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Response of Maize to Nutrients Foliar Application Under Water Deficit Stress Conditions

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Abstract: Problem statement: To investigate the effect of nutrient application on agronomical characteristic and water use efficiency under water deficit stress of hybrid maize 704, an experiment was arranged in a split plot factorial based on a complete randomized block design with four replicates in the research station of Islamic Azad University-Arak Branch, Iran in 2007. **Approach:** Main factors studied were four irrigation levels including irrigation equal to crop water requirement, water deficit stress at eight- leaf stage (V_8), stage of blister (R_2) and stage of filling grain in the main plot. Combined levels of selenium treatment (without and with application 20 g ha^{-1}) were applied 2 weeks before execution of water stress treatment and micronutrients (without and with application) that was provided by specific fertilizer for maize called "Biomin", which contained Fe, Zn, Cu, Mn, B, Mo and Mg in the form of foliar application at six-leaf stage and 1 week before tasseling stage at the rate of 2 L ha^{-1} were situated in sub plots. **Results:** Results indicated that effect of water deficit stress on 1000 grain weight, grain yield, harvest index and water use efficiency at different growth stages was significant at 1% level. Water deficit stress decreased grain yield 33% in grain filling stage as compared with control. Using selenium increased mentioned traits but the increase was non significant. Effects of twofold interactions of water deficit stress and selenium showed that using selenium in water deficit stress condition increased measured traits as compared with treatment without selenium. A negative antagonistic interaction was found between selenium and micronutrients on some measured traits. In between treatments of water deficit stress, highest grain yield (8159.33 kg ha^{-1}) was obtained from combined treatment of water deficit stress at eight-leaf stage with selenium application and without micronutrients which compared with treatment of irrigation equal to crop water requirement, without selenium and microelements did not differ significant. **Conclusion:** According to the results of experiment, using microelements in optimum water availability and using selenium in water deficit stress condition increased mentioned traits as compared to treatments control.

Key words: water deficit, selenium, water use efficiency, grain yield

INTRODUCTION

Maize as a C_4 plant, uptakes a large amount of nutrients from soil during its growth period. In many Asian countries (e.g., Iran) due to the calcareous nature of the soils, high pH, low Organic Matter (OM), salty soil, continuous drought, high bicarbonates in the irrigation water and an imbalanced application of fertilizers[4], plants growth most of the time affected by different abiotic limitations. Across the globe today, maize (*Zea mays* L.) 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[8]. Drought and its consequent stress are one of the important factors which restrict agriculture production in Iran and reduce the use efficiency of dry lands. Therefore recognition and utilization crops tolerant to drought and the special crops improvement methods make it possible to use semi arid region[16].

Significant yield losses occur due to water stress in both temperate and tropical environments of other continents that also provide maize for local and global

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consumption[8]. In order to stabilize and increase global maize production for a burgeoning world population, the development of maize varieties with enhanced drought tolerance continues to be an important objective. Maize producers in drought-prone areas of developing nations can often adopt plant breeding improvements more efficiently and effectively than high-input agronomic practices which often depend on input availability, appropriate infrastructure, market access and requisite crop and soil management skills[9]. Additionally, in many regions such as the lowland tropics, the use of drought-tolerant cultivars may be the only economical option for many small- scale farmers[3]. Since water availability is variable across fields and producers typically grow only one hybrid in a particular field, a moderate amount of drought tolerance is necessary in all maize hybrids[5]. Thus, the development and adoption of drought-tolerant varieties is seen as a long-term solution to many of the problems plaguing drought-prone maize production regions around the globe[23]. In many arid and semiarid regions of the world, drought limits crop productivity. Soil water deficit reduces yield of maize and other grain crops by different mechanisms. Drought induced limitation of leaf area expansion, by temporary of wilting, or by early leaf senescence[33]. Drought stress may limit grain yield of maize by reducing the harvest index (HI, The fraction of crop dry matter allocated to the grain). This can occur even in the absence of a strong reduction in total crop dry matter accumulation, if a brief period of stress coincides with the critical developmental stage around silking. Developing ovaries appear to be weak sinks and will fail if there are insufficient new (concurrent) photosynthates available for their growth[2,30]. Alternatively water stress may prevent ovary fertilization by reducing silk receptivity[2], or low kernel at ear potential may cause kernel growth to cease prematurely[15,30]. This latter effect may lead to a reduced HI even if water stress occurs late in the grain filling stage.

Selenium (Se) is a trace element with some important functions in living organisms, in particular in animals[22,32]. Although its role in the animal organism is known in detail, further investigation is required to elucidate its role in plants[5,14]. It is known that selenium occurs as selenate, selenite, selenide, elemental Se and organic selenium in the soil and that the uptake of selenium by plants is governed by many soil and plant factors[34]. One of the most important factors determining the uptake of this element is the form and concentration of selenium in the soil[5,14]. Selenium affects metal distribution and sometimes increases the excretion of toxic elements[20]. In some plant species drought stimulates oxidation process which causes accumulation of poisonous oxygen such as free oxygen radical, Hydrogen peroxide and hydroxyl radicals. Variety of active oxygen forms which are produced through stress can damage such cellular constituents as, lipids, carbohydrates, proteins and nucleic acids. Oxidative stress can prevent photosynthetic activity, respiration process and plant growth. Plants are naturally provided by enzymatic and non-enzymatic systems to take care active oxygen[13].

It is commonly accepted that macro- and microelements play significant roles in plant cells[9,11,18,24]. The interactions between the elements in the soil and in plant organisms are very important and well known[10,24,28].

Iron (Fe) enters many plant enzymes that play dominant roles in oxidoredox reactions of photosynthesis and respiration. Iron participates in content of many enzymes: Cytochromes, ferredoxine, Superoxide Dismutase (SOD), Catalase (CAT), peroxidase and nitrate reductase. The deficiency of Fe in plants causes significant changes in the plant metabolism and induces chlorosis, especially in young leaves and leads to very low re-utilization[18].

Manganese (Mn), in turn, is regarded as an activator of many different enzymatic reactions and takes part in photosynthesis. Manganese activates decarboxylase and dehydrogenase and is a constituent of complex PSII-protein, SOD and phosphatase. Deficiency of Mn induces inhibition of growth, chlorosis and necrosis, early leaf fall and low re-utilization[18].

Copper (Cu) is an essential micronutrient for plant metabolism, acts as a component of several enzymes and is involved in carbohydrates, N and cell wall metabolism. It is constituent of plastocyanine, cytochrome oxidase, tyrosinase, SOD and nitrate reductase. Deficiency of Cu induces chlorosis of leaves[18].

Zinc (Zn) is an essential trace element for every living organism. About 200 enzymes and transcription factors require Zn as a functional component. This element plays an important role in protein and carbohydrate synthesis and takes part in metabolism regulation of saccharides, nucleic acid and lipid metabolism. One of the first symptoms of Zn deficiency is an inhibition of cell growth and proliferation. Zinc affects growth of shoots and roots and growth symptoms of Zn toxicity in plants, generally, are similar to those of Zn deficiency. The toxic concentrations of Zn negatively affect photosynthetic electron transport and photophosphorylation and have an effect on the photosynthetic enzymes.

Table 1: Result of physical and chemical soil analysis

Year	Depth (cm)	EC ds m^{-1}	pH	OC (%)	N (%)	P (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Sand (%)	Silt (%)	Clay (%)
2007	0-30	1.2	7.5	0.82	0.08	5.0	150	0.8	4.6	10.6	1.14	29	35	36
	30-60	1.7	7.4	0.61	0.061	3.6	120	0.4	4.0	6.6	0.88	27	29	44

One of the primary mechanisms of Zn toxicity may be an increased permeability of root membranes, which will cause nutrients to leak out from the roots[18]. Application of microelements fertilizers can enhance plants resistance to environmental stresses such as drought and salinity[7].

In this study, the effect of the selenite ion and microelements on some agrophysiological characteristics of maize has been studied under water deficit stress conditions.

MATERIALS AND METHODS

In order to study the effect of water deficit stress and nutrient elements application on kernel number per ear, 1000 kernel weight, grain yield, harvest index and water use efficiency in maize (KSC 704), a field experiment was carried out in the Research Station of Islamic Azad University, Arak Branch, Iran in 2007. The experimental design was split plot factorial based on complete randomized block design with four replications. Four irrigation levels including, without water stress (control), water deficit stress in Vegetative stage (V_8), water deficit stress in blister stage (R_2) and water deficit stress in grain filling stage (R_4) were assigned to main plot and combination of 20 g ha^{-1} Se (without and with using sodium selenite-NaHSeO3) and microelements without and with using specific fertilizer for maize called "Biomin" which contained Fe, Zn, Cu, Mn, B, Mo and Mg in the form of foliar application at six-leaf stage and one week before tasseling stage at the rate of 2 lit ha^{-1} were situated in sub plots that randomized to sub-plots. Soil preparation including ploughing was done in fall and perpendicular disks in May 2007. Each plot constituted seeded liners distanced 75 cm from each other and 20 cm distance between each two plants on the lines. The length of each seeded line was six meters and two furrows between each two plots were unseeded. Lines were hand-seeded on 18th of May 2007. One third of nitrogen and all of phosphorous fertilizers on the basis of soil analysis applied at sowing time and the remaining nitrogen fertilizer at two different periods during plant growth stages. Before sowing, combined soil samples to a 0-30 and 30-60 cm depth were collected and their physical and chemical properties were tested. Specifically, our test included determination pH using the hydrometry method[12] and of a saturated paste[29], organic C (wet oxidation method)[26], total N (Kjeldahl method)[25] and the concentration of available P (sodium bicarbonate extraction method)[27], available K(flame photometer method, emission spectrophotometry)[19], Fe and Mn (Diethylenetriaminepentaacetic Acid (DTPA), using atomic absorption spectrometer, Model Perkin Elmer 3110) were determined (Table 1). Final harvest was performed at physiological maturity stage when a black layer was formed at seed base.

At maturity stage, grain yield was determined from a harvest area of 1.5×4 m (2 rows middle of each experimental plot) and expressed on a 15% moisture basis. To determine water use efficiency the following relation was applied:

$$\text{Water use economic efficiency} = \text{Grain yield (kg ha}^{-1})/\text{water used (m}^3\text{ ha}^{-1})$$

Mean comparison was conducted using Duncan's multiple range test[31].

RESULTS AND DISCUSSION

Effects of water deficit stress on 1000 grain weight, grain yield, harvest index and water use efficiency at different growth stages was significant at 1% level. Mean comparison of treatments indicate that highest rate of 1000 grain weight, grain yield, harvest index and water use efficiency related to treatment of without water deficit stress and the lowest grain yield, harvest index and water use efficiency belonged to plants under water deficit stress in grain filling stage (Table 2). Water deficit stress decreased grain yield 12.75% in stage V_8, 16.3% in stage of blister and 33% in stage of grain filling as compared with control. In seed filling period, reducing growth period irregularities in transfer of photosynthetic materials caused by water deficit, will effect on seed weights as one of the yield components. Decrease in grain yield can due to reduced leaf, silk and grain kernel expansion, reduced assimilate flux to growing organs, accelerated leaf senescence, delayed silk growth and greater ear and kernel abortion[2]. Also result of this research is parallel with results of other researchers[2,3,21,30].

Effect of selenium on grain yield, harvest index and water use efficiency was not significant, but with using selenium mentioned traits, were increased.

Application of selenium increased grain yield 2.1% in compared with control (Table 2). This is important from viewpoint of quantity and quality for consumption human and animals.

Application of microelements decreased kernel number per ear and grain yield significantly at 5% level, but on 1000 grain weight, harvest index and water use efficiency was not significant. This may be related to antagonistic interaction of microelements to each other. In maize, with copper application alone and along with iron and manganese decreased kernel number per ear, 1000 grain weight and grain yield[17].

Results of two fold interactions water deficit stress and selenium on grain yield, harvest index and water use efficiency was significant. Highest seed yield was obtained from control treatment (Without stress and without Selenium) which showed significant differences in compared to other treatments. Using selenium in water deficit stress condition increased mentioned traits as compared to treatment without using selenium. In between treatments of stress, the highest magnitude of measured traits was found from treatment of water deficit stress in stage V_8. Least grain yield under water deficit was obtained from treatment of water deficit stress in grain filling stage and without Selenium application (Table 3). This might be indicative of plant sensitivity due to no protection factor under water stress. Using microelements in water optimum conditions increased traits measured as compared to without microelements but in water deficit stress conditions in all growth stages, all of traits were decreased. Presumable in water deficit stress condition due to increasing of concentration these elements in plant toxicity created.

Table 2: Mean comparison of main and interaction effects of characters on Kernel Number per ear (KNE), 1000 grain weight (1000 GW), Grain Yield (GY), Harvest Index (HI) and Water Use Efficiency (WUE)

Treatment	KNE	1000 gw (g)	GY (kg ha^{-1})	HI (%)	WUE (kg m^{-3})
Water limitation:					
L_1	503.26a	199.66a	8024.87a	53.39a	0.95a
L_2	403.62b	194.66a	6989.19b	48.51b	0.97a
L_3	438.44ab	174.97b	6712.08b	47.94b	0.93a
L_4	471.92ab	142.66c	5385.73c	44.59b	0.75b
Selenium:					
Se_0	448.39a	175.97a	6703.49a	48.50a	0.88a
Se_1	460.22a	180.00a	6852.45a	48.73a	0.91a
Microelement:					
M_0	466.61a	178.26a	6938.41a	48.66a	0.92a
M_1	442.01b	177.70a	6617.53b	48.56a	0.87a

Mean followed by the same letters in each column are not significantly (Duncan's multiple rang test 5%): L_1: Optimum condition: M_0: Without microelement; L_2: Water limitation inV8 stages; M_1: With microelement; L_3: Water limitation in blister stages; Se_0: Without selenium; L_4: Water limitation in dough stages; Se_1: With selenium

Table 3: Mean comparison of twofold interaction effects of characters on Kernel Number per Ear (KNE), 1000 Grain Weight (1000 GW), Grain Yield (GY), Harvest Index (HI) and Water Use Efficiency (WUE)

Treatment		KNE	1000 kw (g)	GY (kg ha^{-1})	HI (%)	WUE (kg m^{-3})
Water limitation	Selenium					
L_1	Se_0	516.75a	206.16a	9143.88a	55.09a	1.08a
	Se_1	489.77a	183.13bc	6904.86bc	51.70ab	0.82c
L_2	Se_0	393.28c	198.70ab	6617.66c	47.19bc	0.92b
	Se_1	411.51bc	200.62ab	7360.72b	49.83bc	1.02a
L_3	Se_0	439.30b	166.98cd	6594.80c	49.83bc	0.91b
	Se_1	437.59b	182.96bc	6829.35bc	49.32bc	0.94b
L_4	Se_0	444.24b	132.04e	4457.60d	42.39d	0.62d
	Se_1	499.59a	153.29d	631n3.87c	46.79cd	0.87b
Water limitation	Microelement					
L_1	M_0	505.13a	178.97bc	7841.27a	52.31ab	0.93ab
	M_1	501.38a	210.31a	8208.47a	54.47a	0.97ab
L_2	M_0	418.62b	204.69a	7152.66b	47.72bc	0.99a
	M_1	388.62b	194.64ab	6825.72bc	49.31bc	0.95ab
L_3	M_0	476.58b	182.14bc	6994.74bc	47.40c	0.97ab
	M_1	400.31b	182.14bc	6429.41c	48.49bc	0.89b
L_4	M_0	466.09a	147.25d	5764.96d	47.22c	0.80c
	M_1	477.74a	138.07d	5006.51e	41.96d	0.70b
Selenium	Microelement					
Se_0	M_0	459.16a	176.71a	6717.35b	49.00a	0.88b
	M_1	437.16a	175.23a	6689.62b	48.00a	0.88b
Se_1	M_0	473.59a	179.82a	7159.46a	48.33a	0.96a
	M_1	446.86a	180.17a	6545.43b	49.12a	0.87b

Mean followed by the same letters in each column are not significantly (Duncan multiple rang test 5%)%): L_1: Optimum condition: M_0: Without microelement; L_2: Water limitation inV8 stages; M_1: With microelement; L_3: Water limitation in blister stages; Se_0: Without selenium; L_4: Water limitation in dough stages; Se_1: With selenium

Table 4: Mean comparison of threefold interaction effects of characters on Kernel Number per Ear (KNE), 1000 Grain Weight (1000 GW), Grain Yield (GY), Harvest Index (HI) and Water Use Efficiency (WUE)

Treatment Water limitation/selenium/microelement			KNE	1000 kw (g)	GY (kg ha^{-1})	HI (%)	WUE (kg m^{-3})
L_1	Se_0	M_0	526.40a	199.74abc	8768.72ab	54.15ab	1.03ab
	Se_0	M_1	507.10ab	212.56a	9519.05a	56.03a	1.11a
	Se_1	M_0	483.87abc	158.19efg	6913.83cde	50.47abcde	0.82ef
	Se_1	M_1	495.67abc	208.06ab	6897.90cde	52.92abc	0.82f
L_2	Se_0	M_0	391.14f	201.53abc	6146.00def	46.42cdef	0.86def
	Se_0	M_1	395.43ef	195.88abc	7089.33cd	47.97bcde	0.99bc
	Se_1	M_0	446.10bcdef	207.85ab	8159.33b	49.02abcde	1.13a
	Se_1	M_1	381.80f	193.39abcd	6562.11cdef	50.65abcde	0.91cdef
L_3	Se_0	M_0	489.23abc	175.85cde	7242.94c	51.08abcd	1.00bc
	Se_0	M_1	389.37f	158.12efg	5946.66ef	47.56bcde	0.82ef
	Se_1	M_0	463.93abcd	188.44abcd	6746.55cdef	43.72ef	0.93bcde
	Se_1	M_1	411.25def	177.47bcde	6912.16cde	49.41abcde	0.96bcd
L_4	Se_0	M_0	431.73cdef	129.70g	4711.77g	44.34def	0.65g
	Se_0	M_1	456.76bcde	134.38g	4202.44g	40.44f	0.61g
	Se_1	M_0	500.46ab	164.80def	6818.16cde	50.09abcde	0.94bcd
	Se_1	M_1	498.73ab	141.77fg	5809.58f	43.49ef	0.80f

Mean followed by the same letters in each column are not significantly (Duncan multiple rang test 5%) %): L_1: Optimum condition: M_0: Without microelement; L_2: Water limitation inV8 stages; M_1: With microelement; L_3: Water limitation in blister stages; Se_0: Without selenium; L_4: Water limitation in dough stages; Se_1: With selenium

A negative antagonistic interaction was found between selenium and microelements in traits of kernel number per ear, grain yield and water use efficiency but 1000 grain weight and harvest index were increased with using both selenium and microelements not significantly (Table 3). Decrease in amount of these traits may be due to antagonistic interaction between microelements and selenium.

Three fold interactions experimental factors had significant effect on grain yield and water use efficiency.

The highest amounts of 1000 grain weight (212.56 g), grain yield (9519.05 kg ha^{-1}), harvest index (56.03%) and water use efficiency (1.11 kg m^{-3}) obtain from treatment of water optimum conditions + without selenium + with microelements (Table 4). Using selenium and microelements alone in water deficit stress conditions in vegetative growth stage and dough stage increased grain yield, water use efficiency in compared to without using this elements in water stress conditions (Table 4). Presumable in the end of growth period that increased stress conditions, selenium and microelements with take part in biological activity of cells, induced health protection and permanent in function of membranes. In general, it is concluded that by using selenium and microelements under water stress can yield better as compared to without using this elements. Microelements take part in protein synthesis, metabolism regulation of saccharides, nucleic acid and lipid metabolism. Enters the oxidoredoctase enzymes, acts as a component of several enzymes: Superoxide Dismutase (SOD), catalase, peroxidase and nitrate reductase and cytochromes, ferredoxine. Therefore when plants are deficient of these elements, activities of antioxidant enzymes decrease imposing and increased sensitivity to environmental stresses.

CONCLUSION

Long-term trends in global climate change and the expansion of maize production into marginal areas are generating a greater number of drought-prone maize production environments across the globe. Increases in global temperatures as a result of rising greenhouse gas concentrations could potentially accelerate maize growth and development, hasten maturity and reduce soil moisture. Improvements in maize drought tolerance are therefore vital for maintaining local and global food security. In general, plants tolerated unfavorable environmental conditions by changing their morphology as living indices. Selenium as necessary trace element for living organisms is an essential component for activity of antioxidant enzymes system. With using selenium traits of grain yield, harvest index and water use efficiency increased. Use of selenium in water deficit stress condition increased grain yield, harvest index and water use efficiency significantly. Other microelements such as Fe, Zn, Cu, Mg and Mn also play their role as cofactors in the structure of many antioxidant enzymes, therefore when plants are deficient of these elements activities of antioxidant enzymes decrease imposing increased sensitivity to environmental stresses. Using microelements in water optimum condition increased traits measured as compared to without microelements but in water deficit stress condition in all growth stages traits were decreased. Using of selenium and microelements in water deficit stress condition in vegetative growth stage and dough stage increased yield, water use efficiency as compared to without using this elements in water stress condition.

The combined results of these studies indicate that by using selenium and microelements under water stress can produce stable yield as compared to without using this elements.

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