ESTIMATING ACTUAL EVAPOTRANSPIRATION AND WATER STRESS COEFFICIENT FOR GROUNDNUT CROP UNDER DIFFERENT SALT CONCENTRATIONS IN SANDY SOIL

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ABSTRACT

Field experimental was conducted to study the influence of different irrigation water salinity levels on actual evapotranspiration, water stress coefficient, yield and water use efficiency for groundnut crop under trickle irrigation system in sandy soil located at 30^o 24$^`$ N latitude, 31$^o$ 35$^`$ E longitude while the altitude is 20m above the sea level.

Four irrigation water salinity levels were used; 2.4 (S_1), 2.7 (S_2), 3.3 (S_3) and 4.4 (S_4) dS m^{-1}, beside a fresh water (FW) as a control (0.5 dS m^{-1}). Cattle manure was added as a soil amendment as a rate of 48 m^3 ha^{-1}. Neutron moisture meter was used to determine soil moisture content and depilation through the soil depths of 30, 45, 60, 75 and 90cm. Soil moisture content of 15 cm soil depth was determined gravimetrically.

The applied irrigation water was 700 mm/season based on 100 % of recommended crop water requirements according to FAO Irrigation and Drainage Paper No.33. The obtained results showed that actual evapotranspiration (ET_a) and water stress coefficient (K_s) were slightly deceased by increasing the salinity of irrigation water especially under S_4 salinity treatment (4.4 dS m^{-1}).

Regarding the yield, water use efficiency (WUE) and irrigation water use efficiency (IWUE) of groundnut crop, the high salinity of irrigation water reduced both yield; WUE and IWUE. The yield of groundnut follows the order FW (3.89 ton ha^{-1}) > S_1 (2.19 ton ha^{-1}) > S_2 (1.63 ton ha^{-1}) > S_3 (1.54 ton ha^{-1}) > S_4 (1.19 ton ha^{-1}). Concerning soil chemical properties; the salinity of irrigation water significantly increased soil (EC_e). This increment was reached 6 fold of that found for soils irrigated with fresh water.

Key words: *Actual evapotranspiration, water stress coefficient, saline water, sandy soil, groundnut, WUE.*

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INTRODUCTION

Water is one of the most important resources for the growth and development of human communities. Water demand for agriculture is increasing worldwide to meet the increasing demand for food by the rapidly growing population and to improve the living standards of a large part of the population (UN Population Division, 1994). Groundnut *(Arachis hypogaea* L.*)* is one of the most important crops grown in the arid and semi arid zone. It is either grown for its nut, oil or its vegetative residue. Recently, the use of groundnut meal is becoming more recognized not only as a dietary supplement for children on protein poor cereals-based diets but also as effective treatment for children with protein related malnutrition. Groundnut production is influenced by several environmental factors, especially by moisture stress and temperature as reported by several authors (Karim, 1990, Ravindra et al., 1990, Ntare et al., 2001). Present world production is about 38.2 million tons shelled nuts from 24.6 million ha (FAOSTAT, 2008)

One of the most important concepts regarding water balance in semi-arid areas is crop evapotranspiration (ET_c) which is a key factor for determining proper irrigation scheduling and for improving water use efficiency in irrigated agriculture. Accurate estimation of evapotranspiration constitutes a very important part of irrigation system planning and designing, and accurate spatial determination is crucial to achieving sustainable agriculture (Er-Raki et al., 2007). Climate factors determining the crop water requirements needed for unrestricted optimum growth and yield. The demand for water by the crop must be met by the water in the soil, via the root system. The actual rate of water uptake by the crop from the soil in relation to its. ET_c is determined by whether, the available water in the soil is adequate or whether the crop will suffer from stress inducing water deficit. The effect of water stress on growth and yield depends on the crop species and the variety on the one hand and the magnitude and the time of occurrence of water deficit on the other Doorenbos and Pruitt (1977).

Soil salinity is one of the most serious environmental threats for plant distribution, survival and productivity (Ashraf and Harris, 2004). Salinity affects 19.5% of irrigated area and 2.1% of dry land agriculture across the globe (FAO, 2000). Salinity impacts on soil and water quality and crop production and causes serious off-site environmental degradation (*van* Hoorn and *van* Alphen, 1994). Consequently, salinity is one of the most challenging environmental problems facing irrigation landscapes around the world, including Egypt.

The water consumptive use (Cu) was increased with the progressive in plant growth and reaches to a peak during some part of the plant growth period, depending on plant type, growth characteristics and environmental conditions, and then tapered off by harvest time. In other words, the actual evapotranspiration was decreased with increasing soil water stress (K_s). This reduction in the actual crop evapotranspiration rate could be attributed to the shortage of available water in the root zone which occurred when the amounts of added water were decreased (Doorenbos and Pruitt, 1977). Also, Allen et al. (1998) said that the forces acting on the soil water decrease its potential energy and make it less available for plant root extraction. When the soil is wet, the water has a high potential energy, is relatively free to move and is easily taken up by the plant roots. In dry soils, the water has a low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop. The objective of this work is to study the influence of salinity stress on yield of ground nut, water use efficiency, actual evapotranspiration and water stress coefficient.

MATERIALS AND METHODS

Location

An experiment was conducted at the Farm of Soil and Water Research Department, Nuclear Research Center, Atomic Energy Authority, Inshas area, Sharkia Governorate, Egypt (30^{o} 24` N: $31^{o}$ 35` E and elevated above the sea level by 20m). Additionally, Table (1) shows the average weather data in summer season of groundnut crop.

Table (1): The meteorological data at Inshas area, during growing season of groundnut crop

Period		Temperature		Relative humidity		Wind speed	Sun shine	Net radiation	Rain
Months	Duration (d)	T_{max} (ºC)	T_{min} (ºC)	RH_{max} (%)	RH_{min} (%)	U_2 ($m\ s^{-1}$)	n ($hr\ d^{-1}$)	R_n ($MJ\ m^{-2}\ d^{-1}$)	P ($mm\ d^{-1}$)
June	1-10	35.4	22.5	73.4	22.4	3.89	12.3	16.1	0.00
	11-20	33.8	21.0	79.2	27.7	4.11	12.3	16.4	0.00
	21-30	35.7	24.1	73.8	26.7	2.53	12.3	16.5	0.00
July	1-10	34.8	23.5	84.7	33.1	3.17	12.3	16.9	0.00
	11-20	34.0	23.9	84.3	36.3	3.64	12.1	16.8	0.00
	21-31	33.5	23.8	80.5	34.7	3.51	12.0	16.2	0.00
August	1-10	34.6	23.6	84.0	34.9	2.81	11.8	15.9	0.00
	11-20	35.1	24.8	83.2	35.0	3.36	11.3	15.2	0.00
	21-31	35.5	25.0	83.5	34.9	3.43	10.9	14.4	0.00
September	1-10	33.3	22.9	84.2	39.0	3.11	10.4	13.3	0.00
	11-23	34.1	24.1	76.8	30.3	2.84	10.0	11.8	0.00

Cattle manure was mixed at the rate of 48 $m^3\ ha^{-1}$ with the upper 25 cm of the soil layer. The used manure was mixed and incorporated into the surface soil layer before cultivation of groundnut. All the agronomic practices were applied commonly used for growing groundnut and carried out according to the recommendation of the Ministry of Agriculture. The recommended NPK fertilizers were added at a rate of:

A. Ammonium sulphate [20.6% $(NH_4)_2SO_4$] was added at rate of 580 kg ha^{-1}, divided in to six parts before flowering.

B. Super phosphate [15% P_2O_5] was added at rate of 715 kg ha^{-1}, added before planting.

C. Potassium sulphate [48% K_2O] was added at rate of 120 kg ha^{-1}, divided in to two parts before and during flowering.

Tables (2 and 3) show some physical properties according to (Klute, 1986) and chemical properties according to (Page, 1982) of an experimental sandy soil.

Table (2): Some physical characteristics of experimental soil

Depth (cm)	Practical size distribution (%)			Texture class	Bulk density ($g\ cm^{-3}$)	Moisture content by volume (%)		
	Sand	Silt	Clay			F.C	W.P	A.W
0-15	97.66	1.87	0.47	Sand	1.63	9.92	1.38	8.54
15-30	98.73	0.80	0.47	Sand	1.68	8.83	1.30	7.53
30-45	98.60	0.87	0.53	Sand	1.67	8.97	1.31	7.66
45-60	98.60	0.87	0.53	Sand	1.67	8.97	1.31	7.66
60-75	98.47	0.73	0.80	Sand	1.63	9.11	1.32	7.79
75-90	98.80	0.80	0.40	Sand	1.66	8.76	1.30	7.46

Table (3): Some chemical characteristics of experimental soil

Depth (cm)	EC ($dS\ m^{-1}$)	Cl^- ($meq\ l^{-1}$)	HCO_3^- ($meq\ l^{-1}$)	SO_4^{--} ($meq\ l^{-1}$)	Ca^{++} ($meq\ l^{-1}$)	Mg^{++} ($meq\ l^{-1}$)	Na^+ ($meq\ l^{-1}$)	K^+ ($meq\ l^{-1}$)
0-15	0.60	2.10	2.90	0.13	1.46	0.90	2.55	0.22
15-30	0.56	2.30	2.85	0.36	1.48	0.96	2.48	0.59
30-45	0.54	2.03	2.88	0.14	1.50	1.28	1.84	0.43
45-60	0.54	1.90	2.90	0.32	1.36	1.64	1.78	0.34
60-75	0.50	1.57	2.55	0.45	1.20	1.56	1.40	0.41
75-90	0.44	1.23	2.80	0.22	1.40	1.64	1.04	0.17

Irrigation scheduling and treatments

Five different water salinity levels were used; control treatment with fresh water and the other four saline water treatments were: 2.4 (S_1), 2.7 (S_2), 3.3 (S_3) and 4.4 (S_4) dS m^{-1}, tabled in FAO Irrigation and Drainage Paper No.29 (Ayers and Westcot, 1985). The saline water was prepared by mixing fresh water (0.50 dS m^{-1}) with (Sodium chloride) salt at certain ratios. The chemical composition of irrigation water is given in Table (4).

Table (4): Some chemical characteristics of irrigation water

Treat-ments	EC ($dS\ m^{-1}$)	Cl^- ($meq\ l^{-1}$)	HCO_3^- ($meq\ l^{-1}$)	SO_4^{--} ($meq\ l^{-1}$)	Ca^{++} ($meq\ l^{-1}$)	Mg^{++} ($meq\ l^{-1}$)	Na^+ ($meq\ l^{-1}$)	K^+ ($meq\ l^{-1}$)
F.W	0.50	2.20	2.10	0.10	1.60	1.40	1.17	0.23
S_1	2.40	16.0	2.90	4.35	4.00	3.40	15.3	0.49
S_2	2.70	16.0	3.20	5.56	2.20	5.60	16.0	0.88
S_3	3.30	21.5	2.20	6.85	2.40	7.40	19.3	1.41
S_4	4.40	29.2	4.00	3.21	2.00	8.00	24.8	1.60

The amount of applied irrigation water was 700 mm for total growing period. The nuts were irrigated with different saline water from seedling. Crop water requirements, added according to FAO Irrigation and

Drainage Paper No.33 (Doorenbos and Kassam, 1979) based on the plant growth stages as shown in ***Table (5)***.

Table (5): The amount of water applied every day and growth stages.

Growth stages	Duration (d)	Period (d/stages)	K_c (-)	Water applied (mm d^{-1})	Water depth (mm)
Initial	1/6-25/6	25	0.4	2.95	73.7
Development	26/6-9/8	45	0.8	5.89	265
Mid-season	10/8-9/9	30	1.1	8.11	243
Late-season	11/9-30/9	20	0.8	5.89	118
Total		**120**			**700**

The experimental design and system

The groundnut *(Arachis hypogaea* L.*)* variety Giza 6 was planted on May 29, 2008 and harvested at September 24, 2008. The amount of nuts required to one hectare was 180kg pods/ha. The nuts were treated by bacterial pollination before planting. The experiment was arranged in a randomized complete block design with four replications. Each experimental plot took up an area of 17.64m^2 (4.20m x 4.20m) with plant spacing 30cm within rows and 60cm between rows. There was a gap of 2m width between the plots. The plots were irrigated by trickle irrigation; with PVC pipes of 50mm (OD) diameter in main and submain lines, the lateral line was 16mm (OD) diameter of polyethylene with GR built in trickle line emitter at 30cm spacing with manufacturing discharge 4 l hr^{-1} at an operating pressure of 1bar to serve crop rows. A trickle irrigation network consisting of sand and screen media filter, pressure gauges and control valves, two small pumps and four plastic tanks of 2000 L capacity each was designed to apply varying amount of saline irrigation water for the treatments. The performance of trickle irrigation system was evaluated by calculating the distribution uniformity (*DU*), determined in the field, according to the principles of Keller and Karmeli (1974) it was 96.13%, which was classified as “Excellent“ with coefficient of variation (C_v) 0.029, which was classified as “uniform“ according to ASAE standard (2002). The layout of experiment is shown in Figure (1).

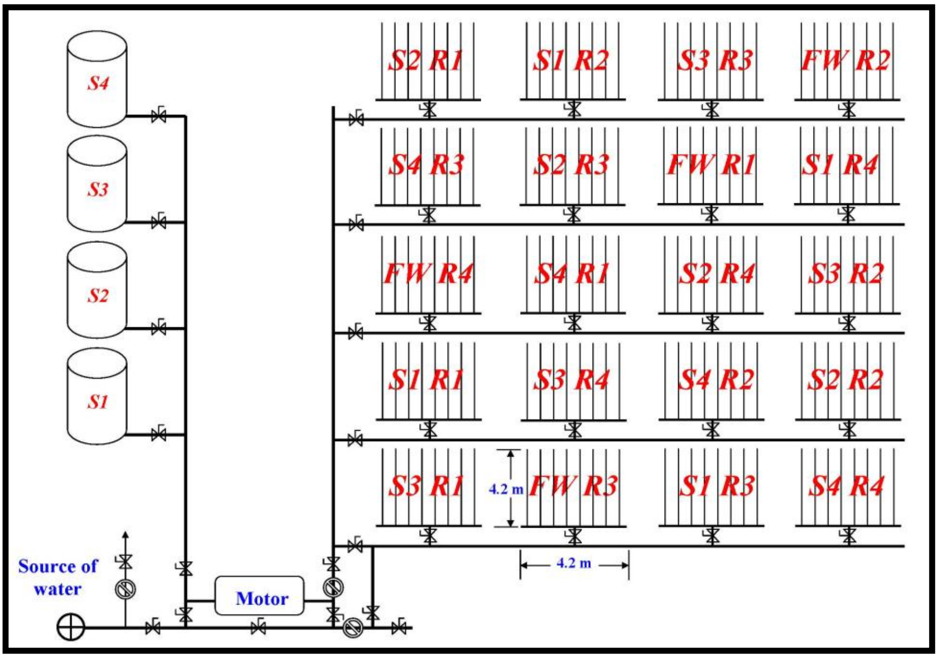

Figure (1): Layout of groundnut crop experiment

Reference crop evapotranspiration (ET_o)

Reference crop evapotranspiration (ET_o) was calculated by Penman-Monteith equation (Allen et al., 1998) as following in Equation (1):

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (1)$$

Where:

ET_o : Reference evapotranspiration [mm d^{-1}],

Δ : Slope vapour pressure curve [kPa $°C^{-1}$],

R_n : Net radiation at the crop surface [MJ m^{-2} d^{-1}],

G : Soil heat flux density [MJ m^{-2} d^{-1}],

e_s : Saturation vapour pressure [kPa],

e_a : Actual vapour pressure [kPa],

$e_s - e_a$: Saturation vapour pressure deficit [kPa],

u_2 : Wind speed at 2 m height [m s^{-1}], and

γ : Psychometric constant [kPa $°C^{-1}$].

Crop evapotranspiration (ET_c)

There are two methods to estimate crop evapotranspiration, one under standard conditions according to (Allen et al., 1998) calculated by multiplying the reference crop evapotranspiration (ET_o) by a crop coefficient (K_c) as the follows Equation (2):

$$ET_c = K_c \, ET_o \qquad (2)$$

Where:

ET_c : The crop evapotranspiration [mm d^{-1}],

K_c : The single crop coefficient [dimensionless], and

ET_o : The reference crop evapotranspiration [mm d^{-1}]

The second under non-standard conditions ($ET_{c\ adj}$) which is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. The crop evapotranspiration under non-standard conditions is calculated by using a water stress coefficient K_s and/or by adjusting K_c for all kinds of other stresses and environmental constraints on crop evapotranspiration. Where the single crop coefficient is used, the effect of water stress (K_s) is incorporated into (K_c) as in Equation (3):

$$ET_{c\ adj} = K_s \, K_c \, ET_o \qquad (3)$$

Where:

$ET_{c\ adj}$: The ET_c under non-standard conditions [mm d^{-1}],

K_s : The water stress coefficient [dimensionless],

K_c : The single crop coefficient [dimensionless], and

ET_o : The reference crop evapotranspiration [mm d^{-1}].

K_s describe the effect of water stress on crop transpiration. When salinity stress occurs without water stress, for these conditions ($EC_e > EC_{e\ threshold}$), soil water depletion is less than the readily available soil water depth (D_r < RAW), the K_s Calculated by Equation (4):

$$K_s = 1 - \frac{b}{K_y \; 100}\left(EC_e - EC_{e\;threshold}\right) \qquad (4)$$

Where:

- EC_e : Mean electrical conductivity of the saturation extract for the root zone [dS m^{-1}],
- $EC_{e\;threshold}$: Electrical conductivity of the saturation extract at the threshold of EC_e when crop yield first reduces below Y_m [dS m^{-1}],
- b : Reduction in yield per increase in EC_e [%/(dS m^{-1})],
- K_y : Yield response factor [-].
- D_r : Root zone depletion (mm), and
- RAW : Readily available soil water in the root zone (mm).

This equation is suggested by (Allen et al., 1998) as only an approximate estimation of salinity impacts on ET_c, and represents the general effects of salinity on evapotranspiration as occurring over an extended period of time (as measured in weeks or months) and use of this equation should usually be restricted to $EC_e < EC_{e\;threshold} + 50/b$.

Neutron calibration of neutron moisture meter

Field calibration curves at 30, 45, 60, 75 and 90 cm depth of neutron moisture were done at these soil. Table (6) show the regression equation of calibration curves for the soil depths under study.

Table (6): The regression equation of calibration curves for the soil depths under study

Soil depth (cm)	Regression Equation	Coefficient of determination R^2
15-30	θ_v % = 22.533 * CR - 5.142	0.9663
30-45	θ_v % = 14.753 * CR - 2.303	0.9339
45-60	θ_v % = 19.354 * CR - 4.877	0.9922
60-75	θ_v % = 19.092 * CR - 4.128	0.9031
75-90	θ_v % = 18.130 * CR - 4.299	0.9316

Actual evapotranspiration ET_a (Consumptive Use Cu)

To calculate the actual water evapotranspiration or the consumptive use by plant, soil moisture content was determined before and after each irrigation (1 hour) within the soil profile for different soil layer up to 90cm soil depth by using the neutron moisture meter. The moisture content in the surface layer (0-15cm) was determined by using gravimetric method, where fast neutrons escape to air, so, using gravimetric method is better.

Water use efficiency (WUE)

Water use efficiency (WUE) is the ratio of yield to seasonal crop evapotranspiration (ET_c) (Payero et al., 2008), given by Equation (5):

$$WUE = \frac{yield\ (Y)}{seasonal\ crop\ evapotranspiration\ (ET_c)} \qquad (5)$$

Where:

WUE : Water use efficiency (kg m^{-3}),

Y : Yield (kg ha^{-1}), and

ET_c : Seasonal crop evapotranspiration (m^3 ha^{-1}).

Irrigation water use efficiency (IWUE)

Irrigation water use efficiency (IWUE) is the ratio of yield to seasonal irrigation (I) (Payero et al., 2008), given by Equation (6):

$$IWUE = \frac{yield\ (Y)}{Seasonal\ irrigation\ (I)} \qquad (6)$$

Where:

IWUE : Irrigation water use efficacy (kg m^{-3}).

Y : Yield (kg ha^{-1}), and

I : Seasonal irrigation (m^3 ha^{-1}).

RESULTS AND DISCUSSIONS

Reference evapotranspiration (ET_o)

Based on the agrometrological data collected for the studied area and values of reference evapotranspiration (ET_o) was calculated by CROPWAT model (Smith, 1992). Table (7) shows values of reference crop evapotranspiration through the growth stages of groundnut season. The values of ET_o through growth season indicate that it was high with the beginning of season and decreased till harvesting time. This is may be due to the changes in the climatologically norms for the area, as the cultivation starts with both relatively high temperature and solar radiation and ends by a decreased than it's. The total ET_o value during the growth season of groundnut was 871.6 mm (8716 $m^3\ ha^{-1}$).

Table (7): Values of ET_o through different growth stages of groundnut

Growth stages	Initial	Development	Mid-season	Late	Total
Duration (d)	**25**	**45**	**31**	**14**	**115**
mm / stage	215.3	344.4	220.4	91.5	**871.6**
$m^3\ ha^{-1}$	2153	3444	2204	915	**8716**

Actual evapotranspiration (ET_a)

Actual evapotranspiration (ET_a) is the actual rate of water uptake by the plant which is determined by the level of available water in the soil (Phocaides, 2000). Data presented in Table (8) shows the actual evapotranspiration values for the groundnut crop. It's clearly that the total amount of ET_a is high for the fresh water (FW) treatment (629.8 mm/season) compared to salinity water (S_4) treatment (545.7 mm/season) under all tested treatments. Referring to the effect of irrigation water salinities on the water consumptive use, data presented in Table (8) reveals that the water consumed by the plant during the different periods of plant growth follows the order of (FW) > (S_1) > (S_2) > (S_3) > (S_4) treatments. This finding is in agreement with Bhantana and Lazarovitch (2010); they found that the daily ET_a of pomegranate is significantly lower under saline water irrigation than under FW irrigation.

Table (8): The average seasonal ET_a values at all growth stages of groundnut crop under different irrigation salinity treatment

Treat-ments	Growth stages								Total Season
	Initial		Development		Mid-season		Late		
	mm d^{-1}	mm	mm d^{-1}	mm	mm d^{-1}	mm	mm d^{-1}	mm	mm
FW	3.19	79.7	6.61	297.5	5.81	180.2	5.17	72.4	629.8
S_1	2.9	72.5	6.18	278.1	6.08	188.4	4.99	69.8	608.9
S_2	3.16	79.1	5.68	255.4	6.04	187.1	5.52	77.3	598.9
S_3	3.1	77.6	6.08	273.4	5.62	174.1	5.12	71.7	596.8
S_4	3.24	81.1	5.78	260.1	4.69	145.4	4.18	58.5	545.1

From the data presented in Table (8), it could be noticed that the average daily and seasonal ET_a values of all growth stages were varied as the changing in climatic conditions, salt concentration of irrigation water and plant growth stage. At the initial stage, the average daily ET_a was low, it were 3.19, 2.90, 3.16, 3.10, 3.24 mm d^{-1} for S_1, S_2, S_3 and S_4, respectively, then increased to reach maximum value at the end of development stage, it were 6.61, 6.18, 5.68, 6.08, 5.78 mm d^{-1} for S_1, S_2, S_3 and S_4, respectively. At the mid-season it decreased until the late stage, the rate of ET_a declined as the crop became mature. This is agreement with the finding of Doorenbos and Pruitt (1977), in that reported the water consumptive use increases with the progression in plant growth and reaches a peak during some part of the plant growth period, depending on the plant type, growth characteristics and the environmental conditions, and then tapers off till harvest time.

Crop coefficient (K_c)

Figure (2) illustrate the average crop coefficient of groundnut for four stages of growth season under the different treatments of groundnut, the average K_c values (Eq. 3) clearly differ from the average K_c values of FAO No.33 (Doorenbos and Kassam, 1979) during the initial and mid-season stages, where in the initial stage the average K_c values were approximately 7, 16, 8, 10 and 6% for FW, S_1, S_2, S_3 respectively and S_4 which are lower than the average K_c values suggested by FAO No.33; meanwhile, at the development stage, the average K_c values were identical and/or closely to the average K_c values as suggested by FAO

No.33. However, during the mid-season stage the K_c values were 26, 22, 23, 28 and 40% for FW, S_1, S_2, S_3 respectively and S_4 which are lower than the average K_c values suggested by FAO No.33. In the end stage, the K_c values were 0.79, 0.76, 0.85 and 0.78 for FW, S_1, S_2 and S_3 respectively; additionally, the average K_c value was 25% for S_4 which is lower than the average K_c values of FAO No.33.

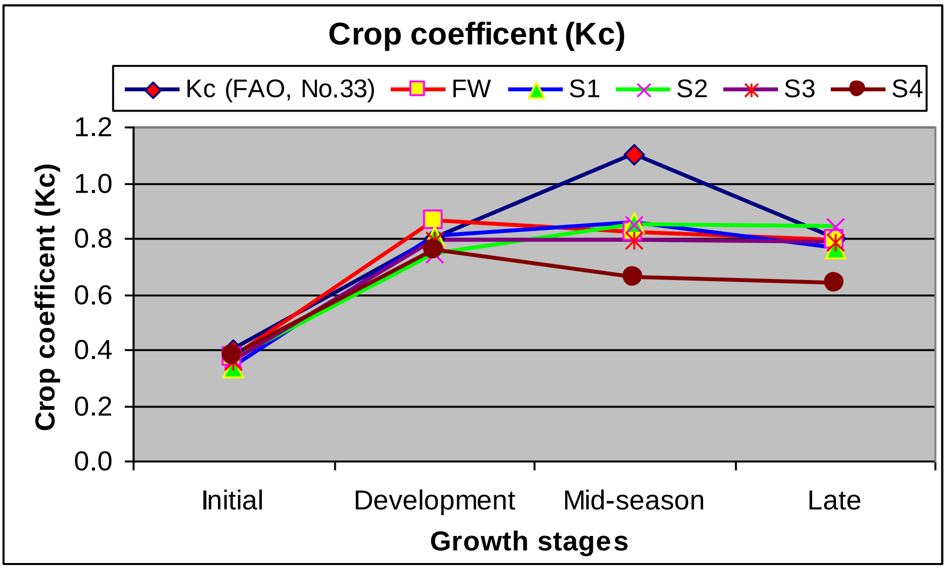

Figure (2): Crop coefficient for four stages of groundnut at all treatments.

According to the results in this study, the calculated values of crop coefficients markedly differed from those suggested by FAO No.33 for the crops considered herein. For groundnut, a marked differences between the estimated K_c values and the average K_c value suggested by the FAO No.33 in the initial and mid-season stages. Where it was found to be lower the differences are attributed primarily to specific cultivator, the changes in local climatic conditions, and seasonal differences in crop growth patterns. Such differences obviously reflect the difficulty not only in extrapolating crop coefficients to other environments, but also in applying crop coefficients in individual year with differing crop development patterns.

Water stress coefficient (K_s)

The effects of soil water stress on crop ET are described by reducing the value for the crop coefficient (K_c). This is accomplished by multiplying the crop coefficient by the water stress coefficient, K_s (Eq. 3).

Table (9) illustrates the mean values of soil electrical conductivity in the root zone 0 – 30 cm; it was used to calculate the water stress coefficient (K_s). Table (10) illustrates water stress coefficient (K_s) of groundnut for four growing stages under irrigation treatments. The K_s values clearly differ from stage to other because the salt stress causes both osmotic stress, due to a decrease in the soil water potential, and ionic stress, due to toxicity caused by high concentrations of certain ions within the plant (Cramer, 1997). During the initial stage, the K_s values (Eq. 4) are close to 1.00 for FW, S_1, S_2 and S_3 which mean that the root zone salinity (EC_e) did not reach to $EC_{e\ threshold}$ value (3.2 dS m^{-1}) (Doorenbos and Kassam, 1979) but a slight effect appears for S_4 with K_s (0.94), on the other hand, soil texture may play an important role in this respect beside the effect of salt accumulation in the root zone for this stage. The accumulation of solutes may allow plants to maintain a positive pressure potential, which is required to keep stomata open and to sustain gas exchange and growth (White et al., 2000). Meanwhile, development stage, the data demonstrates the gradual increments in the salt concentration in the root zone. The K_s values were identical (1.00) to FW, but the K_s values were 0.98, 0.94, 0.90 and 0.85 for S_1, S_2, S_3 and S_4, respectively. However, during the mid-season stage the peak values of soil salinity (EC_e) in the root zone were obtained, which means the lowest values of K_s, it were 1.00, 0.72, 0.65, 0.57 and 0.47 for FW, S_1, S_2, S_3 and S_4, respectively. The direct increase in salt accumulation as well as the irrigation with saline water had reduced the K_s values, by 28, 35, 43 and 53% for S_1, S_2, S_3 and S_4, respectively, compared with FW. In the end stage, the K_s values were 1.00, 0.94, 0.86, 0.62 and 0.59 for FW, S_1, S_2, S_3 and S_4, respectively. Generally, the average lowest values for all growth stages of K_s were graduated according to the following series; S_4 (0.71) > S_3 (0.77) > S_2 (0.86) > S_1 (0.91) > FW (1.00).

Table (9): Electrical conductivity EC_e (dS m^{-1}) in the root zone of groundnut crop

Growth stages	Initial	Development	Mid-season	Late
Day after planting (d)	**25**	**70**	**101**	**115**
FW	0.95	1.09	0.58	0.63
S1	1.20	3.25	3.88	3.35
S2	2.85	3.34	4.05	3.54
S3	2.30	3.45	4.25	4.13
S4	3.35	3.55	4.48	4.20

Table (10): Water stress coefficient (K_s) for four stages of groundnut crop at all treatments

Growth stages	Initial	Development	Mid-season	Late	Average
Pried (d)	**25**	**45**	**31**	**14**	
FW	1.00	1.00	1.00	1.00	**1.00**
S1	1.00	0.98	0.72	0.94	**0.91**
S2	1.00	0.94	0.65	0.86	**0.86**
S3	1.00	0.90	0.57	0.62	**0.77**
S4	0.94	0.85	0.47	0.59	**0.71**

Crop evapotranspiration under standard conditions (ET_c) (Fresh water) and nonstandard conditions ($ET_{c\ adj}$) (Saline water)

Table (11) illustrates the total values of crop evapotranspiration for groundnut crop, it was (677.3 mm) for FW (Eq. 2) and then gradually decreased with the increase in the level of water salinity up to S_4 treatment (472.2 mm). This is may due to that the actual evapotranspiration (ET_a) may deviate from ET_c due to non-optimal conditions i.e. pests and diseases, soil salinity, low soil fertility and water shortage or water logging. This may result in scanty plant growth, low plant density and may reduce the evapotranspiration rate below ET_c (Allen et al., 1998). The same Table shows that the large influence of decreasing ET_c happened in mid-season stage due to the maximum value of soil salinity (EC_e) occurring in this stage. This result agreed with those obtained by (Dudley et al., 2008) they reported that the used saline water in irrigation causes a reduction in transpiration, which subsequently results in reduced ET.

Table (11): Crop evapotranspiration under standard conditions (ET_c) and nonstandard conditions ($ET_{c\ adj}$)

Treat-ments	Growth stages								Total Season
	Initial		Development		Mid-season		Late		
	mm d^{-1}	mm	mm d^{-1}	mm	mm d^{-1}	mm	mm d^{-1}	mm	mm
FW	3.45	86.1	6.12	275.5	7.82	242.5	5.23	73.2	677.3
S1	3.45	86.1	6.00	270.2	5.61	173.8	4.91	68.7	598.9
S2	3.45	86.1	5.76	259.3	5.07	157.1	4.50	63.0	565.6
S3	3.45	86.1	5.49	247.0	4.42	137.0	3.22	45.1	515.2
S4	3.23	80.8	5.23	235.4	3.66	113.5	3.07	43.0	472.7

Groundnut crop production based on shelled nuts

Figure (3) illustrated that the groundnut yield cultivated under trickle irrigation system as affected by different irrigation water salinities. The total yield varied between 3.89 – 1.18 ton ha^{-1}. The highest yield was obtained, when using fresh water (F.W). It represents nearly a descending order of: (FW) > (S1) > (S2) > (S3) > (S4). As for the effect of irrigation salinity treatments on the groundnut yield, data indicate that with reduced stressed condition (FW) treatment, groundnut yield increased compared with the other salinity treatments.

Very high significant differences were obtained between FW yield (control) and other salinity treatments. S_1, S_2 and S_3 treatments gave the same yield approximately; where there is no significant difference between them. As well as, there is no significant different between S_2, S_3 and S_4 treatments, however there is significant differences between S_1 and S_4 treatments. Salinity can inhibit plant growth by a range of mechanisms, including low external water potential, ion toxicity and interference with the uptake of nutrients (Taffouo et al., 2008, 2009). According to Munns (2002) studies, salinity reduces the ability of plants to take up water, and this quickly causes reductions in growth rate and yield. These results are similar with those found by Taffouo et al. (2010); they said that the soil salinity, saline irrigation water and also the heavy use of fertilizers salts can severely restrict plant growth, causing foliage damage and even death of the plants.

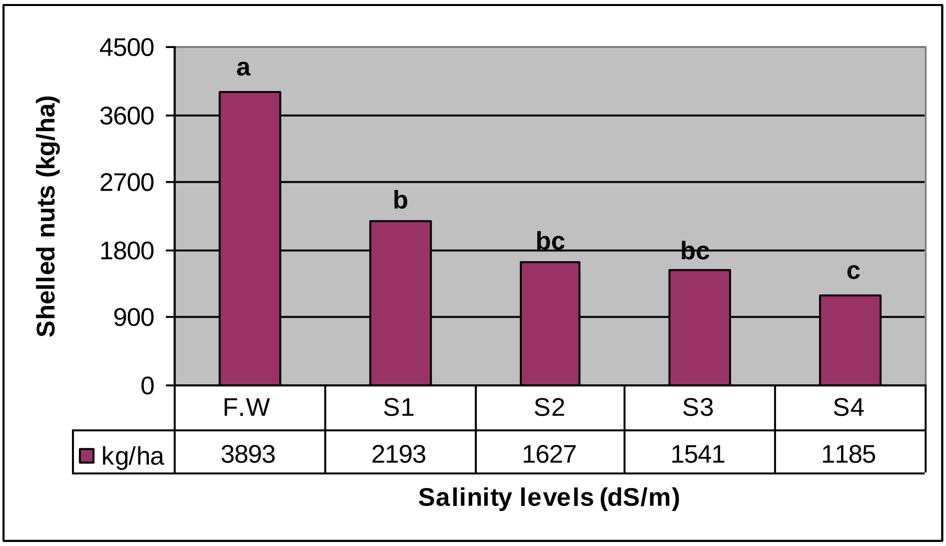

Figure (3): Effect of water salinity levels on groundnut yield (shelled nuts)

Water use efficiency related to ETa (WUE)

The data in the concomitant Table with Figure (4) show WUE for the different treatments as functions of saline irrigation water. The data in the concomitant Table with Figure (4) presented sharply decreased of water use efficiency with increasing salt concentration of irrigation water. The highest WUE value was obtained by (FW) followed by S_1, S_2, S_3 and then S_4 treatment.

The data in the concomitant Table with Figure (4) shows that the increasing salinity level of irrigation water progressively decreased water use efficiency. The values of WUE were 0.36, 0.27, 0.26, and 0.22, for S_1, S_2, S_3 and S_4, respectively compared to irrigation with fresh water (0.62 kg m^{-3}). This may be due to the decrease in total crop yield with increasing salinity level of irrigation water which increases the energy that plant must expend to acquire water from the soil and make the biochemical adjustments necessary to survive. Also, reduction in photosynthesis and plant dry mass with increased salinity could be attributed to the difference in the efficiency of root system in limiting the transport of ions to shoots (Munns et al., 2006) and to induced water deficit (Abed Alrahman et al., 2005). The inhibition of photosynthesis under salinity stress may be attributed to stomatal closure due to water deficit (Meloni et al., 2003). Generally, WUE for groundnut yield decrease with increasing the salt concentration of irrigation water.

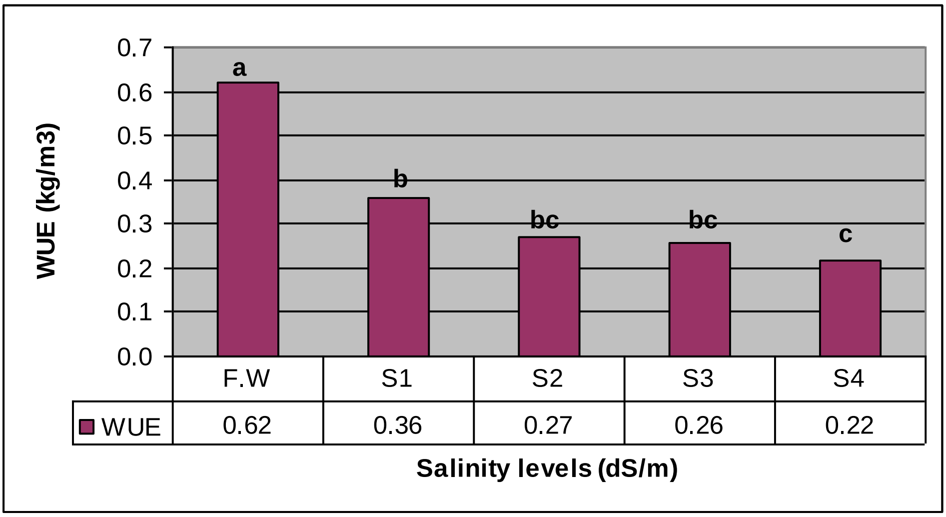

Figure (4): Water use efficiency (WUE) for different saline water levels of groundnut crop.

Irrigation water use efficiency (IWUE) related to applied water (I)

The data in the concomitant Table with Figure (5) shows IWUE for the different treatments as function of saline irrigation water. The data in the concomitant Table with Figure (5) presented a sharp decrease in irrigation water use efficiency with increasing salt concentration of irrigation water. The highest IWUE value was obtained by (FW) followed by S_1, S_2, S_3 and then S_4 treatment, with similar tendencies observed in WUE. The data in the concomitant Table with Figure (5) shows that the increasing salinity level of irrigation water progressively decreased water use efficiency. The percentages of decrease reached 0.31, 0.23, 0.22 and 0.17 for S_1, S_2, S_3 and S_4, respectively compared to irrigation with fresh water (0.56 kg m^{-3}). Generally, IWUE for groundnut yield (Shelled nuts) decrease with increasing salt concentration of irrigation water. The highest IWUE values were found for the nearly non-stressed salinity condition treatment.

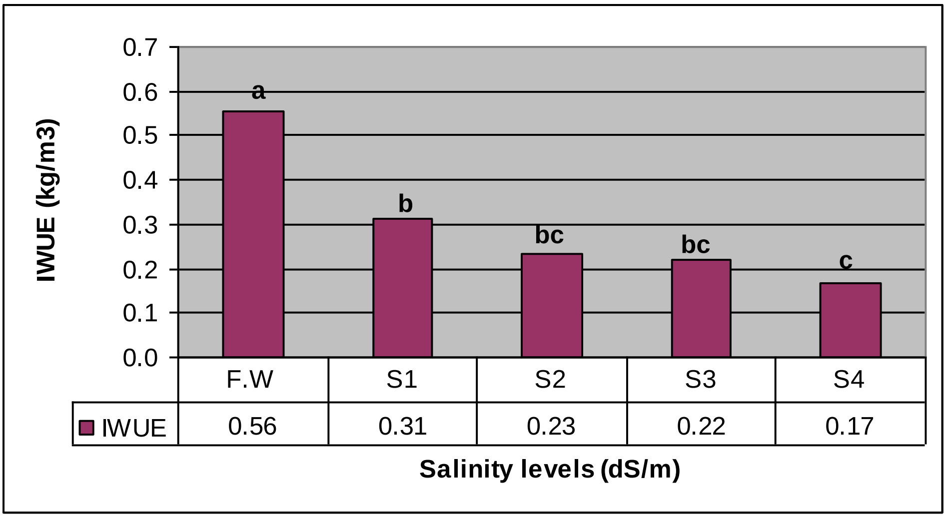

Figure (5): Irrigation water use efficiency (IWUE) for different saline water levels of groundnut.

CONCLUSIONS

This study evaluated the effect of different salt concentrations on groundnut seasonal actual evapotranspiration (ET_a), water stress coefficient (K_s), yield and water use efficiency under different saline irrigation water treatments in Inshas region. When cultivating crops in the field, the actual crop evapotranspiration may deviate from ET_c due to non-optimal conditions such as soil salinity. This may reduce the evapotranspiration rate below ET_c. Under saline irrigation water, the daily ET_a of groundnut is significantly lower than under freshwater irrigation. This is why due attention should be paid to delivering the correct amount of water for irrigation. Moreover, an increase in root-zone salinity is the prime factor reducing plant ET and growth, as the measured EC_e in the S_4 treatment was much higher than that in the EC_e in the FW treatment.

The K_c values of groundnut were developed based on the field experiment, which were recommended by Allen et al. (1998) as standard method. The estimated K_c values in this region during the crop development and the late-season stages for groundnut were in agreement in between the measured crop coefficients and those obtained using the FAO-56 methodology. However the in initial and mid-season stages, it was less than that suggested by FAO-56. Also, the correlations of water stress coefficient (K_s) to crop evapotranspiration (ET_c) and actual evapotranspiration (ET_a) estimated under salinity stress in the semiarid region, based on reference crop evapotranspiration (ET_o) by the Penman-Monteith formula and with a crop coefficient (K_c), gave the satisfactory results when compared with field observations. Salinity stress affects water availability due to limitation of water uptake of plants, and excessive uptake of Na^+ and Cl^-; which may result in limited assimilation of mineral nutrients and causes greater decrease in leaf water potential. Since water uptake by roots is not the same in different soil layers and soil salinity. Water stress coefficient (K_s) adjusts according to reductions in ET according to salinity stress.

The data of S_1, S_2, S_3, S_4 treatment was recorded in the yield of groundnut plant according to salt stress as indicated by the increase in the dry weight. But when the plant was exposed to higher concentrations of sodium chloride, the biomass of the plant was substantially reduced. The major reason for the detrimental effects may be the negative osmotic pressure caused by the salt in the root zone or the growth inhibition due to injury of cells in transpiring leaves. Moreover, severe water stress was observed on the salt limited yields for groundnut which were 1.78 to 3.29 times lower than control potential yields at the selected groundnut fields.

Water use efficiency (WUE) quantifies the kg crop produced per m^3 water used in different hydrological processes such as transpiration, evapotranspiration and percolation, and provides the opportunity to identify ‘where water can be saved’ in the irrigated agriculture. WUE decreased nonlinearly with seasonal ET_a and with yield; and IWUE followed similar trends observed with applied water. The good relationships obtained in the study between seasonal ET_c and crop performance indicators (such as yield, WUE and IWUE) demonstrates that accurate estimates of ET_a in a daily and seasonal basis can be valuable for making tactical in-crop irrigation management decisions and for long-term and pre-season strategic irrigation planning. Such a detailed water use analysis is very useful for many irrigated areas which deal with water scarcity. As this study shows, ordinary data on climate, soil and crop under salinity stress conditions and water produced from wells with the proportion of the salts can be used to give the requirements of the saline water that is used in irrigation agricultural land in desert areas.

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الملخص العربى

تقدير البخر نتح الفعلي و معامل الإجهاد المائي لمحصول الفول السوداني تحت تركيزات مختلفة من الأملاح في الأرض الرملية

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أجريت تجربة حقلية لدراسة تأثير مستويات مختلفة من ملوحة مياه الري على البخر-نتح الفعلي ، و معامل الإجهاد المائي و الإنتاج و كفاءة استخدام المياه لمحصول الفول السوداني تحت نظام الري بالتنقيط في التربة الرملية بأنشاص التي تقع على خط عرض ٢٤/ ٣٠° و خط طول ٣٥/ ٣١° و فوق سطح البحر بارتفاع ٢٠متر.

استخدمت أربع مستويات من ملوحة مياه الري وكانت ($2.4, 2.7, 3.3$ and 4.4 dS m^{-1}) ، S_1, S_2, S_3 S_4، على التوالي ، بالإضافة إلى المياه العذبة (FW) ككنترول (0.5 dS m^{-1}). أضيف السماد البلدي وذلك لتحسين التربة بمعدل ٤٨ م٣/هكتار وقد استخدم جهاز التشتت النيتروني لتحديد محتوى الرطوبة الأرضي و المستنفذ عند أعماق ٣٠ و ٤٥ و ٦٠ و ٧٥ و ٩٠سم. و محتوى الرطوبة في العمق ١٥ سم تم تحديده بالطريقة الوزنية. أضيف ٧٠٠مم/موسم من مياه الري على أساس ١٠٠ ٪ من الاحتياجات المائية للمحصول طبقا لتوصيات منظمة الأغذية والزراعة للأمم المتحدة برقم ٣٣.

أظهرت النتائج التي تم الحصول عليها أن البخرنتح الفعلي (ET_a) و معامل الإجهاد المائي (K_s) ينخفضا تدريجيا عند زيادة ملوحة مياه الري خصوصا في معاملة الملوحة (4.4 dS m^{-1}) S_4 .

وفيما يتعلق بالإنتاج و كفاءة استخدام المياه (WUE) وكفاءة استخدام مياه الري (IWUE) لمحصول الفول السوداني ،أدى ارتفاع درجة الملوحة في مياه الري إلى نقص الإنتاج و كفاءة استخدام المياه وكفاءة استخدام مياه الري على حد سواء. الإنتاج في محصول الفول السوداني اتبع الترتيب التنازلى التالي:

FW (3.89 ton ha^{-1}) > S_1 (2.19 ton ha^{-1}) > S_2 (1.63 ton ha^{-1}) > S_3 (1.54 ton ha^{-1}) > S_4 (1.19 ton ha^{-1}).

بشأن الخصائص الكيميائية للتربة ، ملوحة مياه الري أدت إلى زيادة معنوية في (التوصيل الكهربي) للتربة. هذه الزيادة بلغت حوالي ٦ أضعاف التي وجدت في التربة المروية بمياه عذبة.

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