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Water Use Efficiency of Maize (*Zea mays*) Grown on a Calcareous Soil under Drip Irrigation System

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ABSTRACT

A field experiment was conducted at the experimental farm of Nubaria Horticulture Research Station, Agriculture Research Center to quantify the response of maize grown on calcareous soil to three different water regimes: 100%, 75% and 50% of the Et_c (symboled (I_1), (I_2) and (I_3)), and different applications of K and N fertilizers with regards to enhance the water use efficiency (WUE). Three potassium rates (K_0 = Zero, K_{24} = 24 and K_{48} = 48 kg K_2O/fed as potassium sulfate, 48% KO_2) and two nitrogen rates (N_{90} = 90 and N_{120} = 120 kg N/fed as Urea, 46% N) were used. The experiment was conducted over two growing seasons (2005 and 2006). The average values of cumulative consumptive use (CU) at development, mid-season and late season stages for I_1, I_2 and I_3 were calculated as 375.5, 307.0, and 221.5 mm, respectively. The highest values of CU were obtained with K_{48} and N_{120} treatments. The K_{48} presented the highest value of WUE in the 1st season, while no significant differences were observed between K_{24} and K_{48} in 2nd season. The N_{120} dose significantly increased WUE by 13.5% and 19.7 % than the N_{90} dose in 1st and 2nd seasons, respectively. The interaction between irrigation regimes and potassium levels significantly affected WUE. The I_3 presented the highest value of irrigation water use efficiency (IWUE) were 1.511 and 1.621 kg/m^3, followed by I_2 (1.325 and 1.389 kg/m^3), whereas I_1 presented the least value (1.111 and 1.2 kg/m^3) in 1st and 2nd season, respectively. K_{48} presented the highest value of IWUE (1.562 and 1.513 kg/m^3), followed by K_{24} (1.285 and 1.418 kg/m^3), whereas K_0 presented the least value (1.1 and 1.282 kg/m^3) in 1st and 2nd season, respectively. The N_{120} significantly increased IWUE by 17.9 and 24 % than N_{90} dose in 1st and 2nd season, respectively. The interaction between irrigation regimes and potassium levels significantly affected IWUE. A significant effect was observed as a result of the interaction between irrigation regimes and potassium levels on grain yield of maize in the two growing seasons. The irrigation scheduling of I_3, and I_2 saves 23%, and 46 % of applied irrigation water compared to treatment I_1 during the two seasons, respectively.

Key words: NK fertilizer- consumptive use- -water use efficiency- irrigation water use efficiency.

INTRODUCTION

Irrigation water use efficiency is an important economical concept under water limiting conditions. It is a useful indicator for quantifying the impact of irrigation scheduling decisions regarding water management and is used to define the relationship between crop yield and water consumption of the crop. The climatic changes suggest a future increase in aridity and in the frequency of extreme events, such as lower rainfall, longer drought periods, and higher temperatures, in many areas of the earth (IPCC, 2001). This requires innovative and sustainable research and an appropriate technology transfer and need for improving the irrigation methods and their respective performance as a fundamental tool to reduce the demand for water at the farm level, and to control the negative environmental impacts of over-irrigation, including salt stressed areas(Pereira *et al.*, 2002). Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop (Kirda, 2002).

Potassium (k) plays an important role in contributing to the survival of plants under drought environmental conditions. K plays role in stress response because its levels in plant cells increase under a number of environmental stress conditions under DS, but not under control conditions. Lixin Z. *et al.* (2014) studied the role of potassium (K) in mitigating the adverse effects of drought stress (DS) on 2 maize (Zea mays L.) cultivars, 'Shaandan 9' (S9 ; drought-tolerant) and 'Shaandan 911' (S911; drought-sensitive), was assessed. K application increased dry matter across all growth stages and grain yield in both cultivars. Additionally, K application increased relative water content, nitrate reeducate activity, and concentrations of potassium ion, free proline, soluble protein, and endogenous glycine betaine in both cultivars. These positive effects due to K fertilization under DS were greater for S911 than for S9. In contrast, the differences in the above parameters between K-treated plants and plants under control conditions were either non significant or marginal. This study provides direct evidence of the beneficial physiological function of

K fertilization in mitigating the adverse effects of DS by increased nitrate assimilation and osmotic regulation, but not due to its nutritive role. K showed more clear functions in increasing dry matter and grain yield with water stress (Egilla *et.al.* 2005). Anac *et al.* (2003) studied the effect of K rates and timing of K fertilizer application on the yield of maize under full and deficit irrigation conditions in a wheat-maize crop rotation. They found that the effect of K was significant when the crop was exposed to dry conditions. Yapa *et al.* (1991) and Premachandra *et al.* (1993) concluded that higher levels of K fertilizer application may be beneficial for maize plants to tolerate to water stress conditions. Mottram (1985)reported that cumulative evapotranspiration and yield of maize increased with increasing K rates and were higher with adequate water than with water stress at various times. Yapa *et al.* (1991) and Hefny and Ali (2008) found that maize N deficiency caused delay in flowering time, reduction in total dry matter production, N-uptake by plants and grain yield components .Zhang *et al.* (2007) suggest that nitrogen should be applied to a water-sensitive variety to bring out its potential under drought. Ogola *et al.* (2002) showed the water use efficiency of maize was increased by application of N fertilizer.

In Egypt, the optimum utilization of the present water resources and the proper management of water demand are applied to minimize water losses, increase water use efficiency and to expand the total agricultural land, which could contribute to bridge the country's food gap. In this paper, irrigation scheduling is presented as a good tool to save water and to achieve best water use efficiency (WUE) of Hybrid maize SC10 (*Zea mays* L.). The objective of this research was to determine the effect of different levels of water regime on water consumption, water-use efficiency, and yield of maize grown in calcareous soil at the Horticulture Research Station Farm, located at the Nubaria Region, El-Behera Governorate, Egypt. The experiment was conducted over two growing seasons (2005 and 2006).

MATERIALS AND METHODS

Experimental site

The experimental site is located at the farm of Horticulture Research Station, Nubaria Region (30° 54′ N; 29° 52′ E; and 25m.a.s.l.), Egypt. The climate of the area is classified as a warm semi-arid. The maximum and minimum average temperatures in summer were 29.5 °C and 22 °C, respectively. The average yearly of total rain was 196 mm (winter rain) with 1500 mm of water deficit and a dry period of 9 months. The soil is classified as Calciorthids, with sandy loam texture. Soil samples were collected from representative areas of the experimental site (0-15, 15-30, 30-45 and 45-60 cm depths). The chemical properties of the soil samples; pH, electrical conductivity (EC) of the extract of the saturated soil paste, water soluble cations and anions, cation exchange capacity (CEC), calcium carbonate percentage and organic matter (OM) were determined according to the methods outlined by Page *et al.* (1982). The following soil physical parameters were determined according to the standard methods; particle size distribution (sand, silt and clay percentages and soil texture class) were determined (FAO, 1970), soil bulk density was determined in undisturbed soil samples using the core method (Black and Hartge, 1986), saturated hydraulic conductivity was measured in the laboratory according to Klute and Dirksen (1986) and available water was determined. The main physical and chemical characteristics of the soil samples are presented in Tables (1 and 2).

Experimental design and tested variables

Hybrid SC10 maize (*Zea mays*) plants were irrigated by a surface drip irrigation system (one dripper per plant at 4 liters per hour). Plants were spaced at 75cm between rows and 25cm between plants. The experimental design was a split split-plot with four replicates. The main plots were three irrigation treatments [based on determined crop evapotranspiration (ETc) using Class A pan evaporation data]. These irrigation treatments were 100%, 75%, 50% of the ETc and marked as (I_1), (I_2) and (I_3), respectively. Three potassium rates of zero kg K_2O/fed (K_0), 24 kg K_2O/fed (K_{24}) and 48 kg K_2O/fed (K_{48}) were applied as K_2SO_4 fertilizer(48% KO_2) and represented the sub-plots and two nitrogen rates of 90 kg N/fed (N_{90}) and 120 kg N/fed (N_{120}) were applied as Urea fertilizer (46% N) and represented the sub sub-plots. The plot area was 7.5 m^2.

Table 1: Determined main physical properties of the soils at the experimental site.

Texture class	Particle size (%)			Available water*	Saturated Hydraulic	Bulk density	Soil Depth
	Sand	silt	clay	(mm)	conductivity ($m\ s^{-1}$)	($Mg.\ m^{-3}$)	(cm)
sandy loam	16.9	24.2	58.9	28.67	5.4×10^{-6}	1.25	0-15
sandy loam	15.2	24.5	60.3	32.55	4.9×10^{-6}	1.27	15-30
sandy loam	17.2	26.1	56.7	37.67	5.2×10^{-6}	1.30	30-45
sandy loam	17.3	25.6	57.1	37.24	5.8×10^{-6}	1.30	45-60

* calculated as average moisture contents at -10 and -33 kPa minus moisture contents at -1500 kPa.

Table 2: Determined main chemical properties of the soils at the experimental site.

Soil depth (cm)	pH (1:2.5)	EC (dS m^{-1})	CEC (cmol kg^{-1})	$CaCO_3$ (%)	OM (%)
0-15	8.29	2.76	39.58	25.9	0.25
15-30	8.39	2.73	38.17	24.9	0.12
30-45	8.39	2.73	42.08	26.7	0.24
45-60	8.39	2.46	39.92	25.4	0.26

Soil depth (cm)	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})			
	Na^+	K^+	Ca^{++}	Mg^{++}	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
0-15	12.58	2.44	9.38	2.87	0.0	8.67	16.67	2.26
15-30	14.39	1.45	6.92	4.91	0.0	9.67	15.78	1.85
30-45	14.93	1.47	8.38	2.37	0.0	7.67	17.56	2.07
45-60	17.14	1.62	5.49	1.60	0.0	8.56	12.67	3.37

Crop Water-Use Parameters

Systematic determination of several water parameters was carried out to provide information for the interpretation of the experimental results. The following parameters were determined:

Reference Evapotranspiration (ETo)

The values of ETo were calculated using the class A pan evaporation method (Doorenbos and Kassam, 1986) according to the following equation:

$$ETo = Epan \times Kpan$$

Where: ET_o: reference evapotranspiration (mm.d^{-1}), E_{pan}: daily measured pan evaporation rate (mm d^{-1}) and K_{pan}: pan coefficient that depends on the relative humidity, wind speed, and the site conditions (bare or cultivated), and a value of 0.8 was used for the experimental site according to local climatic condition (FAO, 1975).

Crop coefficient (Kc)

The crop coefficient (Kc) values, for different growth stages of maize crop were within the range 0.3-0.5, 0.7-0.85, 1.05-1.2 and 0.55-0.6 for the initial stage (20 days), the development stage (35 days), the mid-season stage (30 days), and the late season stage (30 days), respectively (FAO, 1975).

Applied Irrigation Water

The amount of applied water was calculated according to the following equation (Vermeiren and Jopling, 1984):

$$AIW = \frac{ETo \,.\, Kc \,.\, Kr \,.\, I}{Ea}$$

where: AIW: depth of applied irrigation water (mm), ET_o: reference evapotranspiration (mm d^{-1}) obtained from class A pan data, K_c: crop coefficient of maize, K_r: reduction factor that depends on the type of crop; a value of 1.0 was used since spacing between drip lines was less than 1.8 m (James, 1988), E_a: irrigation efficiency of the drip system. A value of 0.9 was used as an average value of E_a as determined at the experimental site, and I: irrigation intervals (2 days).

Irrigation time was calculated before an irrigation event by collecting the actual emitter discharges according to the equation given by Ismail (2002) as follows:

$$t = \left(\frac{AIW \times A}{q}\right)$$

Where: t: irrigation time (hr), A: wetted area by an emitter (m^2) and q: emitter discharge (l.hr^{-1}).

Water Consumptive Use

Gravimetric soil samples, from soil surface down to 0.6 m depth at 0.15 m intervals, were collected from all treatments after initial growth stage of plant, before and after each irrigation and at harvest time to determine water consumptive use (CU) which is considered as equal to actual evapotranspiration (ETa). Consumptive use was calculated according to Israelsen and Hansen (1962) as follows:

$$CU = \sum_{i=1}^{i=4} \frac{(\theta_2 - \theta_1)}{100} \times \frac{\rho_b}{\rho_\omega} \times D$$

Where: CU: water consumptive use (mm), θ_1 and θ_2 percentage of gravimetric soil moisture content just before the next irrigation event and after an irrigation event, respectively. ρ_b :bulk density (Mg.m^{-3}), ρ_w: water density (Mg.m^{-3}), D: depth of soil layer (mm) and i : soil layers.

Water Use Efficiency and Irrigation Water Use Efficiency

Water use efficiency (kg crop yield per m^3 of water consumed) was calculated according to Jensen (1983) as follows:

$$WUE = \frac{CropYield(kg/fed)}{ConsumedIrrigationWater(m^3/fed)}$$

Irrigation water use efficiency was calculated according to the following formula:

$$IWUE = \frac{CropYield(kg/fed)}{AppliedIrrigationWater(m^3/fed)}$$

Statistical Analysis:

The obtained data were statistically analyzed using the COSTAT Software (CoHort, 1986). The average values from the four replicates of each treatment were interpreted using the analysis of variance (ANOVA). The Duncan's Multiple Range Test was used for comparisons between different sources of variance according to Steel and Torrie (1984).

RESULTS AND DISCUSSIONS

Maize water-use parameters

Water use parameters of maize includes reference evapotranspiration (ET_o), crop evapotranspiration (ET_c), scheduling of irrigation and the effect of water stress, on water consumptive use (CU), water use efficiency (WUE) and irrigation water use efficiency (IWUE).

Reference Evapotranspiration (ETo)

The values of reference evapotranspiration (ET_o) at the experimental site using class A pan in the two growing seasons are presented in Fig. (1).The average daily ET_o was 5 mm d^{-1} and seasonal ET_o values were 520 mm in the two growing seasons. The fluctuation of ET_o during the different growth stages was attributed to the changes of weather conditions and crop water requirement. These data were in agreement with those obtained by Abou-hadid *et al.* (1988) and FAO (1998) who stated that the change of radiation, air temperature, humidity, wind speed and light intensity would affect the evapotranspiration rate.

Crop Evapotranspiration (ETc)

Daily crop evapotranspiration (ET_c) values of maize during the two growing seasons were estimated by multiplying ET_o and crop coefficient (K_c) (Fig. 1). This data showed that the mean ET_c values in the 1st season were 1.4, 4.0, 6.2 and 3.4 mm.d^{-1} for initial, development, mid-season and late season stages, respectively. During the 2nd season, the mean crop ET_c values were 1.9, 4.2, 5.4 and 3.4 mm d^{-1} for the respective growth stages, respectively. Seasonal ET_c values were 414.5 and 400.7 mm in 1st and 2nd growing seasons, respectively.The data in Fig. (1), could indicate also that maize ET_c values varied due to the change in both climatic conditions (ET_o change) and plant growth (K_c values). The ET_c values gradually increased with proceeding plant age till the mid-season stage, then the rate decreased till the end of the growth season. This trend is in agreement with the finding of Erik *et al.* (1982) and Doorenbos and Pruitt (1977) who reported that ET_c values increased with the progress in plant growth and reached a peak during some part of the plant growth period, depending on the plant type, growth characteristics and environmental conditions, then tapered off by harvest time.

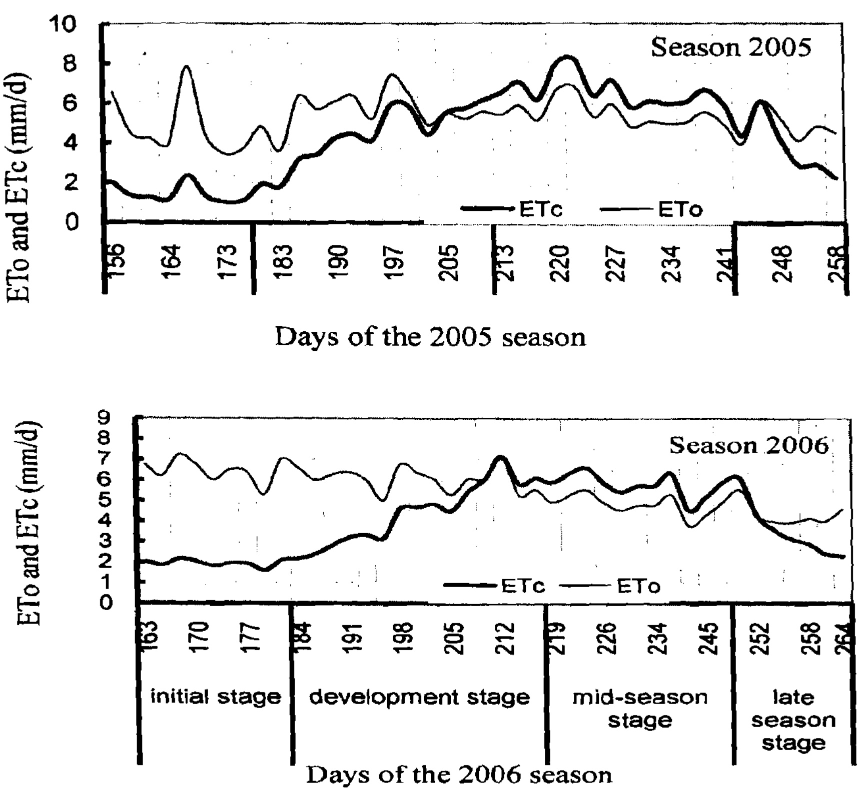

Fig. 1: The reference and crop evapotranspiration (mm.d^{-1}) during the two growing seasons of maize.

Amount of Irrigation Water (AIW)

The amounts of applied irrigation water to maize plant at different growth stages in the two growing seasons under different irrigation regimes are presented in Table (3). The irrigation treatments were applied after the initial growth stage, where all the experimental plots received equal amounts of irrigation water at initial stage to ensure good establishment of the plants, after that, the amounts of applied irrigation water for I_2 and I_3 were 75% and 50 % of I_1, respectively. As in case of ET_c, the amounts of AIW increased with the development in growth stages to reach the peak at mid-season stage and then decreased at late season stage.

Water Consumptive Use (CU)

Water Consumptive use of maize (actual crop evapotranspiration, mm/day, is defined as the unit amount of water used in transpiration on a given area, building of plant tissues, and evaporation from adjacent soil (Erik *et al.* 1982). After initial stage, the changes between two successive soil moisture contents were used to calculate the actual CU of maize (Israelsen and Hansen, 1962). The CU values of maize crop at development, mid-season and late season growth stages under different irrigation treatments in the two growing seasons are presented in Fig. (2). Results show that, as plants developed, gradual increase in water consumption was observed. At mid-season stage, the CU reached its peak (195, 163, 114 mm in the two seasons for I_1, I_2 and I_3, respectively. After this period, CU decreased (Fig.2). This trend was in parallel to that of AIW trend in (Table 3).

Effect of Irrigation Regimes on CU

The effect of a water stress (deficit irrigation) on CU was severe in treatments with projected water shortage in soil profile during all growth stages. Results in Figure (2) show that the highest CU was found in case of I_1 treatment followed by I_2 in the two growing seasons. Results indicate that the seasonal CU or actual evapotranspiration (ETa) values were influenced by the moisture regimes. Average CU values in the two seasons for the stressed soil water treatments (I_3 and I_2) were 58.4 and 80.8 % of the CU when irrigation water is not limited (I_1). These results agree with those obtained by Zhang *et al.* (2004), Kirda (2002) and Payero *et al.* (2006), who reported that a severe or slight soil water deficit significantly reduces actual crop evapotranspiration, which mainly depends on irrigation amounts.

These results indicate a positive linear relationship between AIW (mm) an d CU (mm) in the two growing seasons. The obtained relation could be expressed in the following equation: CU = 0.79 AIW - 0.77 ($R^2 = 0.96$).

Effect of Irrigation Regimes on Water Use Efficiency (WUE):

The effect of water deficit on WUE of maize is presented in Figure (3). It is clear from the results that WUE increased in the case of water deficit, and increased significantly with 50% water deficit treatment (I_3) (17.6 and 24% in 1st and 2nd seasons, respectively) in comparison with non-stressed treatment (I_1). The data also showed that there were no significant differences between I_2 and I_1 and between I_3 and I_2 treatments in the two growing seasons. These findings are comparable to those of Eck (1986), Kang *et al.* (2000) and Karam *et al.* (2003), Faci and Fereres (1980) reported that WUE was decreased with increasing irrigation of sorghum.

Effect of Irrigation Regimes on Irrigation Water Use Efficiency (IWUE)

Figure (4) Shows that water deficit increased IWUE significantly in the two growth seasons. The two treatments I_2 and I_3 consistently resulted in a decrease of IWUE relative to I_1 treatment. The average values of IWUE decrease for I_2 and I_3 relative to I_1 were 19.3% and 36% in the 1st season and 15.4% and 34.6% in the 2nd season, respectively. These results are in agreement with those obtained by Otegui *et al.* (1995), Oktem *et al.* (2003), Kirda. (2002) and Farre and Faci (2006) who noted that IWUE in maize decreased markedly with decreasing the amounts of water applied. Contrary to our findings, El-Hendawy *et al.* (2008) reported that high irrigation rates displayed the highest IWUE.

Table 3: Applied irrigation water (mm) at different growth stages under different irrigation treatments.

Growth stage (G.S.)	Length of growing season. (days)	2005				2006			
		No. of IRs	applied water (mm)			No. of IRs	applied water (mm)		
			I_1	I_2	I_3		I_1	I_2	I_3
initial stage	20	8	39	39	39	9	53	53	53
development stage	35	13	195	146	98	15	201	150	100
mid-season stage	30	13	256	192	128	11	222	167	111
late season stage	30	6	80	60	40	7	75	56	38
Total	115	40	570	437	305	42	551	427	302

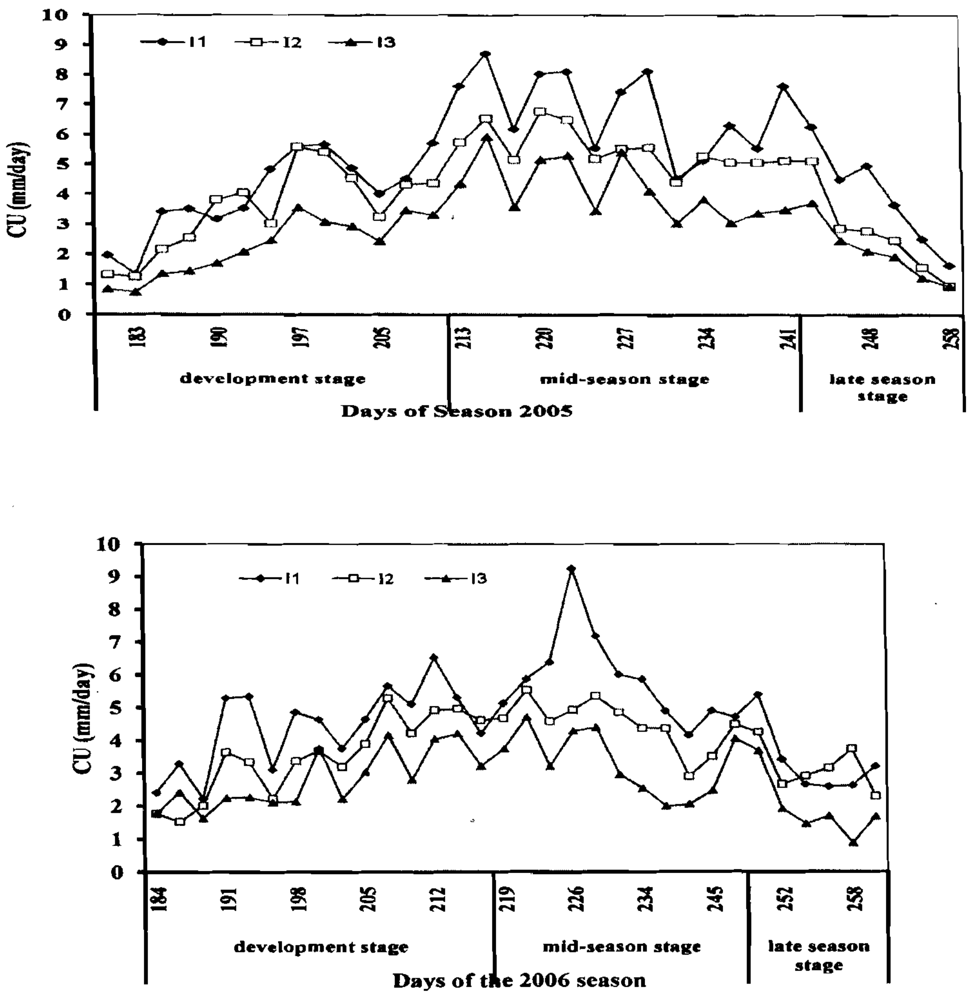

Fig. 2: Effect of water deficit on water consumptive use (CU) at different growth stages of maize during the two growing seasons

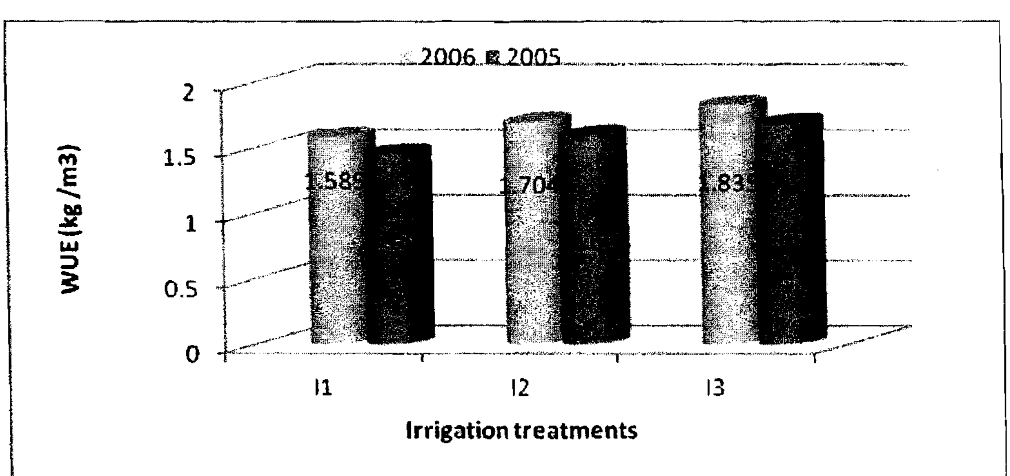

Fig. 3: Effect of irrigation treatments on WUE of maize growth in the two growing seasons.

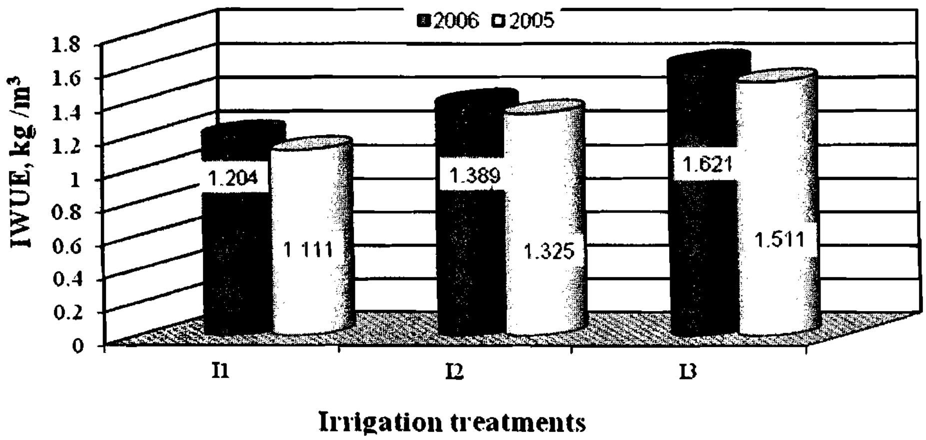

Fig. 4: Effect of maize irrigation treatments on IWUE during the two growing seasons.

Effect of Deficit Irrigation on Grain Yield

The data presented in Fig.5 indicate that grain yield was significantly affected by water deficit in the two growth seasons. The highest grain yield was recorded at I_1 treatments which received 570 mm and 551mm in the 1st and 2nd season respectively, followed by I_2, which received 437 and 427mm of seasonal AIW in the 1st and 2nd season, respectively. The lowest grain yield was recorded at the treatment I_3 which received only 305 and 302 mm of water in 1st and 2nd season, respectively. A comparison between mean grain yields of the irrigation treatments show that the grain yield was highly dependent on seasonal AIW, hence, plants grown under I_3 (saving 46.5% and 45.2% of AIW) had, statistically, the highest significant differences reach to 27.2% and 26.2 %, followed by I_2 (saving 23.3% and 22.5% of AIW) with a reduction in grain yield of 8.5% and 10.6 % as compared with I_1, in 1st and 2nd seasons, respectively. Similar decrease in grain yield of maize with water stress was reported by Claassen and Shaw (1970), Ogola *et al.* (2002), Karam *et al.* (2003), Cakir (2004), Zhang *et al.* (2004), Kirda (2002), Payero *et al.* (2006), Zhang *et al.* (2007), O'Neill *et al.* (2008) and Lixin Z. *et al.* (2014).

Effect of Potassium and Nitrogen on Water Consumptive Use

It is clear, that K_{48} achieved the highest increase in CU under I_3 in the two growing seasons (Table 4). The values of the average increase in CU in case of K_{24} and K48 treatments as compared to K_0 treatment were 4.1%, 8.8% under I_1, and 6.6 %, 9.85% under I_2 and 14.1%, 14.5 %, in I_3. These results agreed with those of Mottram (1985) and Premachandra *et al.* (1993). The data in Table 4 indicated that N_{120} achieved the highest relative increase in CU values under I_2 in the two growing seasons. The percentages of increase were 2.4%, 5.0%, and 4.2 % under I_1, I_2 and I_3, respectively. This indicates that high doses of N increasing root growth, especially when exposed to slight water stress. Hence, the effects of N on crop water use are expected to vary with the availability of soil moisture.

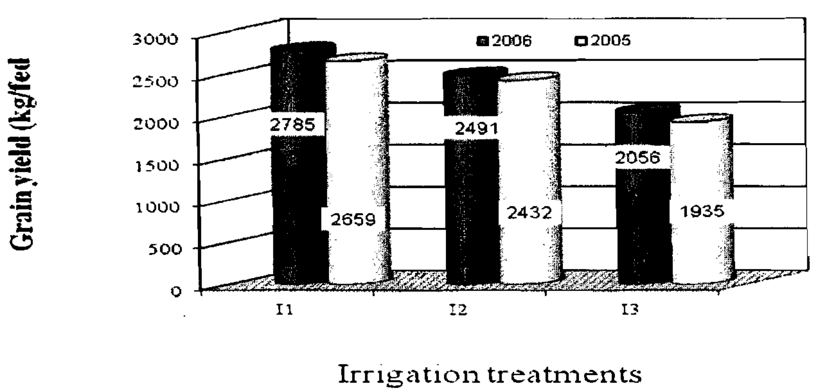

Fig. 5: Effect of irrigation treatments on maize grain yield in the two growing seasons.

Table 4: Effects of water deficit, K and N doses on CU, mm of maize growth in the two growing seasons

Irrigation treatments	K doses	N doses	Seasonal CU, mm	
			Season I 2005	Season II II 2006
I_1	K0	N90	365	354
		N120	373	358
	K24	N90	383	361
		N120	397	368
	K48	N90	414	372
		N120	433	375
I_2	K0	N90	291	264
		N120	302	283
	K24	N90	318	290
		N120	329	303
	K48	N90	327	300
		N120	354	320
I_3	K0	N90	210	194
		N120	221	203
	K24	N90	224	208
		N120	231	219
	K48	N90	244	222
		N120	252	230

The results were in agreement with those of Ogola *et al.* (2002). This could be due to the contribution of nitrogen to the enhancing of root depth as well as total root mass, hence alleviating drought effects where deep sub-soil moisture is present. The obtained results agreed with those reported by Linscott *et al.* (1962), Keller and Smith (1967), Mackay and Barber (1986) and Eghball *et al.* (1993).

Effect of Potassium and Nitrogen Levels on Water Use Efficiency (WUE)

Figure (6) Indicates that K_{48} presented the highest value of WUE, while no significant differences were observed between K_{24} and K_{48} in the 2nd season. This indicates that K-fertilizer increased WUE of maize and decreased the negative impact of water stress. Similar K-fertilizer effect on WUE was reported by Mottram (1985), Ming De and Shengxiu, LI. (1996) and Lixin Z. *et al.* (2014) who pointed out that plants well supplied with K responded to stress by immediate closure, whereas closure in K-deficient plants was slow and inefficient.

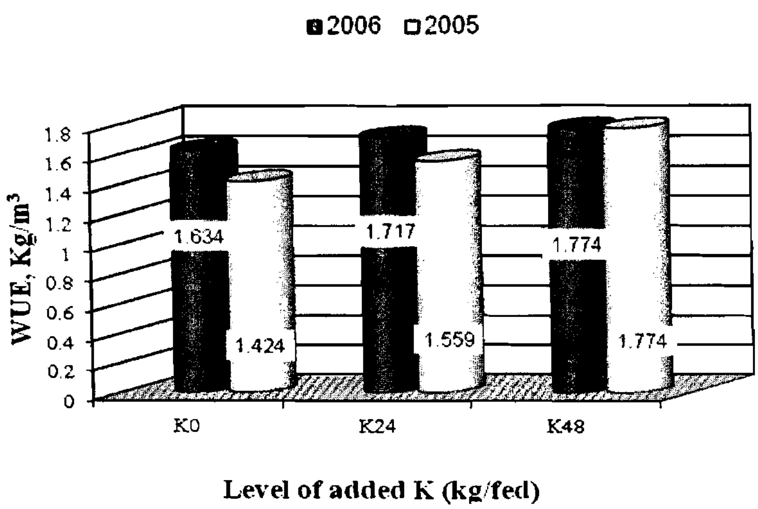

Fig. 6: Effect of potassium doses on WUE in maize in the two growing seasons.

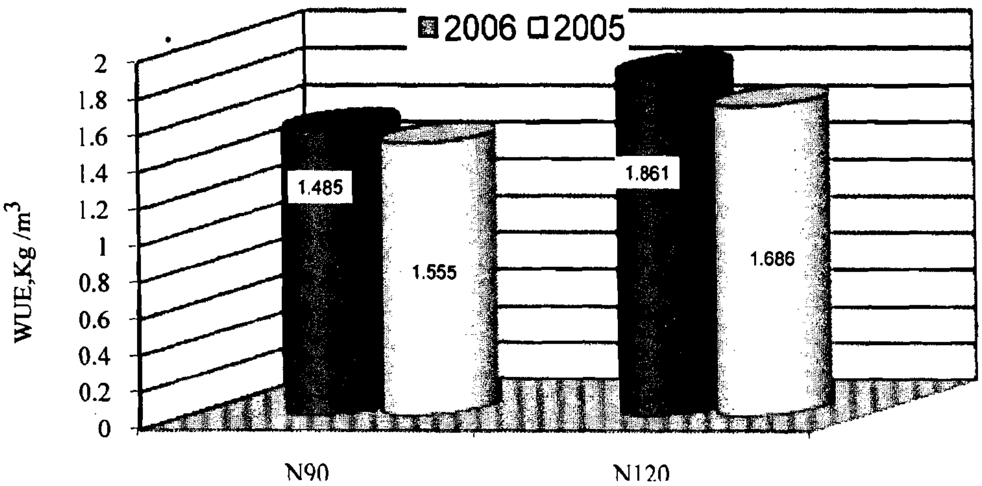

Fig. 7: Effect of nitrogen doses on WUE in maize in the two growing seasons.

The obtained results showed also that high nitrogen applications lead to significant increase in WUE (Fig. 7) since WUE with N_{120} was greater than N_{90} by 13.5% and 19.7 % in 1st and 2nd season, respectively. This compares well with the findings of Ogola *et al.* (2002) and Lixin Z. *et al.* (2014), who observed that WUE of maize was increased by application N fertilizer.

Effect of Potassium and Nitrogen interactions on WUE

The interaction effect between irrigation rate and potassium levels on WUE was significant in both growing seasons (Table, 5). The highest WUE was obtained from K_{48} under I_3 (2.053 and 1.877 kg.m^{-3} in 1st and 2nd season, respectively. The other interactions not show significant effect on WUE in the two growing seasons.

Effect of Potassium and Nitrogen doses on Grain Yield

Fig. (8) shows t significant differences among the tested potassium levels on maize grain yield in the two growth seasons. The K_{48} was the most effective in increasing maize grain yield (37.2% and 18%) with a significant difference from other potassium levels, followed by K_{24} (13.% and 9.6%) as compared with K_0, in 1st and 2nd seasons, respectively. These results have a similar trend as those of Mottram (1985), Vilela and Bull (1999), Negm *et al.* (2002) and Lixin Z. *et al.* (2014).

It is clear that the differences between nitrogen doses on maize grain yield were significant in both seasons as shown in Fig. 9. The highest dose of nitrogen fertilization (N_{120}) had the highest grain yield (2523 and 2684 kg/fed) with a significant difference with N_{90} (2161 and 2204 kg/fed) in the 1st and 2nd seasons, respectively. Similar results were reported by Ogunlela *et al.* (1988), Ogola *et al.* (2002), Coque and Gallais (2007), Zhang *et al.* (2007) and Hefny *and Ali,* (2008) and Lixin Z. *et al.* (2014).

Effect of interactions on Grain Yield

Results regarding the effect of interaction between irrigation regimes and potassium levels presented in Table (6) showed significant effect on grain yield in the two growing seasons. The highest value of grain yield of maize was found in the plants fertilized with K_{48} grown in soil irrigated with I_1 (3033 kg/fed and 3105 kg/fed in 1st and 2nd season, respectively). Likewise, Yapa *et al.* (1991), Anac *et al.* (2003) and El-Hadi and Khadr (2003) found a significant interaction between increasing K and soil moisture on maize grain yield. The other interactions did not have any significant effect on grain yield of maize in the two growing seasons.

CONCLUSION

The data obtained from this study show the effect of soil, water and plant relationship on maize crop grown in calcareous soil with an average daily ETo of 4.98 mm d^{-1} and 5.26 mm d^{-1} in 1st and 2nd growing seasons, respectively. Seasonal ETo values are 508.3 mm and 531.3 mm in 1st and 2nd growing seasons, respectively. The rate of ETc (mm d^{-1}) in initial, development, mid-season and late season stage is 1.4mm d^{-1}, 4.0mm d^{-1} mm d^{-1}, 6.2 mm d^{-1} and 3.4mm d^{-1}, and 1.9 mmd^{-1}, 4.2mm d^{-1}, 5.4mm d^{-1} and 3.4 mm d^{-1} in 1st and 2nd growing seasons, respectively. The irrigation scheduling of I_3, and I_2 saves 23%, and 46 % of applied irrigation water compared to treatment I_1 during the two seasons, respectively. As plants developed, gradual increase in water consumption was found and the CU reached its peak at mid-season stage, the rates of CU then decreased.

Table 5: Effect of water deficit, K and N doses on WUE of maize in the two growing seasons.

Irrigation regimes	WUE ($kg.m^{-3}$)													
	2005							2006						
	K_0		K_{24}		K_{48}		Average	K_0		K_{24}		K_{48}		Average
	N_{90}	N_{120}	N_{90}	N_{120}	N_{90}	N_{120}		N_{90}	N_{120}	N_{90}	N_{120}	N_{90}	N_{120}	
I_1	1.498	1.508	1.222	1.405	1.464	1.655	1.459^b	1.491	1.627	1.352	1.576	1.662	1.803	1.585^b
I_2	1.256	1.471	1.688	1.783	1.625	1.792	1.603^{ab}	1.441	1.654	1.721	1.985	1.547	1.876	1.704^{ab}
I_3	1.236	1.573	1.409	1.847	1.967	2.138	1.695^a	1.458	2.133	1.562	2.106	1.765	1.989	1.835^a
Means	1.330	1.517	1.440	1.679	1.685	1.862		1.464	1.805	1.545	1.889	1.658	1.889	
L.S.D$_{0.05}$ Irrigation			0.197					0.20						
L.S.D$_{0.05}$ Potassium× Nitrogen			(ns)					(ns)						
L.S.D$_{0.05}$ Irrigation× Potassium× Nitrogen			(ns)					(ns)						

Irrigation Regimes	2005					2006				
	N		K			N		K		
	N_{90}	N_{120}	K_0	K_{24}	K_{48}	N_{90}	N_{120}	K_0	K_{24}	K_{48}
I_1	1.395	1.523	1.503	1.314	1.560	1.502	1.669	1.559	1.464	1.732
I_2	1.523	1.682	1.364	1.736	1.708	1.570	1.838	1.548	1.853	1.712
I_3	1.537	1.853	1.404	1.628	2.053	1.595	2.076	1.796	1.834	1.877
Means	1.485^b	1.686^a	1.424^c	1.559^b	1.774^a	1.555^b	1.861^a	1.634^b	1.717^{ab}	1.774^a
L.S.D$_{0.05}$ Potassium			0.113					0.093		
L.S.D$_{0.05}$ Nitrogen			0.115					0.148		
L.S.D0.05 Irrigation× Potassium			0.196					0.321		
L.S.D$_{0.05}$ Irrigation × Nitrogen			(ns)					(ns)		

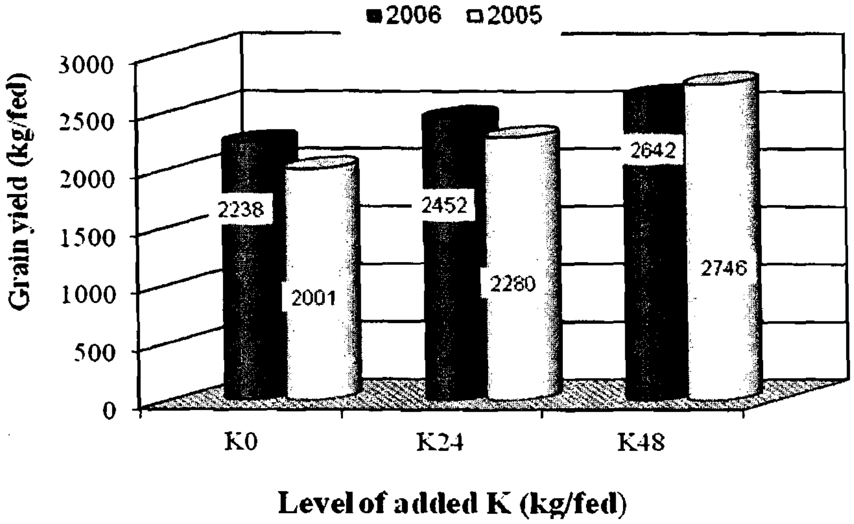

Fig. 8: Effect of potassium doses on maize grain yield in the two growing seasons.

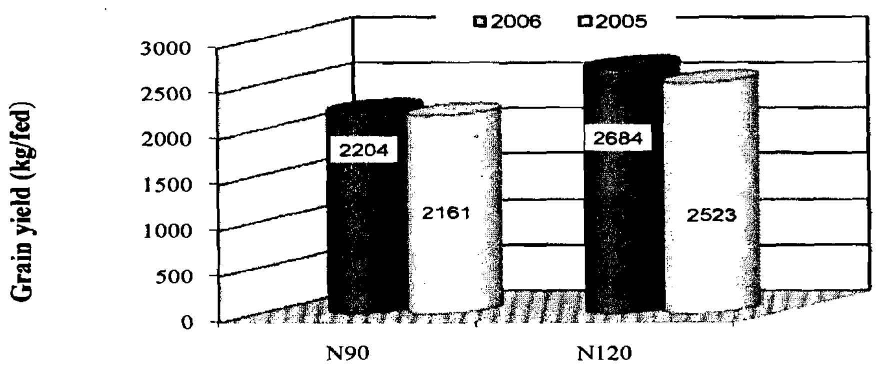

Fig. 9: Effect of nitrogen doses on maize grain yield in the two growing seasons.

A positive linear relationship between AIW (mm) and CU (mm) over the two growing seasons was obtained (CU = 0.79 AIW- 0.77, R^2 = 0.96). Under treatment I_3 significant increase in the relative water use efficiency ($WUEI_3$/ $WUEI_1$) by 20.8%. Irrigation water use efficiency IWUE was highest for I_3 (1.57 kg/m3) followed by I_2 (1.36 kg/m3), whereas I_1 had the lowest value (1.15 kg/m3). All K-fertilizer levels significantly increased WUE values compared to the control and K_{48} and N_{120} doses produced the highest value of IWUE.

REFERENCES

Anac, D., O.G. Kilic, N. Eryuce, and B. Okur. **2003**. Effect of potassium amount and time of application on maize yields under water deficit. Potassium and water management in West Asia and North Africa Proceedings of the Regional Workshop of the International Potash Institute. pp 67-75.

Abu-hadid, A.F., A.S. El-Beltagy, and H.M. El-Said.1988. Potential evapotranspiration for different regions and water consumptive use patterns under plastic house conditions in Egypt. J. Hort.,**15**: 1-12.

Black, G., and K.Hartge, **1986**. Bulk Density (363-377). In Klute, A. (ed.): Methods of Soil Analysis. Physical and Mineralogical Methods,2nd Ed. Soil Sci..Soc. Am. Madison, Wisconsin, USA.

Cakir, R. **2004**. Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Res. **89**: 1-16.

Cavero, J., I. Farre, P. Debaeke, J. Faci, and E. Playan. **2000**. Simulation of maize yield under water stress with EPICphase and CROPWAT in a semiarid climate. Agronomy J. **92**: 679–690.

Claassen, M.M., and R.H. Shaw. **1970**. Water deficit effects on corn. II. Grain components. Agronomy J. **62**: 652–655.

CoHort Software. **1986**. Costat Statistical package (version 3.03), Berkeley, CA, USA.

Coque, M., and A. Gallais. **2007**. Genetic variation among European maize varieties for nitrogen use efficiency under low and high nitrogen fertilization. Maydica **52**: 383-397

Doorenbos, J. and A. Kassam. **1986**. Yield response to water. FAO, Irrigation &Drainage paper No. **33**, Rome, Italy.

Doorenbos, J., and W.O. Pruitt. **1977**. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage paper **24**. FAO, Rome.

Eck, H.V. **1986**. Effects of water deficits on yield, yield components, and water use efficiency of irrigated corn. Agronomy J. **78**: 1035–1040.

Eghball, B., J.R. Settimi, J.W. Maranville, and A.M. Parkhurst. **1993**. Fractal analysis for morphological description of corn roots under nitrogen stress. Agronomy J. **85**: 287–289.

Egilla, J.N., F.T. Davies, and T.W. Boutton. **2005**. Drought stress influences leaf water content, photosynthesis and water-use efficiency of Hibisucusrosa-sinensis at three potassium concentrations. Photosynthetica **43**: 135-140.

El-Hadi, A.H.A., and M.S. Khadr. **2003**. Efficiency of potassium fertilization under saline and drought conditions in Egyptian soils. Potassium and water management in West Asia and North Africa Proceedings of the Regional Workshop of the International Potash Institute. pp 85-96.

El-Hendawya, S.E., E.A. Abd El-Lattief, M.S. Ahmed, and U. Schmidhalter. **2008**. Irrigation rate and plant density effects on yield and water use efficiency of drip-irrigated corn. Agricultural Water Management **95**: 836-844.

Erik, L.J., O.F. French, D.A. Bucks, and K. Harris. **1982**. Consumptive use of water by major crops in the Southwestern United States. U.S. Department of Agriculture, Agriculture Research Service Conservation Research Report no. **29**.

Faci, J.M., and E. Fereres. 1980. Responses of grain sorghum to variable water supply under two irrigation frequencies. Irrigation Sci. **1**: 149–159.

FAO. **1970**. Physical and Chemical Methods of Soil and Water Analysis. Soils Bull. No. **10**, FAO, Rome, Italy.

FAO. **1975**. Crop water requirements. Irrigation and Drainage Paper.No. 24.FAO, Rome, Italy.

FAO. **1998**. Crop evapotranspiration-Guidelines for computing crop water requirement. Irrigation and Drainage Paper.No. 56.FAO, Rome, Italy.

Farre, I., and J.M. Faci. **2006**. Comparative response of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) to deficit irrigation in a Mediterranean environment. Agricultural Water Management **83**: 135-143.

Hefny, M.M., and A.A. Aly. **2008**. Yielding ability and nitrogen use efficiency in maize inbred lines and their crosses. International Journal of Agricultural Research **3**: 27-39

IPCC. 2001. Climate change **2001**: The scientific basis. *In:* Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M.,Van der Linden, Pj.,Xiaosu, D. (eds.), Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK.

Ismail, S.M. **2002**. Design and Management of Field Irrigation System.(In Arabic), 1st Ed., Monshaet El-Maaref, Alexandria, Egypt, pp 367.

Israelson, O.W., and V.E. Hansen. **1962**. Irrigation Principals and Practice. 3rd Ed. John Wiley and Sons Inc., New York, USA.

James, L.G. **1988**. Principles of Farm Irrigation System Design. John Wiley and Sons, Inc., New York, USA.

Jensen, M.E. 1983. Design and Operation of Farm Irrigation Systems. American Society Agricultural Engineering, St. Joseph, USA, Pp. 827.

Kang, S., W. Shi, and J. Zhang. **2000**. An improved water-use efficiency for maize grown under regulated deficit irrigation. Field Crops Res. **67**: 207–214.

Karam, F., J. Breidy, C. Stephan, and J. Rouphael. 2003. Evapotranspiration, yield and water use efficiency of drip irrigated corn in the Bekaa Valley of Lebanon. Agricultural Water Management **63**: 125-137.

Keller, W.D., and G.E. Smith. **1967**. Ground water contamination by dissolved nitrate. Geological Soc. of Am.**90**: 48–59.

Kirda, C. **2002**. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. FAO, Water Reports. **22**: 3-10.

Klute, A., and C. Dirksen. **1986**. Hydraulic Conductivity and Diffusivity: Laboratory Methods, In Klute,A. (ed.). Methods of Soil Analysis: Physical and Mineralogical Methods. (2ed Ed). Madison, WI, USA. 687-733.

Li, Y., J. Cui, T. Zhang, and H. Zhao. **2003**. Measurement of evapotranspiration of irrigated spring wheat and maize in a semi-arid region of north China. Agricultural Water Management **61**:1-12.

Linscott, D.L., R.L. Fox, and R.C. Lipps. **1962**. Corn root distribution and moisture extraction in relation to nitrogen fertilization and soil properties. Agronomy Journal **54**: 85–189.

Lixin, Z., Mei GAO, Shengxiu LI, Ashok Kumar, A. and M. Ashraf. **2014**. Potassium fertilization mitigates the adverse effects of drought on selected Zea mays cultivars. Turk J Bot. **38**: 713-723.

Mackay, A.D. and S.A. Barber. **1986**. Effect of nitrogen on root growth of two corn genotypes in the field. Agronomy J. **78**: 699–703.

Ming De, L. and Z. Shengxiu. **1996**. Influence of potassium nutrition on growth and drought resistance of maize. Soils and Fertilizers Beijing **4**: 10-12.

Mottram, R. **1985**. Influence of potassium on the plant water relations of maize. Proceedings of the fifteenth annual congress of the South African Society of Crop Production: 145-157.

Negm, M.A., R.G. Kerlous, L.A. Hussein, and A.H. Elssayed. **2002**. Effect of farmyard manure and potassium sulphate applications on maize in a calcareous soil. Egyptian J. of Soil Sci. **42**: 435-447.

Ogola, J.B.O., T.R. Wheeler, and P.M. Harris. **2002**. Effects of nitrogen and irrigation on water use of maize crops. Field Crops Res. **78**: 105-117.

Ogunlela, V.B., G.M. Amoruwa, and O.O. Ologunde. **1988**. Growth, yield components and micronutrient nutrition of field-grown maize (Zea mays L.) as affected by nitrogen fertilization and plant density. Nutrient Cycling in Agro ecosystems **17**: 189-196.

Oktem, A., M. Simsek, and A.G. Oktem. **2003**. Deficit irrigation effects on sweet corn (*Zea mays, Saccharasturt*) with drip irrigation system in a semi-arid region. 1- Water yield relationship. Agricultural Water Management **61**: 63-74.

O'Neill, C.J., E. Humphreys, J. Louis, and A. Katupitiya. **2008**. Maize productivity in southern New South Wales under furrow and pressurized irrigation. Australian Journal of Experimental Agriculture **48**: 285-295.

Otegui, M.E., F.H. Andrade, and E.E. Suero. **1995**. Growth, water use, and kernel abortion of maize subjected to drought at silking. Field Crops Research **40**: 87-94.

Page, A.L., R.H. Miller, and D.R. Keeny. **1982**. Methods of Soil Analysis, Part 2: Chemical and Microbiological properties. America Society of Agronomy, Madison, Wisconsin, USA.

Payero, J.O., S.R. Melvin, S. Irmak, and D. Tarkalsona. **2006**. Yield response of corn to deficit irrigation in a semiarid climate. Agricultural Water Management **84**: 101-112.

Pereira, L. S., T. Oweis, and A. Zairi. **2002**. Irrigation management under water scarcity. Agricultural Water Management **57**:175-206.

Premachandra, G.S., H. Saneoka, K. Fujita, and S. Ogata. **1993**. Water stress and potassium fertilization in field grown maize (Zea mays L.): effects on leaf water relations and leaf rolling. Agronomy and Crop Science **170**: 195-201.

Steel, R.G. and T.H. Torrie. **1984**. Principals and Procedures of Statistics. McGrow Hill, New York, USA.

Tumwesigye, E.K., and F. Musiitwa. **2001**. Characterizing drought patterns for appropriate development and transfer of drought resistant maize cultivars in Uganda. Seventh Eastern and Southern Africa Regional Maize Conference: 260-262.

Vermeiren, L., and G.A. Jopling. **1984**. Localized irrigation. FAO Irrigation and Drainage paper No. **36**, Rome, Italy.

Vilela, E.F., and L.T. Bull. **1999**. Evaluation of maize growth as a function of potassium rates and water stress. Revista Brasileira de Ciencia do Solo. **23**: 281-289.

Yapa, L.G.G., W. M. U. N. Wanasundara, and B.V.R. Punyawardena. **1991**. The role of potassium fertilizer in drought tolerance of corn grown in noncalcic brown soils (Haplustalfs). Soil Science Society of Sri Lanka **7**: 76-90.

Yazar, A., S. Sezen, and B. Gencel. 2002. Drip irrigation of corn in the Southeast Anatolia Project (GAP) area in Turkey. Irrigation and Drainage **51**: 293–300.

Zhang, Y., C. Liu, Y. Tang, and Y. Yang. **2007**. Trends in pan evaporation and reference and actual evapotranspiration across the Tibetan Plateau, Journal of Geophysical Research 112: 12110.

Zhang, Y., E. Kendy, Y. Qiang, L. Changming, S. Yanjun, and S. Hongyong. **2004**. Effect of soil water deficit on evapotranspiration, crop yield, and water use efficiency in the North China Plain. Agricultural Water Management **64**: 107-122.

الملخص العربى

كفاءة استخدام المياه لنبات الذرة النامية في الاراضى الجيرية تحت نظام الري بالتنقيط

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الهدف من إجراء هذه الدراسة هو تقدير تأثير مستويات مختلفة من الرجيم المائى على كل من الاستهلاك المائى، كفاءة استخدام مياة الرى ومحصول الذرة النامى فى أرض جيرية بمزرعة محطة بحوث الخضر بمنطقة النوبارية التابعة لمحافظة البحيرة – مصر. أظهرت النتائج أن المعدل اليومي للبخرنتح القياسى(ET_0) تتراوح بين ٤,٩٨ و ٥,٢٦ مم/ يوم في موسمى النمو على التوالي. كانت القيم الموسمية للبخرنتح القياسى (ET_0) ٥٠٨,٣ و٥٣١,٣ مم فى موسم الزراعة الأول والثانى على التوالي. كان معدل البخرنتح الفعلى اليومى(ET_C) في المرحلة الأولي من النمو، فترة التقدم، منتصف الموسم والمرحلة الأخيرة من موسم النمو ١,٤، ٤,٠، ٦,٢ و٣,٤ مم/ يوم للموسم الاول و ١,٩ و ٤,٢ و ٥,٤ و ٣,٤ مم/ يوم للموسم الثانى. وفرت جدولة الري فى المعاملتينI_2، I_3 ٢٣% و٤٦% من مياه الري بالمقارنة بالمعاملةI_1 خلال موسمي النمو على التوالي. مع تطور نمو النباتات، حدثت زيادة تدريجية في استهلاك المياه حيث وصلت قيم معدل الاستهلاك المائى(CU) ذروته في مرحلة منتصف الموسم، ثم انخفضت معدلات CU. تم الحصول على علاقة خطية طردية بين AIW (مم) وCU (مم) خلال موسمى النمو (CU =0.79* AIW - 0.77) حيث كانت قيمة معامل التقدير (R^2 = 0.96). لوحظ فى معاملة الرىI_3 زيادة كبيرة في الكفاءة النسبية لإستخدام مياه الرى ($WUEI_3$ / $WUEI_1$) حيث وصلت الى ٢٠,٨٪. كانت قيمة كفاءة استخدام مياه الري IWUE أعلى فى المعاملة I_3 (1.57كجم/م٣)، تلتها معاملة I_2 (1.36 كجم/م٣)، في حين I_1 كانت أقل قيمة (١,١٥ كجم/م٣). جميع مستويات التسميد بالبوتسيوم أوضحت زيادة كبيرة في قيم WUE مقارنة بالكنترول وأعطت جرعات التسميد K48 وN120 أعلى قيم IWUE.