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**FOLIAR APPLICATION OF ZINC IMPROVES SEED YIELD AND QUALITY
OF CORN (*ZEA MAYS* L.) GROWN UNDER WATER DEFICIT STRESS**

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ABSTRACT

In order to study effect of zinc foliar application and normal and limited irrigation, on quantitative characteristics of corn an experiment was conducted in research field of Islamic Azad University, Varamin Branch in Iran during 2011 growing season. The experimental design was laid out in a randomized complete block with a factorial arrangement of treatments in four replications. Factors included three different levels of irrigation (complete irrigation, irrigation after 90 mm of water evaporation and irrigation after 130 mm of water evaporation from class A Pan) and zinc foliar application were (0, zinc sulfate and zinc chelate). The result showed that severe water deficit stress decreased all agronomical attributes. Zinc foliar application increased seed yield under sever water deficit stress; on the other hand, use of zinc sulfate foliar application had the highest positive effect on seed number in row, total seed number in ear, seed yield, and days to maturity, oil and protein percentage. In general, application of zinc sulfate under conditions of late season drought stress is recommended to corn seed production.

**Keywords: Corn, Water Deficit Stress, Zinc Foliar Application, Yield and Yield
Components**

INTRODUCTION

Across the globe today, maize is a direct staple food for millions of individuals and, through indirect consumption as a feed crop, is an essential component of global food security (Campos *et al.*, 2004). In Iran water is a scarce resource due to the high variability of rainfall. The effects of water stress depend on the timing, duration and magnitude of the deficits (Pandey *et al.*, 2001). It causes stress in plants and is not only caused by the reduction of rainfalls and great heat, but in the cases where there is moisture in the soil, this moisture cannot be used for plants for some reasons such as excessive soil salinity or soil frost, and plants will be stressed (Baydar and Erbas, 2005; Borrell *et al.*, 2008). Foliar nutrition is an option when nutrient deficiency cannot be corrected by applications of nutrients to the soil (Sarkar *et al.*, 2007; Cakmak, 2008). Several studies have been shown that a small amount of nutrients, particularly Zn and Mn applied by foliar spraying can significantly increase the yield of crops (Crabtree, 1999; Gadallah, 2000; Hebborn *et al.*, 2005; Mirzapour and Khoshgoftar, 2006; Sarkar *et al.*, 2007). Also, foliar nutrition is an option when nutrient deficiencies

cannot be corrected by applications of nutrients to the soil (Crabtree, 1999; Sarkar *et al.*, 2007; Cakmak, 2008). It is likely therefore, in open-field conditions, where the factors that influence the uptake of the nutrients are very variable, foliar fertilization is a privilege. Among the micronutrients, Zn and Mn nutrition can affect the susceptibility of plants to drought stress (Khan *et al.*, 2003). Zinc plays an important role in the production of biomass (Kaya and Higgs, 2002; Cakmak, 2008). Furthermore, zinc may be required for chlorophyll production, pollen function, fertilization and germination (Kaya and Higgs, 2002; Pandey *et al.*, 2006; Cakmak, 2008).

However, to the best of our knowledge, information regarding the effect of foliar application of zinc on the growth and development of corn under water deficiency is not available. Therefore, the purpose of this study is to understand whether application of micronutrients, Zn, raises seed yield and quality of corn under water deficiency.

MATERIAL AND METHODS

In order to study effect of zinc foliar application and normal and limited irrigation, on quantitative characteristics

of corn an experiment was conducted in research field of Islamic Azad University, Varamin Branch in Iran during 2011 growing season. Site of study was situated at 31° 51' 9" E and 20° 35' 9" N and 1050 m above sea level. Latitude and longitude of research place were 35°, 19' N and 51°, 39' E, respectively and site of study was located 900 m above sea level. Before beginning of experiment, soil samples were taken in order to determine the physical and chemical properties. A composite soil sample was collected at a depth of 0-30 cm. It was air dried, crushed, and tested for physical and chemical properties. The research field had a clay loam soil. Details of soil properties are shown in **Table 1**. After plow and disk, plots were prepared. The experimental design was laid out in a randomized complete block with a factorial arrangement of treatments in four replications. Factors included three different levels of irrigation: complete irrigation, irrigation after 90 mm of water evaporation (mild drought stress) and irrigation after 130 mm of water evaporation from class A Pan (severe drought stress) and zinc foliar application (untreated, zinc sulfate and zinc chelate). After plow and disk, plots were prepared.

Treflan and gallant super were applied to control weeds. According to soil analysis, phosphorus ($150 \text{ kg} \cdot \text{ha}^{-1} \text{ P}$) and potassium ($200 \text{ kg} \cdot \text{ha}^{-1} \text{ K}$) fertilizers were applied into the soil. Nitrogen was supplied from ammonium nitrate source ($300 \text{ kg} \cdot \text{ha}^{-1}$) at three stages; seed sowing, end of rosette stage and before flowering stage. The plots were sown with corn seeds (S.C 704) with 75 cm row to row distance and 20 cm between plants. Corn was planted manually in May 2011. Seeds were sown 6 cm deep. Two seeds were sown in each position and the plots thinned to the desired plant population (67000 plant per ha). After seed sowing, irrigation was applied as required during the growing season. The plots were 7 m long and consisted of five rows, 0.5 m apart. Between all plots, 2 m alley was kept to eliminate all influence of lateral water movement. Zinc foliar application was done at stem elongation stages. The foliar application was applied with a pressurized backpack sprayer (12 l capacity) calibrated to deliver $1000 \text{ l} \cdot \text{ha}^{-1}$ of spray solution. Sprayer was equipped with a spiral solid cone spray nozzle. At the end of growing season crop were harvested and agronomic traits such as plant height, row number in ear, seed number in row,

total seed number in ear, 1000 seed weight, seed yield, biological yield, oil percentage, protein percentage and days to maturity were assayed. Oil and protein percentage were calculated using soxhlet and kjeldahl methods, respectively. All data were analyzed using SAS software

(SAS Institute, 2002). Duncan's multiple range tests was used to test for statistical differences between treatment means and controls. Comparisons with P values <0.05 or <0.01 were considered significantly different.

Depth	EC (ds m ⁻¹)	pH	O.C (%)	T.N.V (%)	K (ppm)	P(ppm)	Total N (%)	Texture
0-30 cm	4.1	7.4	0.71	<10	368	25.9	0/079	Clay loam

RESULTS AND DISCUSSION

Analysis of variance showed that water stress had significant effect on all agronomic traits except for row number in ear (Table 2). In addition, effect of zinc foliar application significant on all traits except for row number in ear, thousand seed weight and days to maturity (Table 2). Interaction of experimental factors (water stress × zinc foliar application) was significant except for row number in ear and oil percentage (Table 2).

Plant height

As can be seen from table 3, water stress significantly decreased plant height. In the other word irrigation after 90 and 130 mm of water evaporation (mild stress and severe stress) decrease plant height (Table 3). Hayashi and Hanada (1985) have reported that water stress during growing

season inhibit internode growth in safflower plants and so final height decreased, while water stress was induced before flowering there was significant decreased in plant height. In addition, it has been reported that water stress at vegetative stage affect on nutrient uptake, transport and physiological processes and thus cell division and growth would be decreased. It can be concluded also that the enhancement effect of spraying corn plants with zinc sulfate and zinc chelate on plant height. Such enhancement effect might be attributed to the favorable influence of this nutrient on metabolism and biological activity and its stimulating effect on photosynthetic pigments and enzyme activity which in turn encourage vegetative growth of plants (Michail *et al.*, 2004). The interaction between

irrigation treatment and zinc foliar application had significantly affected on plant height. However, foliar application of zinc recorded the highest value for on plant height under normal irrigation treatment (**Table 3**). Similar results were obtained by **Thomas et al., (2004)**. Such differences might be due to the variation existing among the role of plant nutrients on stress resistance and repair mechanisms (**Michail et al., 2004**).

Row number in ear

The result showed that the effect of water stress, zinc foliar application and interaction between water stress and zinc foliar application was not significant on row number in ear (**Table 2, 3 & 4**).

Seed number in ear

Seed number decreased as result of water stress at irrigation after 90 mm of water evaporation (**Table 3 and 4**). Water deficit stress during flowering and pollination affect on metabolism, physiology and morphology of plants. In this study, water stress after 90 and 130 mm of water evaporation decreased seed number in row at by 32 and 38 percent respectively in compare with control treatment. It seems that decrease in seed number in row is due to lack of fertilization. In addition, water stress leads to reduction in nutrient uptake

and photosynthesis rate and thus reproductive organs will damage (**Table 3**). Zinc foliar application increased seed number per row (**Table 3 and 4**). Comparison of means showed that those plants which were treated by zinc produced more seed when grown under water stress deficit compared with those plants was not treated. Interaction between zinc foliar application and irrigation withholding was significant on seed number per row. Under non stress conditions zinc sulfate application increased seed number per row (**Table 3**). Under stress conditions (both mild stress and severe stress) zinc sulfate application increased seed number per row than zinc chelate application and control.

Total seed number per ear

The result showed that there was significant difference among irrigation regimes in respect of total seed number per ear (**Table 2 and 3**). Total seed number decreased as result of mild and severe water stress at by 20 % and 37%, respectively (**Table 3**). Water deficit stress during flowering and pollination affect on metabolism, physiology and morphology of plants. It seems that decrease in seed number is due to lack of fertilization. In addition, water stress leads

to reduction in nutrient uptake and photosynthesis rate and thus reproductive organs will damage (**Table 3**). Our results are in agreement with findings of **Hirisch, et al., (2007)**. Increase of seed number per ear can be due to positive effect of normal irrigation on improving of productivity potential and increase of anther area. Zinc foliar application increased seed number per ear. The results showed that sulfate zinc foliar application had most positive effect on total seed number per ear than chelate zinc foliar application (**Table 3**). Results indicated that zinc foliar application under conditions of water deficit stress improves fertilization and seed number per ear. The obtained results are in full agreement with the findings of **Basole et al., (2003), Gupta et al., (2003) and Kassab (2005)**. These results suggested that foliar application of nutrient solutions partially alleviates the adverse effects of water stress on photosynthesis and photosynthesis related parameters, yield and yield components through mitigating the nutrient demands of water-stressed plants. In this concern, **Ved et al., (2002)** stated that foliar applied zinc enhances photosynthesis, early growth of plants, improves nitrogen fixation, grain protein and yields. The

interaction between irrigation treatment and zinc foliar application had also a significant impact on the increase of the number of seeds per ear. Zinc sulfate spraying had increased the number of seeds per ear in mild and severe drought stress and control conditions (**Table 4**). The results of experiments by **Agele et al. (2007)** also indicate the positive effect of micronutrient fertilizers such as zinc sulfate on the number of seeds regarding the sunflower. Moreover, some reports have been presented on the positive role of the use of zinc sulfate fertilizer on the number of seeds generated in the shrub of wheat, canola and sunflower.

Thousand seed weight

As can be seen from **Table 3**, irrigation after 90 and 130 mm of water evaporation (mild stress and severe stress) decreased thousand seed weight (**Table 3**). It is worth mentioning that there was not significant difference between two water stress levels. So that under mild stress conditions, assimilate transportation and seed weight decreased. In addition, water deficit stresses affects on source and sink relations. But under severe stress conditions, seed number in plants and seed weight decreased. These results are in agreement with those obtained by

Unger, (1992) and Yegappan, *et al.*, (1982) they reported that the most important factor in increase of seed weight is soil water content during seed filling stage (Francois *et al.*, 1984). Water stress affect on available assimilates during seed filling stage and decreases sink capacity and leads to unfilled seeds and low seed weight (Li *et al.*, 2000). The interaction between irrigation treatment and zinc foliar application had also a significant impact on thousand seed weight (Table 4). Under severe stress conditions zinc sulfate application increased thousand seed weight than zinc chelate application and control. These results suggested that foliar application of nutrient solutions partially alleviates the adverse effects of water stress on photosynthesis and photosynthesis related parameters, yield and yield components through mitigating the nutrient demands of water-stressed plants. In this concern, Ved *et al.*, (2002) stated that foliar applied zinc enhances photosynthesis, early growth of plants, improves nitrogen fixation, grain protein and yields.

Seed yield

Also we found that irrigation after 90 and 130 mm of water evaporation (mild stress and severe stress) decrease seed yield by

14.63% and 33.12%, respectively when data were compared with control treatment. This decrease can be due to early senescence and decrease seed filling period. Similar results were obtained by Ghorpad *et al* (1993) who reported that water stress significantly decreased seed yield. Decrease in seed yield due to decrease in yield components especially seed weight has been reported by other researchers previously Unger,1992 and Yegappan *et al.*, 1982). Decrease in length of seed filling stage due to water stress is the main factor to decrease seed weight (Cantagallo *et al.*, 1997). Also the highest seed yield belongs to zinc sulfate foliar application (Table 3). It seems that zinc sulfate plays a more important role in stomata regulation and ion balance in plant systems to reduce the tensions of draught. The interaction between water stress and zinc foliar application showed that under non stress conditions, zinc sulfate application increased seed yield (Table 4). Under stress conditions (both mild stress and severe stress) zinc sulfate application increased seed yield than zinc chelate application and control. Zinc application was superior with respect to straw and biological yield. The obtained result are in full agreement with the

findings of **Basole et al., (2003)**, **Gupta et al., (2003)** and **Kassab (2005)**. These results suggested that foliar application of nutrient solutions partially alleviates the adverse effects of water stress on photosynthesis and photosynthesis-related parameters, yield and yield components through mitigating the nutrient demands of water-stressed plants. In this concern, **Ved et al., (2002)** stated that foliar applied zinc enhances photosynthesis, early growth of plants, improves nitrogen fixation, grain protein and yields.

Number of days to maturity stage

Number of days to maturity stage was affected by irrigation regime levels (**Table 2 and 3**) so that irrigation after 130 mm of water evaporation led to short seed filling period. In this treatment, number of days to maturity decreased to 109 days. In addition, there was no significant difference between mild and severe drought stress (**Table 3**). Under those conditions that water stress occurs during vegetative phase, there are some mechanisms against draught stress in plants such as shortening in flowering and maturity period. Effect of zinc foliar application was not significant on number of days to maturity. Zinc sulfate foliar

application increased number of days to maturity both drought stress and control conditions (**Table 4**).

Oil percentage

Different irrigation had significant effect on oil percentage (**Table 2 and 3**) so that water stress during reproductive stage decreased oil percentage. So that water stress during reproductive stage decreased oil percentage. The highest oil percentage was obtained from control treatment while severe water deficit stress decreased oil percentage by 13.20% when data were compared with control treatment (**Table 3**). Decease of oil percentage is due to decrease in seed weight. **Rudra naik et al (2001)** has reported that water deficit stress decreased seed weight and oil percentage of safflower plants. Oil percentage was affected by zinc foliar application. Zinc improves photosynthesis and assimilates transportation to sinks and finally increased oil percentage. **Singh and Sinha (2005)** reported that the decrease in oil concentration may be due to the oxidation of some polyunsaturated fatty acids.

Protein percentage

Irrigation regimes had significant effect on protein percentage (**Table 2 and 3**). So that water stress during reproductive stage

decreased protein percentage. The highest protein percentage was obtained from control treatment while severe water deficit stress decreased protein percentage by 30.76% when data were compared with control treatment (**Table 3**). In water deficit stress conditions, radical oxygen caused to oxidation protein and protein content decrease in corn plant. Decrease in protein content has been reported by other researchers previously **Bradford and Hsiao, (1982)**. Zinc foliar application and interaction between water stress and zinc foliar application were significant on protein percentage. **Ved et al., (2002)** stated that foliar applied zinc enhances photosynthesis, early growth of plants, improves nitrogen fixation, grain protein and yields.

Table 2: Analysis of variance on corn attributes affected by water stress and zinc foliar application

S.O.V	d.f	Plant height	Row number in ear	Seed number in row	Total seed number in ear	1000 seed weight	Seed yield	Days to maturity	Oil percentage	Protein percentage
Replication	3	ns	ns	ns	ns	ns	ns	Ns	ns	ns
Water stress	2	*	ns	**	**	*	**	*	**	**
Error (a)	6									
Zinc foliar application	2	**	ns	**	**	ns	**	Ns	*	**
Water stress × Zinc foliar application	4	**	ns	**	**	**	**	**	ns	**
Error (b)	18									
C.V		2.35	6.02	8.23	8.22	8.15	14.23	3.68	8.48	10.48

*, ** and ns significant at 0.05, 0.01 probability level and no significant, respectively

Table 3: Comparison of main means corn attributes affected by water stress and zinc foliar application

Treatments	Plant height	Row number in ear	Seed number in row	Total seed number in ear	1000 seed weight	Seed yield	Days to maturity	Oil percentage	Protein percentage
Irrigation									
Complete irrigation	219 a	13.54a	38.53a	529.50 a	356.38a	12.71a	116 a	5.3a	13a
Irrigation after 90 mm of water evaporation	215 b	13.89a	26.30b	424.64b	318.31b	10.85b	112 b	5.3a	11b
Irrigation after 130mm of water evaporation	210c	13.83a	23.96b	335.68 c	302.43b	8.50c	109 b	4.6b	9c
Zinc									
Untreated(0 ppm)	212b	13.82a	22.88c	345.22c	303.43a	8.98c	114a	4.96b	9c
Zinc sulfate foliar application	221 a	13.85a	35.19a	474.22b	341.82a	11.87a	111a	5.06a	12a
Zinc chelate foliar application	220 a	13.59a	30.72b	470.35a	331.90a	11.20b	113a	5.22a	11b

Values within the each column and followed by the same letter are not different at P < 0.05 by an ANOVA protected Duncan's Multiple Range Test.

Table 4: Interaction between water stress and zinc foliar application on corn attributes

Irrigation	Foliar Application of Ascorbic acid	Plant height	Row number in ear	Seed number in row	Total seed number in ear	1000 seed weight	Seed yield	Days to maturity	Oil percentage	Protein percentage
Complete Irrigation	Untreated(0 ppm)	212.27de	13.97a	33.71b	479.25bc	338.38ab	11.42c	115ab	5.05c	10b
	Zinc sulfate foliar application	215.87cde	13.07a	43.45a	597.80a	367.35a	14.22a	119 a	5.48a	14a
	Zinc chelate foliar application	227.97a	13.57a	38.42ab	511.46b	363.43a	12.47b	116 ab	5.46a	14a
Irrigation after 90 mm of water evaporation	Untreated(0 ppm)	213.80de	14.35a	18.51d	363.62de	290.40cd	8.95e	109c	5.10a	9b
	Zinc sulfate foliar application	227.40ab	14.17a	32.07b	501.75b	332.38abc	12.72b	113ab	5.58a	13a
	Zinc chelate foliar application	222.12abc	14.15a	28.32c	408.47cd	332.15abc	10.87cd	113ab	5.32a	10b
Irrigation after 130mm of water evaporation	Untreated(0 ppm)	210.55e	13.15a	16.42d	192.80f	281.43d	6.57f	106c	4.51c	9b
	Zinc sulfate foliar application	219.72bcd	14.30a	30.05b	491.12b	325.75a	10.42d	113ab	4.62bc	10b
	Zinc chelate foliar application	212.15de	14.05a	25.42c	323.13e	300.13cd	8.50e	109c	4.60bc	9b

Values within the each column and followed by the same letter are not different at $P < 0.05$ by an ANOVA protected Duncan's Multiple Range Test.

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