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EFFECTS OF ZINC APPLICATION ON YIELD AND YIELD COMPONENTS OF CORN (*Zea mays* L.) IRRIGATED WITH SALINE WATER

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ABSTRACT: *Greenhouse trials were established to study the response of corn irrigated with saline water (EC = 0.72, 5.0 or 10.0 dS m^{-1}) and to zinc fertilization. The treatments consisted of three zinc rates (0, 25 and 50 kg Zn ha^{-1}) as hydrated zinc sulphate. Treatment effects on nutrient concentration and yield components were measured. Fresh water irrigation resulted 25.08 and 8.26 Mg ha^{-1} biomass and grain yield, respectively, while the Irrigation with saline water (EC = 5.0 and 10.0 dS m^{-1}) greatly decreased the biomass yield by about 25.4 and 53.8% and grain yield by about 40.0 and 74.0%, respectively. Application of 50 kg Zn ha^{-1} to fresh water-irrigated plants increased biomass by about 17.8% and grain by about 20.2% and there was no marked changes in the yield of plants received 25 kg Zn ha^{-1} compared with the control treatments. Under salinity stress, the rate of 25 kg Zn ha^{-1} increased biomass yield by 3.14 Mg ha^{-1} more than the control treatment for plants irrigated with 5.0 dS cm^{-1} water. Addition of 50 kg Zn ha^{-1} increased the biomass yield to 4.26 Mg ha^{-1} and the grain yield to 1.04 Mg ha^{-1} above those obtained from non-fertilized plants. The irrigation with 10 dS m^{-1} water increased biomass yield by 9.6 and 47.8% and the grain yield by 40.47 and 79.53% for plants received 25 and 50 kg Zn ha^{-1}, respectively. Addition of 50 kg Zn ha^{-1} improved the ear length and diameter for all treatments. The kernel number per row of plant irrigated with 10 dS m^{-1} water significantly improved with the highest rate of applied Zn. Application of Zn maintained high K^+/Na^+ ratio in plant tissues and reflected an indirect role in improvement of salinity tolerance when applied to corn plants.*

Key words: *Zea maize, saline water, zinc, salinity tolerance, lacustrine soils.*

INTRODUCTION

Corn (*Zea mays* L.) is rated as the third most important crop in the world and it has contributed greatly to the economic growth of many developing countries. In the last few decades, corn production has increased in Egypt to mix it with wheat for bread production and to introduce it as a protein-rich fodder for livestock. Maize is a relatively sensitive to saline irrigation water showing 50 % reduction in the grain yield at EC_{iw} 3.9 dS m^{-1} (Ayres and Westcot 1985). Corn is sensitive at early growth stages but could withstand at later growth stages to saline irrigation water (Shirazi *et al.* 1971). Sufficient work does not seem to have been focused on the physiological behavior of corn to salinity of irrigation water, since most of the research has been centered on salt build up in soils and their subsequent detrimental effects on growth and yield. Salt stress may reduce plant growth and subsequent yield by water deficit, ion toxicity, ion imbalance, or a combination of these factors (Cramer *et al.*, 1986). The role of zinc in plant is greatly known through its essentiality to higher plants and enrolment in synthesis processes of plant enzymes. As suggested by Parker *et al.*, (1992) and Marschner and Cakmak (1986) root cell membrane permeability is increased under Zn deficiency which might be related to the functions of Zn in cell membranes. As reported by Welch *et al.* (1982), Zn is necessary for root cell membrane integrity. From this point of view, external Zn concentrations could mitigate the adverse effect of NaCl salinity by inhibiting Na^+ and/or Cl^- uptake or translocation. Gupta and Gupta (1984) showed that application of zinc sulfate by rates 5 and 10 ppm to soybean grown under 44, 88 and 132 meq L^{-1} chloride and sulfate salt conditions in the greenhouse improved shoot yield. The yield improvement was more pronounced in sulfate salt-treated pots than those treated by chlorides.

Soils low in available Zn are widespread in a number of the major grain crop-growing regions of the world, including Egypt (Alloway, 2004). Therefore, zinc is one of the most limiting micronutrients for maize production in the alkaline and calcareous soils. Increasing the level of available Zn can increase grain protein concentration (Hemantaranjan and Garg, 1988), which may preferentially accumulate in glutenin. On the other hand, zinc was found to ameliorate plant growth under alkali soil conditions which was attributed to the correction of Zn deficiency and widening of Ca/Na and K/Na ratios in the plant. No work has been reported on the effect of Zn on plant growth under saline or saline-alkaline soil conditions. Such information may be useful for planning and formulating efficient reclamation measures and better commercial exploitation of the salt-affected soils. Therefore, the present investigation was undertaken to evaluate the ameliorative role of Zn on growth and yield and some chemical composition of corn plants irrigated with saline water under greenhouse growth conditions.

MATERIALS AND METHODS

A top (30 cm) soil sample of lacustrine clay loam soil, containing 0.9 ppm of DTPA-extractable zinc and having a pH value of 8.15, was selected for this study. Some of its physico-chemical properties were determined (Page, 1982) and the data obtained are presented in Table 1. It was collected from a cultivated field in Abis area south-east Alexandria governorate, Egypt. Corn *(Zea mays.* L.) of single hybrid Giza 129 was grown under greenhouse conditions in plastic pots containing 25 kg soil. The base fertilizers of P and K were added at the rates of 90 and 200 kg ha^{-1} in the form of single superphosphate and potassium sulfate , respectively. Nitrogen fertilizer rate of 220 kg ha^{-1} was applied in three doses: one third before sowing in the form of ammonium sulfate ($(NH_4)_2SO_4$), one third at single application of NH_4NO_3 after 30 day of sowing and one third at single application of NH_4NO_3 just before seeding stage. The rate of applied zinc treatments were 0 (*Zn0*), 25 *(Zn1)*, and 50 *(Zn2)* kg ha^{-1} in the form of $ZnSO_4.7H_2O$. It was dissolved in water and added to the soil with the first does of irrigation after sowing. After two weeks of submergence, plants were thinned to two plants. In the first 30-days of emergence, all pots were irrigated with fresh water (EC = 0.72 dS m^{-1}) then they were classed into three groups to receive irrigation water having salinity levels of 0.72, 5.0 or 10.0 dS m^{-1} until two weeks before harvest. During all growth stages, soil moisture was maintained at approximately 75% of the water-holding capacity. Statistical design of the experiment was randomized complete block and all treatments were replicated three times.

At silking stage, ear-leaf samples were collected from all treatments, washed with tap water then by distilled water and oven dried at 70 °C for 24 hrs, crushed and passed through 0.5-ml sieve. The oven-dried plant material was dry-ashed according to Jones and Case (1990) and the concentrations of Zn, Na and K in the digestion solution were measured using ICP-OES spectrometer Thermo Model ICAP 6000 Series.

At harvest, plants were hand-cut at the soil surface and the weight of total biomass was recorded. Maize ears were removed, weighed, shelled, and both cob and grain total fresh mass were determined. Subsamples of cobs, stalks (stem plus leaf sheaths), and grain were weighed and dried to a constant weight at 80°C in a forced hot-air dryer and reweighed. Final grain yield was expressed in Mg ha^{-1}. The variables recorded were: (i) Total biomass and grain yields, (ii) ear length (EL) and diameter (ED) and (iii) number of kernel rows per cob and number of kernels per cob row. The collected data were statistically analyzed using Costat software (Costat 1985).

Table (1). Some physico-chemical properties of the soil sample used in the pot experiment.

Soil Property	
Texture:	
Sand, %	40.51
Silt, %	30.74
Clay, %	28.75
texture class	Clay loam
Total carbonate, %	11.80
Organic Matter, %	1.20
Electrical Conductivity, dS m^{-1} (soil paste extract)	1.53
pH (soil suspension 1 : 2.5 soil : water)	8.15
Cation Exchange Capacity (CEC), $cmol_c$ kg^{-1}	34.80
Olsen P, mg kg^{-1}	5.33
DTPA-Zn, mg kg^{-1}	0.91

RESULTS

1- Effect of Water Salinity and Applied Zinc on Biomass and Grain Yield

Biomass and grain yields were highly affected by salinity levels of irrigation water (Table 2). Fresh water irrigation (EC = 0.72 dS m^{-1}) resulted 25.08 and 8.26 Mg ha^{-1} biomass and grain yield, respectively, while the irrigation with saline water (EC = 5.0 and 10.0 dS m^{-1}) greatly decreased the biomass yield by about 25.4 and 53.8% and the grain yield by about 40.0 and 74.0%, respectively. Similar results were obtained by Katerji et al. (2004) for the grain yield of corn plant grown in lysimeters and irrigated with 15 and 30 meq L^{-1} NaCl solution.

Addition of zinc sulfate by rates of 25 and 50 kg Zn ha^{-1} highly improved corn yield particularly under saline conditions (Table 2). The high rate of applied Zn (50 kg ha^{-1}) to fresh water-irrigated plants increased biomass and grain yields by about 17.8% for each and there was no marked changes in the yield of plants received 25 kg Zn ha^{-1} compared with the control treatments. Under salinity stress, fertilization with Zn by a rate of 25 kg ha^{-1} increased the biomass yield by about 3.14 Mg ha^{-1} more than the non-fertilized pots for plants irrigated with 5.0 dS cm^{-1} water. Whereas the application of 50 kg Zn ha^{-1} increased the biomass yield by about 4.26 Mg ha^{-1} and the grain yield by 1.04 Mg ha^{-1} above those obtained from non-fertilized plants.

(Table 2). Under highly saline conditions (10.0 dSm^{-1} irrigation water), both rates of applied zinc had a significant effect in improving the corn yield where the biomass increased by about 9.6 and 47.8% and the grains increased about 40.47 and 79.53% for plants received 25 and 50 kg Zn ha^{-1}, respectively. Figure (1) summarized the effect of irrigation water salinity and applied zinc on corn yield.

2- Effect of Water Salinity and Applied Zinc on some Agronomic Parameters

The measurements of corn ear length and diameter, kernel raw number per ear and kernel number per raw were selected to represent some of major agronomic parameters which may reflect the response of plant growth to salinity stress and the applied zinc. Figure (2) represents photoes of randomized selected corn cobs resulted from each treatment to demonstrate the effect of water salinity and the high rate of applied zinc sulphate (50 kg ha^{-1}) on their morphology.

Table (2): Effect of Zinc Application on yield, yield components and contents of Zn, Na and K in corn leaves.

Irrigation Water Salinity (dSm^{-1})	Applied Zinc ($kgha^{-1}$)	Yield (Mg ha^{-1})		Agronomic Parameters				Ear-leaf contents (mg kg^{-1} DM)		
		Biomass	Grain	EL (cm)	ED** (cm)	KRN#	KN/R##	Zn	Na	K
0.72	0.0	25.08	8.26	12.30	3.94	12.30	39.70	0.84	810.00	18516.67
	25.0	25.42	8.64	12.60	4.03	13.00	40.30	1.00	805.00	21266.67
	50.0	29.54	9.73	14.00	4.43	13.30	42.70	1.89	843.33	27773.33
5.00	0.0	18.70	4.96	12.00	3.82	12.30	29.30	0.65	966.67	13566.67
	25.0	21.84	5.06	13.00	3.76	12.30	30.70	1.30	950.00	13583.33
	50.0	22.96	6.00	12.30	3.90	12.30	32.70	2.31	973.33	19250.00
10.00	0.0	11.59	2.15	8.00	2.62	8.70	3.70	0.83	1500.0	9583.33
	25.0	12.70	3.02	8.50	2.65	10.70	4.30	0.89	1350.0	10410.00
	50.0	17.13	3.86	10.00	3.20	10.70	23.70	1.49	1283.3	13386.67
$LSD_{0.05}$		0.579	0.219	1.280	0.508	0.935	4.779	0.077	96.154	1951.319

EL: ear length; ** ED: ear diameter; # KRN: kernel raw number; ## KN/R: kernel number per raw.

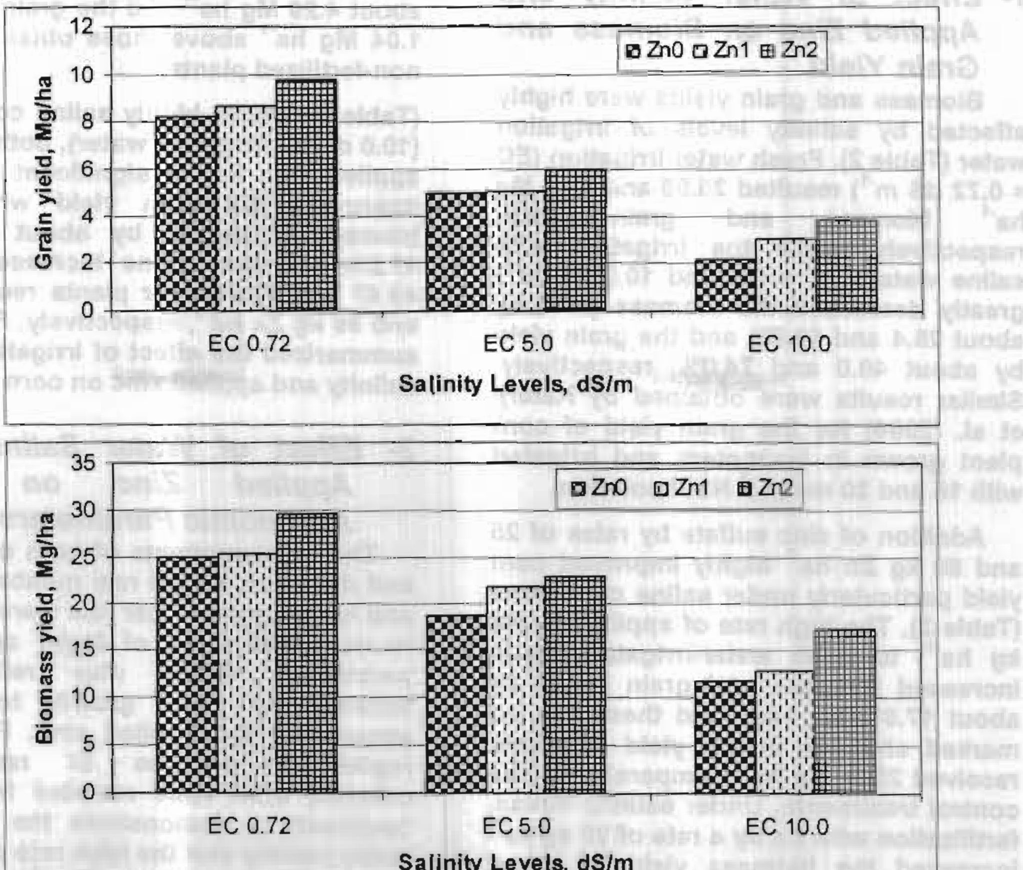

Figure (1). Effect of irrigation water salinity and rates of applied zinc on biomass and grain yield of greenhouse grown corn.

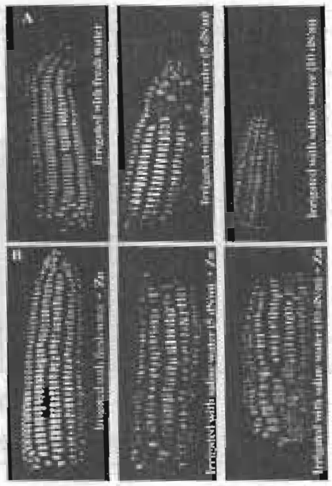

Figure (2): Photoes of corn ears grown under different salinity levels of irrigation water and treated with 0 zinc (A) and 50 kg Zn ha^{-1} zinc (B) in the form of zinc sulphate

The irrigation with 10.0 dS/m water salinity extremely decreased the average of ear length from 12.3 to 8.0 cm whereas the 5.0 dS/m water had no significant effect (Table 2). The ear length of plants received 25 and 50 kg Zn/ha and irrigated with fresh water (0.72 dSm^{-1}) increased by about 2.4 and 13.8%, respectively. Under high rate of saline water, zinc improved the ear length by 6.25 and 25.0% with 25.0 and 50.0 kg ha^{-1}, respectively.

Table (2) showed that Zn application has been found to improve ear diameter, kernel raw number and kernel number per raw for plants irrigated with fresh water (EC = 0.72 dS m^{-1}). Under saline water stress, the ameliorative role of Zn was shown predominantly in the plants irrigated with water of 10.0 dS m^{-1}. Figure (3) illustrates the improvement in kernels number per cob as a results of zinc application to all salinity levels treated plants. Therefore, the data confirm the importance of zinc in improving the grain yield of high salt stressed corn plants.

3- Effect of Water Salinity and Applied Zinc on Zn, Na and K contents

The concentration of zinc in ear-leaf increased with increasing the applied rate of zinc fertilizer. On the other hand, sodium content increased with increasing irrigation water salinity but potassium content decreased with increasing water salinity (Table 2). Previous studies (El-Sherif *et al.*, 1990; Doering *et al.*, 1984; Rahman *et al.*, 1993) showed that Zinc application improved growth in salt-stressed plants and its concentration increased in shoot tissues of bean and maize.

Addition of Zn increased the uptake of potassium in all treatments. Addition of 25 kg Zn ha^{-1} increased K uptake by 14.85, 0.12 and 8.63% in the plants irrigated with 0.72, 5.0 and 10.0 dS m^{-1} water, respectively, while application of 50 kg Zn ha^{-1} increased K uptake by 50.0, 41.89 and 39.69%, respectively, (Fig. 4). Under high salt stress (EC = 10.0 dS m^{-1}) of irrigation water, addition of Zn significantly decreased Na^+ uptake by about 10.0 and 14.5% with the applied rates 25 and 50.0 kg Zn ha^{-1}, respectively (Table 2). Shukla and Mukhi (1985) showed that shoot Na decreased and K increased with applied zinc (10 ppm) to 45-day age maize plants grown on artificial saline soil (EC = 4, 8 or 12 dS m^{-1}) under greenhouse growth conditions.

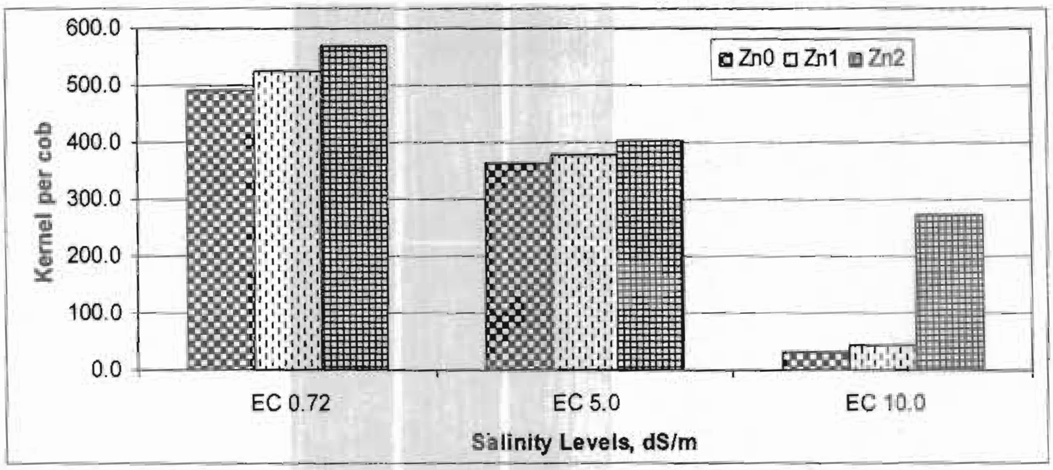

Figure (3): The relation between the number of kernels per cob and zinc application to corn plant grown under different salinity levels of irrigation water.

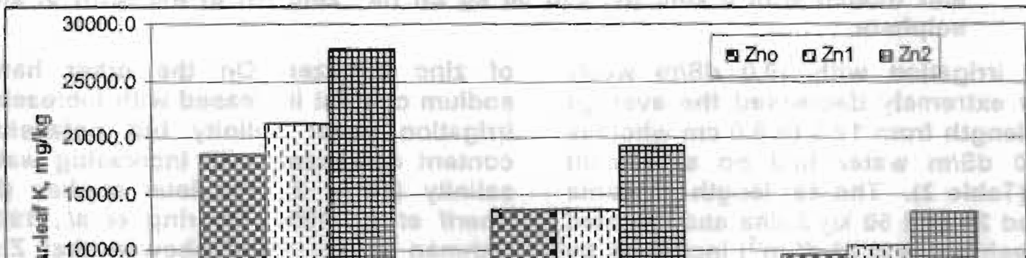

Figure (4): The effect of applied zinc on ear-leaf potassium concentration of corn plant irrigated with different salinity levels of water.

The analysis of variance, which represented in Table (3) by P values, showed that the individual influence of water salinity and applied zinc as independent factors was highly significant for all measured parameters with respect to salinity and most variable with respect to applied Zn but the interaction had no effect.

Discussion and Conclusion

Corn crop grown on saline soils faces three main problems: high salt concentrations in the soil solution (i.e. high osmotic pressure and correspondingly low soil water potential "drought stress"), high concentrations of potentially toxic ions (such as Na^+ and Cl^-) and nutrient imbalance as a result of depressed uptake, impaired internal distribution and shoot transport of minerals (Marschner, 1995). On the other hand, zinc is typically the second most abundant transition metal in organisms after iron (Fe), and the only metal represented in all six enzyme classes

(Broadley *et al.,* 2007). In this study, increasing water salinity significantly decreased corn plant growth and yield. Zinc treatments alleviated the deleterious effects of salinity on plant growth. This effect of Zn on the growth of plants under salinity stress supports the findings of Shakirova *et al.* (2003). The importance of this work comes from the another imperative role of zinc in salt-stressed corn is the regulation of the stomatal aperture which is accounted for possible role of Zn in maintaining a high K content in guard cells. Fig. (5) illustrated that potassium:sodium ratio (K^+/Na^+) was highly increased as the rate of applied Zn increased and reflected an indirect ameliorative effect of zinc in increasing salinity tolerance of corn.

In conclusion, besides its essentiality under normal growth conditions, application of zinc to corn plant irrigated with saline water played an important role in elevating plant tolerance to salt stress and maintained a feasible yield mainly through elevating the K/Na ratio in plant tissues.

Table (3): The analysis of variance (P values) of the experimental data as affected by the interaction between irrigation water salinity and applied zinc.

Source	BY[1]	GY[2]	EL[3]	ED[4]	KRN[5]	KN/R[6]	Zn	Na	K
Salinity	0.000^{***}	0.000^{***}	0.000^{***}	0.000^{***}	0.000^{***}	0.000^{***}	0.000^{***}	0.000^{***}	0.000^{***}
Zinc	0.000^{***}	0.000^{***}	0.0511ns	0.000^{***}	0.1214^{ns}	0.0022^{**}	0.000^{***}	0.3590^{ns}	0.000^{***}
Interaction	0.000^{***}	0.0560^{ns}	0.3173^{ns}	0.1060^{ns}	0.5280^{ns}	0.0161^{*}	0.000^{***}	0.2374^{ns}	0.1969^{ns}

1: BY = biomass yield; 2: GY = grain yield; 3: EL = ear length; 4: ED = ear diameter; 5: KRN = kernel row number; 6: KN/R = kernel number per row.
*: $p<0.05$, **: $p<0.01$; ***: $p<0.001$; ns: non significant

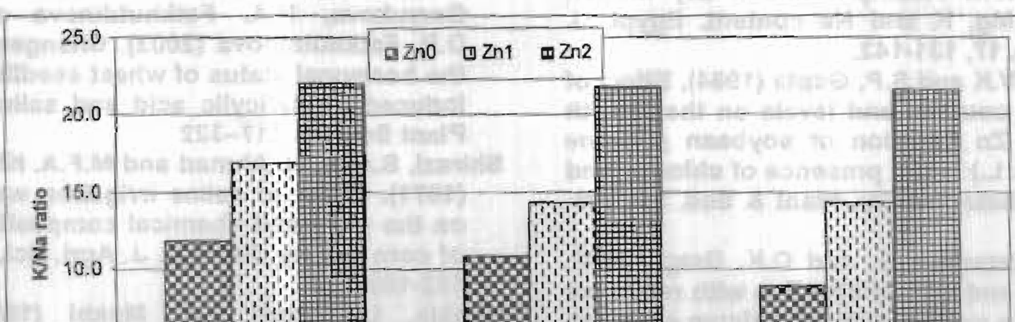

Figure (5): The changes in K/Na ratio of ear-leaf as a results of zinc application to corn plants grown under different salinity levels of irrigation water.

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تأثير إضافة الزنك على محصول نبات الذرة المروى بمياه مالحة

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الملخص العربي

تم إجراء تجارب صوب لدراسة استجابة نباتات الذرة للرى بمياه مالحة وتأثير معدلات إضافة الزنك على تلك الاستجابة. وتضمنت المعاملات الرى بمياه لها توصيل كهربائى ٠،٧٢ و ٥،٠٠ و ١٠،٠٠ ديسيسيمنز/متر والتسميد بمعدلات صفر و ٢٥ و ٥٠ كجم زنك للهكتار فى صورة كبريتات زنك متأدرتة. وتم زراعة الذرة الشامية البيضاء صنف هجين فردى جيزة ١٢٩ فى أصص تحتوى على ٢٥ كجم أرض منقولة من منطقة أبيس جنوب الاسكندرية. بدأ الرى بالمياه المالحة بعد ٣٠ يوم من الزراعة. وعند الحصاد أظهرت النتائج أن الرى بالمياه العذبة أعطى محصول كلى قدره ٢٥,٠٨ طن/هكتار ومحصول حبوب قدره ٨,٢٦ طن/هكتار وأن الرى بالمياه المالحة أدى الى حدوث انخفاض كبير فى كلا المحصولين حيث كانت نسب الانخفاض حوالى ٢٥،٤ و ٥٣،٨% فى المحصول الكلى و٤٠،٠ و ٧٤،٠% فى محصول الحبوب بالنباتات المروية بمياه ملوحتها ٥،٠ و ١٠،٠ ديسيسيمنز/متر على التوالى. إضافة الزنك بمعدل ٥٠ كجم/هكتار زاد من المحصول الكلى ومحصول الحبوب بنسبة ١٧،٨% لكل منهما وذلك للنباتات المروية بالمياه العذبة مقارنة بالنباتات غير المسمدة بالزنك. وقد أدى التسميد بمعدل ٢٥ كجم زنك/هكتار تحت ظروف المياه المالحة الى زيادة المحصول الكلى بمقدار ٣،١٤ طن/هكتار مقارنة بغير المسمدة بينما إضافة ٥٠ كجم زنك للهكتار أدت الى زيادة قدرها ٤,٢٦ طن/هكتار و ١،٠٤ طن/هكتار فى المحصول الكلى ومحصول الحبوب على التوالى فوق محصول النباتات غير المسمدة. ادى التسميد بالزنك بمعدل ٢٥ و ٥٠ كجم زنك للهكتار للنباتات التى تروى بمياه شديدة الملوحة (١٠،٠ ديسيسيمنز/متر) الى زيادة المحصول الكلى بنسبة ٩،٦ و ٤٧،٤% ومحصول الحبوب بنسبة ٤٠،٤٧ و ٧٩،٥٣% على التوالى. حدث تحسن ملحوظ فى كل من طول وقطر الكوز وكذا فى عدد الحبوب فى كل صف من صفوف الكوز للنباتات النامية تحت إجهاد ملحى شديد (١٠ ديسيسيمنز/متر) فى وجود زنك بمعدل ٥٠ كجم/هكتار. أدت اضافة الزنك الى زيادة نسبة البوتاسيوم الى الصوديوم فى انسجة النبات فى كل المعاملات مما يعكس الدور التحسينى للزنك المضاف الى نباتات الذرة النامية تحت إجهاد ملحى.