* 2015). The digestion method of dry burning and hydrochloric acid combination was used to determine the zinc rate in grain. After extract production, the zinc was measured by the flame atomic absorption method and by using the atomic absorption device of the GBC Aventa method (Norden *et al.,* 2015). The overall absorption of the element by the grain was obtained by multiplying the concentration of the absorbed element in the grain by the grain yield. Leaves of the plants and corn grains for sampling were harvested from them and were separated to determine the amount of proline in the hard dough stage, and the proline content of the leaves attached to the corn was calculated by using the following method. Water properties of the research field are shown in Table 4. Water use efficiency was calculated by the following equation:

$$(1) WUE = \frac{YEC}{W}$$

where, YEC is the economic yield of corn grain with 15% moisture in kilograms and w is the water supplied (irrigation) per cubic meter. Leaves of plants, from with corns grains for sampling were harvested, were separated to determine the amount of proline in the hard dough stage, and proline content of leaves attached to corn was calculated by using the method of Kaman *et al.,* (2011). The results of the studied traits in this research were obtained by the MSTATC software and means comparison, with the Duncan's test, was conducted at 5% level (Kaman *et al.,* 2011).

Table 3. The amount and frequencies of irrigation in different treatments.

Year	Treatment	Times of irrigation	Water irrigation amount (lit/m^2)
2014	Complete furrows irrigation(CFI)	9	900
	Fixed furrows irrigation (FFI)	9	526
	Alternate furrows irrigation (AFI)	9	602
2015	Complete furrows irrigation (CFI)	9	877
	Fixed furrows irrigation (FFI)	9	523
	Alternate furrows irrigation (AFI)	9	589

Table 4. Water properties of the research field.

Year	Source of water	ESP	CEC (cmol.kg^{-1})	SAR	HCO_3^- (%)	CO_3^- (%)	Na (%)	Mg (%)	Ca (%)	pH	EC (Ds.m^{-1})
2014	Well	32.60	49.40	8.10	3.20	0.41	32.70	9.21	7.50	7.93	4180
2015	Well	31.77	48.93	7.98	3.17	0.39	32.63	9.18	7.44	7.87	3997

Table 5. Day length in different months.

Year	Source of light	May	June	July	Aug.
2014	Sun	8.9	11.6	10.7	10.5
2015	Sun	8.7	11.7	10.8	10.7

Table 6. Analysis of variance effects of irrigiation methods and Zn spraying on Sweetcorn hybrids.

SOV	Mean square					
	Grain yield	Biological yield	WUE	HI	Grain zinc content	Leaf proline content
Year	111.9 ns	71.5 ns	0.12 ns	5234.22 ns	0.035 ns	4.2ns
R	380011.9 ns	1057895.54 ns	2.424 ns	5893.1 ns	0.021 ns	0.002ns
I	118511132**	61366764.12**	2.21 **	155.378**	0.29**	86.4**
I*Y	139.9 ns	61.25 ns	0.24 ns	4293.1 ns	0.017 ns	8.76
Error 1	7254542	16481188.45	2.26	2.580	2.0156	1.102ns
Zn	21435611**	1374624.42**	2.21 **	112.234**	174.515**	25.3**
Zn*Y	211.6 ns	68.75 ns	2.17 n.s	4294.12 ns	0.036 ns	3.108ns
I.Zn	1245145**	1105687.25**	0.16 **	111.363**	219.471**	16.8**
I*Zn*Y	133.4 ns	44.35 ns	0.15 ns	6313.21 ns	0.015 ns	4.08 ns
V	755412**	1303000.4**	0.121 **	216.001**	251.549**	17.73**
Y*V	432.3 ns	14.05 ns	0.16 ns	6123.26 ns	0.014 ns	0.208ns
I*V	723314.24**	1212629.74**	0.128 **	124.464**	414.077**	41.2**
Y*I*V	233.4 ns	18.75 ns	0.13 ns	8294.12 ns	0.02 ns	3.22ns
Zn*V	7254425**	3566311.25**	0.131**	120.036**	302.792**	18.88**
Y*Zn*V	22.4 ns	24.25 ns	0.17 ns	4014.18 ns	0.05 ns	4.02ns
I*Zn*V	2514562**	1576346.56**	0.128**	136.077**	231.25**	17.73**
Y*I*Zn*V	33.3 ns	21.15 ns	0.13 ns	52354.12 ns	0.0541 ns	4.11ns
Error 2	145987	208015.98	5.151	1.302	0.087	1.514
CV	6.39	14.11	8.19	11.09	8.24	9.96

ns, * and **: Non –significant at the 5% and 1% levels, respectively. I: Irrigation, Zn: Zinc fertilizer, V: Hybrids

Results and Discussions

Canable grain yield: Analysis of results of the trait variance showed that the effect of the irrigation method, zinc, hybrid and their interaction was significant on the grain yield of sweet corn at 1 and 5% probability levels, but the effect of years was not significant (Table 6). The highest grain yield was recorded by AFI and zinc fast in the Challenger hybrid with a mean of 8873 kg .ha^{-1} and the lowest belonged to FFI, without spraying, in the Chase hybrid at 6118 kg .ha^{-1}, showing a significant difference at the 1% level (Table 8). Anderson *et al.,* (2012) indicated that in AFI, with two sides of the roots irrigated, corn maintained a stable growth and reduced the negative effects of deficit irrigation on the farm. The investigation of the irrigation methods showed that FFI had a yield drop in all cases of spraying. In plots of corn, water deficit and low water irrigation reduced yield by 19.47%.

Ahmadi *et al.,* (2013) reported that the highest grain yield was obtained with CFI and the lowest with FFI. He reported the data revealed a significant difference between FFI and AFI. It seems the application of zinc fast caused and an increase in the plant biomass in the growth phase and in case of low water irrigation. Spraying with zinc fast is improper to increase grain yield in low water irrigation cases but it is proper in cases where there is sufficient irrigation. It was found by examining the grain yield drop in the FFI that the Challenger hybrid had a higher yield than the Chase hybrid in different irrigation methods and these results were in line with similar research that had been conducted in the province of Markazi on nut corn.

Biological yield: The highest biological yield was in AFI accompanied by an application of zinc fast in the Challenger hybrid with a mean of 2698 kg.ha^{-1} and the lowest was in the Chase hybrid under FFI treatment without spraying, with an yield of 1254 kg.ha^{-1}, showing a gap of 115%. Low water irrigation in FFI had an effect on the biological yield of 29% in the Chase hybrid and 18% in the Challenger hybrid (Tables 7 and 8). In a similar research that used irrigation rounds of 7, 11 and 15 days, the biological yield was reduced 33% in 15 days (Payero *et al.,* 2014). Low water irrigation from 7 to an 18-day period caused reduction at the rate of 31% in biological yield (loongenecker *et al.,* 2009). AFI caused a reduction at the rate of 8% in the biological yield of corn after spraying with zinc, while the volume of water consumption was reduced by 31% (Evelin *et al.,* 2014). Any stresses such as low water irrigation, leads to a delay in the vegetative period, pollen production, and, ultimately, reduces biological yield, so much so that there may not be any corn formation.

Table 7. Mean comparison of dual interaction effects of treatments.

Treatment	Grain yield ($kg.ha^{-1}$)	Biological yield ($kg.ha^{-1}$)	WUE ($kg .m^{-3}$)	HI (%)	Grain zinc content ($mg.g^{-1}$)	Leaf proline content ($Mg.g^{-1}$)
CFI.Zn_1	7186^{f}	2431^{c}	0.64^{c}	50.47^{d}	22.76^{c}	22.15^{cd}
CFI.Zn_2	7305^{d}	2314^{d}	0.66^{c}	50.72^{d}	24.33^{c}	22.12^{c}
CFI.Zn_3	8789^{a}	2145^{d}	0.63^{a}	50.69^{d}	22.85^{a}	23.01^{c}
FFI.Zn_1	7229^{e}	1532^{f}	0.49^{e}	47.10^{e}	24.31^{e}	30.41^{a}
FFI.Zn_2	7208^{e}	1451^{f}	0.41^{a}	46.54^{f}	18.11^{a}	29.53^{a}
FFI.Zn_3	7572^{e}	1601^{e}	0.44^{c}	47.02^{e}	18.26^{c}	30.14^{a}
AFI.Zn_1	7592^{c}	2412^{c}	0.79^{b}	52.44^{c}	27.86^{b}	24.85^{b}
AFI.Zn_2	8694^{b}	2542^{b}	0.81^{b}	52.73^{b}	27.21^{b}	22.77^{d}
AFI.Zn_3	8861^{a}	2651^{a}	0.84^{a}	52.88^{a}	28.38^{a}	23.73^{c}
CFI.V_1	7801^{c}	2541^{b}	0.69^{a}	50.56^{c}	24.41^{a}	21.35^{cd}
CFI.V_2	7719^{d}	2351^{b}	0.61^{d}	50.69^{c}	23.48^{d}	22.32^{c}
FFI.V_1	7211^{e}	1532^{e}	0.44^{c}	47.07^{e}	24.55^{c}	30.28^{a}
FFI.V_2	7246^{e}	1425^{e}	0.49^{b}	46.71^{e}	19.37^{b}	29.73^{a}
AFI.V_1	8369^{b}	2345^{b}	0.82^{b}	52.56^{b}	27.36^{b}	22.01^{d}
AFI.V_2	8389^{a}	2531^{a}	0.83^{a}	52.81^{a}	28.48^{a}	23.03^{c}
$Zn_1.V_1$	7339e	2001 d	0.69 e	49.96 d	19.44 e	22.05 cd
$Zn_1.V_2$	7326f	2012 d	0.61 b	50.05 c	19.54 b	23.02c
$Zn_2.V_1$	7699 d	2514 b	0.64 d	49.99 d	21.25 d	28.98 a
$Zn_2.V_2$	7773b	2154 c	0.69 c	50.01 c	22.44 c	2893 a
$Zn_3.V_1$	8344b	2564 a	0.73 a	50.24 b	27.63 a	23.01d
$Zn_3.V_2$	8355 a	2598 a	0.74 a	50.15 a	28.36 a	22.03c

* According to Duncan's multi range test, Means with the same letters in each column was not significant difference ($p \leq 0.01$).

CFI: complete irrigation, FFI: Fixed other furrow irrigation, AFI: Alternate furrow irrigation .Zn_1: Without zinc spray (Control), Zn_2: Drop zinc spray (Equivalent 0.002 $Lit.ha^{-1}$), Zn_3: Fast zinc spray (Equivalent 0.002 $Lit.ha^{-1}$). V_1: Chase genotype, V_2: Challenger genotype

Table 8. Mean comparison of triple interaction effects of treatments.

Treatment	Grain yield ($kg.ha^{-1}$)	Biological yield ($kg.ha^{-1}$)	WUE ($kg .m^{-3}$)	HI (%)	Grain zinc content ($mg.g^{-1}$)	Leaf proline content ($Mg.g^{-1}$)
CFI.$Zn_1.V_1$	7181^{i}	2564^{a}	0.39^{j}	50.487^{c}	28.12^{a}	25.01^{g}
CFI.$Zn_1.V_2$	7221^{i}	2456^{b}	0.42^{j}	50.467^{c}	27.02^{b}	25.41^{f}
CFI.$Zn_2.V_1$	7322^{e}	2351^{c}	0.43^{i}	50.560^{c}	28.15^{a}	26.35^{e}
CFI.$Zn_2.V_2$	7289^{f}	2354^{c}	0.44^{i}	50.897^{c}	26.25^{b}	25.14^{g}
CFI.$Zn_3.V_1$	8832^{a}	2145^{d}	0.46^{hi}	50.660^{d}	25.98^{c}	22.85^{i}
CFI.$Zn_3.V_2$	8647^{b}	2541^{a}	0.49^{gh}	50.727^{c}	28.02^{a}	22.73^{i}
FFI.$Zn_1.V_1$	6118^{i}	1254^{h}	0.43^{f}	47.167^{e}	17.12^{ij}	30.21
FFI.$Zn_1.V_2$	7240^{f}	1542^{e}	0.41^{g}	47.040^{g}	18.22^{i}	30.12^{b}
FFI.$Zn_2.V_1$	7163^{i}	1652^{e}	0.42^{f}	46.710^{f}	17.46^{j}	30.73^{c}
FFI.$Zn_2.V_2$	7254^{g}	1325^{g}	0.43^{f}	46.387^{h}	18.25^{i}	30.14^{cd}
FFI.$Zn_3.V_1$	7252^{g}	1542^{f}	0.43^{de}	47.337^{e}	18.64^{h}	30.15^{cd}
FFI.$Zn_3.V_2$	7295^{h}	1564^{f}	0.55^{d}	46.717^{f}	21.21^{ef}	32.12^{a}
AFI.$Zn_1.V_1$	7647^{c}	2564^{a}	0.48^{c}	52.240^{b}	20.94^{g}	26.01^{f}
AFI.$Zn_1.V_2$	7518^{d}	2145^{d}	0.52^{bc}	52.647^{b}	23.12^{e}	25.41^{f}
AFI.$Zn_2.V_1$	8612^{b}	2451^{b}	0.54^{ab}	52.700^{a}	26.25^{b}	23.53^{f}
AFI.$Zn_2.V_2$	8777^{a}	2543^{a}	0.56^{ab}	52.763^{a}	28.12^{a}	26.14^{f}
AFI.$Zn_3.V_1$	8849^{a}	2365^{c}	0.58^{a}	52.747^{a}	27.65^{a}	23.85^{h}
AFI.$Zn_3.V_2$	8873^{a}	2698^{a}	0.62^{a}	53.030^{a}	28.22^{a}	22.73^{i}

* According to Duncan's multi range test, Means with the same letters in each column was not significant difference ($p \leq 0.01$).

CFI: Complete furrow irrigation, FFI: Fixed other furrow irrigation, AFI: Alternate furrow irrigation .Zn_1: Without zinc spray (Control), Zn_2: Drop zinc spray (Equivalent 0.002 $Lit.ha^{-1}$), Zn_3: Fast zinc spray (Equivalent 0.002 $Lit.ha^{-1}$).). V_1: Chase genotype, V_2: Challenger genotype.

Water use efficiency: The highest water use efficiency belonged to AFI, zinc fast, and the Challenger hybrid with a mean of 0.62 $kg.m^{-3}$. The lowest WUE belonged to the CFI treatment (control), without spraying, in the Chase hybrid with 0.19 kg. m^{-3} (Table 8). In CFI, WUE dropped in all cases of spraying. Low water irrigation caused a WUE rise of 20.12%. Nouri Azhar *et al.*, (2015) indicated that the application of zinc fast caused an increase in LAI in the corn vegetative phase and an increase in the production of chlorophyll, which is in accordance with other similar research results. Spraying with zinc fast is proper to increase the WUE in a low water irrigation case but it is improper in a sufficient irrigation case. It was found that the Challenger hybrid, in different irrigation methods, had a higher WUE than the Chase hybrid Rabani *et al.*, (2012).

Harvest index: The highest harvest index was observed in AFI with zinc fast in the Challenger hybrid with a mean of 53.03%, which was 46.387% more than the lowest level (Table 8). It seems that in AFI, with the highest grain yield and biological yield, the corn was able to maintain a stable growth and reduce the negative effects of deficit irrigation on the farm.

According to the results, the highest grain zinc content was in AFI with an application of zinc fast in the Challenger hybrid with a mean of 28.22 $mg.g^{-1}$ and the lowest was in the FFI treatment, without spraying, in the Chase hybrid with 17.12 $mg.g^{-1}$, showing a significant difference at the 1% level. The zinc rate of grain in FFI showed a drop at the rate of 24% compared to the control irrigation but no significant effect was observed in the AFI treatment. Low water irrigation in FFI had an effect on the absorption of zinc of 33% in the Chase hybrid and 26% in the Challenger hybrid. Grain zinc content in corn in FFI was significantly low due to insufficient water to absorb elements. There was no significant difference in the zinc absorption level in grain between AFI and CFI. In zinc fast application treatments, zinc supplement increased by 8% compared to zinc drop application treatments due to high solubility of zinc fast. An interactive application of zinc fast with AFI in the Challenger hybrid showed 12% increase in the zinc absorption level in grain compared to zinc drop application. The Challenger hybrid had a higher zinc absorption power than the Chase hybrid.

Leaf proline content: Results show that the highest proline content belonged to the FFI treatment, zinc fast, and the Challenger hybrid with a mean of 32.12 $mg.g^{-1}$ and its lowest, of 22.73 $mg.g^{-1}$, belonged to the alternate furrow irrigation treatment, fast zinc spraying, and the cultivation of the Challenger hybrid (Table 8). The proline content in AFI reached the lowest rate in figures. Low water irrigation caused a 25.27% increase in proline content, which is consistent with the results of other researchers (Shahbaz *et al.,* 2015). At all levels of spraying, zinc sulfate caused a decrease in praline content but a drop of 13.18% was seen in the zinc fast treatment in control furrow irrigation. It was found that the Challenger hybrid, under different irrigation methods, had a lower proline content than that of the Chase hybrid. The researchers stated that plants, in order to counter the effects of low water irrigation, accumulate proline and ammonium compounds in order to make osmotic adjustment in the cell (Ashraf *et al.,* 2012). Zinc spraying caused a reduction in the accumulation of proline in leaves. The presence of zinc in low water irrigation situations reduced proline by increasing the intracellular concentration and increased plant tolerance of water deficit (Evelin *et al.,* 2014).

Conclusion

In the present study, canable grain yield and other parameters were influenced by the irrigation methods and zinc sulfate application in both hybrids. Significantly, lower yields and yield components were obtained when lower amount of water was supplied during the growth phase, especially in FFI. The data revealed a significant difference between CFI and FFI but no significant difference between CFI and AFI. Application of zinc sulfate reduced the effects of low water irrigation in the studied hybrids. According to the interaction effects of treatments, AFI and zinc fast application in the Challenger hybrid is recommended for farmers of Arak, Markazi province, Iran.

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