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Effect of deficit irrigation and growing seasons on plant water status, fruit yield and water use efficiency of squash under saline soil

Taia A. Abd El-Mageed[a,*], Wael M. Semida[b]

[a] Soil and Water Department, Faculty of Agriculture, Fayoum University, Fayoum 63514, Egypt
[b] Horticulture Department, Faculty of Agriculture, Fayoum University, Fayoum 63514, Egypt

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ABSTRACT

A successive summer and fall experiments were conducted to study the effect of deficit irrigation growing seasons on the squash water status, total fruit yield and water use efficiency (WUE) in saline soil (EC_e 12.6 $dS\,m^{-1}$). Three treatment levels of actual evapotranspiration (ET_c) were tested in each season. The irrigations treatments were: (1) control, (100%) where irrigation was applied in order to avoid any considerable soil water deficit. (2) $DI_{85\%}$, where deficit irrigation (85% of control irrigation regime) was applied and (3) $DI_{70\%}$, where 70% of the control regime was applied. In well-watered conditions seasonal water use by squash was 479 over 86 days in summer and 306 mm over 91 days in fall season, respectively. Interaction between season and deficit irrigation treatment significantly affected plant water status as evaluated by relative water content, canopy temperature, photosynthesis efficiency. Leaf area index (LAI), total soluble solid (TSS), harvest index (HI), water-use efficiency, fruit weight, and fruit length have also been affected. After two seasons (i.e., fall and summer), soil salinity (EC_e), and both of Cl^- and Na^+ concentrations declined significantly in 0–60 cm depth and more reduction were achieved in 0–20 cm soil depth than in 20–40 and 40–60 cm depths. Squash yield the fall growing season was higher by 19.54% comparison with the yield in summer season the highest water use efficiency (WUE) was obtained at $I_{85\%}$ IWA. In two seasons the highest squash yield was recorded under well irrigated treatment, control (100% ET_c) but non-significant differences between $I_{100\%}$ and $I_{85\%}$ were recorded. Therefore, under limited irrigation water, it is recommended to irrigate squash plants at $I_{85\%}$ to produce not only the same yields, approximately, but also to save more of water as compared to $I_{100\%}$ treatment.

1. Introduction

Squash (*Cucurbita pepo* L.) belongs to Cucarbitaceae family; it is one of the most important cash crops, especially, in newly reclaimed areas of Egypt. Squash is rich in carbohydrates and amino acids as well as they contain many minerals beneficial to humans. The total area cultivated to this crop was estimated at 40,000 ha in 2007 with annual yield production of 1 million t (Egyptian Ministry of Agriculture, 2007). Squash is an important commercial crop that has gained popularity for both open-field and greenhouse in the Mediterranean region (Amer, 2011; Rouphael and Colla, 2005). In recent years the available amount of water to agriculture is declining worldwide because the rapid population growth and the greater incidence of drought caused by climate change and different human activities (World Bank, 2006).

Salinity is considered as one of the major limiting factors to plant growth and crop productivity in many areas, particularly in arid and semi-arid regions. Deleteriously affecting over than 800 million hectares of land worldwide (Munns, 2005). Plant morphological and physiological processes are negatively affects by salt stress through osmotic and ionic stress, and different biochemical responses in plants (Khan, 2003). Growth of squash plants was shown to be moderately sensitive to moderately tolerant to salt stress depending on cultivar or growth stage (Francois, 1985).

Successful management of the limited amount of water available for agricultural uses depends on better agricultural practices and enhanced understandings of water productivity (Howell, 2001; Jones, 2004). Deficit irrigation (i.e., irrigation below the optimum crop water requirements) is a strategy for water-saving by which crops are subjected to a certain level of water stress either during a particular period or throughout the whole growing season (Pereira et al., 2002). The main goal of using DI is to increase WUE by

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[*] Corresponding author. Tel.: +20 1067536208; fax: +20 84 6334964.
E-mail address: taa00@fayoum.edu.eg (T.A.A. El-Mageed).

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reducing the amount of water applied with watering or by reducing the number of irrigation events (Kirda, 2002). Deficit irrigation effects on growth and productivity of many vegetables and field crops have been widely investigated (Karam et al., 2006; Ertek et al., 2004; Fereres and Soriano, 2007; Igbadun et al., 2008; Amer, 2011).

Research evidences has shown that DI is successful in increasing water productivity for different crops without causing severe yield reduction (Geerts and Raes, 2009). El-Dewiny (2011) reported that summer squash yield decreased by increasing water deficits. Rouphael and Colla (2005) observed that, the total and marketable yield and fruit weight and number were significantly affected by the growing season and the irrigation system and not by their interaction. The lower yield recorded during the summer-fall growing season was related to a reduction in both fruit mean weight and fruit number. Ertek et al. (2004) showed that, the highest summer squash yield was obtained from an irrigation treatment with a plant-pan coefficient of 0.85 in Van, Turkey. Similarly, the fruit yield of squash was significantly affected by increasing irrigation quantities Al-Omran et al. (2005). Also, WUE values were generally increased with irrigation quantity, but decreased at the highest irrigation level. Also, he found that water use efficiency linearly increased as irrigation water applied increased for deficit irrigation level and decreased for excessive irrigation level. However, the effects of DI are crop-specific. Therefore, it is necessary to evaluate the impact of DI strategies with multi-years open field experiments, before generalizing the most appropriate irrigation scheduling method to be adapted in a specific location for a given crop (Scholberg et al., 2000; Igbadun et al., 2008).

The present study reveals the effect of deficit irrigation with saline water on leaf water status, growth, yield, and WUE of squash in summer and fall season and investigate the temporal changes in the electrical conductivity (EC_e), Cl^- and Na^+ within squash plant root zone (i.e., 0–60 cm).

2. Materials and methods

2.1. Experimental site

This study was conducted in a farmer's field located in El Fayoum province which occupies a depression west of the Nile at 90 km southwest of Cairo, Egypt between latitudes 29°02′ and 29°35′N and longitudes 30°23′ and 31°05′E. Table 1 indicates the climatic data of El Fayoum during the months of the study. According to the aridity index (Ponce et al., 2000) the area is located under hyper arid climatic condition.

2.2. Soil of the experimental site

The soils of the studied area could be classified at the family level as Typic Torripsamments, siliceous, hyperthermic, moderately deep. In addition, the suitability of the studied soil could be ranged between not suitable and marginally suitable (Soil Survey Staff, 1999). The soil of the site where the experiments were carried out for the two seasons had the top soil (0–100 cm depth) as saline sandy loam in texture, with a bulk density of 1.57 kg m^{-3}. The total available water was about 12.88%/60 cm depth. Tables 3 and 4 show some physical and chemical properties of the soil of the experimental site. According to Ayers and Wesctcot (1985) scale the used irrigation water lies within the second categories for salinity and sodicity levels (C_2S_1, EC_{iw} = 0.75–3.00 dS m^{-1} and SAR < 6.0). Table 2 shows some ionic composition for irrigation water.

2.3. Irrigation water application (IWA)

The squash plants were irrigated 2 days intervals by different amounts of water, AIW were determined as a percentage of the crop evapotranspiration (ET_c) representing one of the following three treatments: I_{100} = 100%, $DI_{85\%}$ = 85% and $DI_{70\%}$ = 70% of ET_c. The daily ET_o was computed according to the following equation (Allen et al., 1998) as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(900/(T_{\text{mean}} + 273)\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

where ET_o is the reference evapotranspiration (mm day^{-1}), Δ the slope of the saturation vapor pressure curve at air temperature (kPa °C^{-1}), R_n the net radiation at the crop surface (MJ m^{-2} d^{-1}), G Soil heat flux density (MJ m^{-2} d^{-1}), γ psychometric constant = $(0.665 \times 10^{-3} \times P)$, kPa °C^{-1} (Allen et al., 1998), P is the atmospheric pressure (kPa), U_2 wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a actual vapor pressure (kPa) $(e_s - e_a)$ is the saturation vapor pressure deficit (kPa), and T_{mean} mean daily air temperature at 2 m height (°C). The average of daily ET_o in El-Fayoum was 10.16, 10.74, 10.66, 9.9, 8.64, 6.61, 4.63 and 3.49 mm day^{-1} in May, June, July, August, September, October, November and December, respectively. The crop water requirements (ET_c) were estimated using the crop coefficient according to the following equation:

$$ET_c = ET_o \times K_c \tag{2}$$

where ET_c is the crop water requirement (mm day^{-1}) and K_c is the crop coefficient. The duration of the different crop growth stages were 25, 35, 25, and 15 days for initial, crop development, mid-season and late season stages, respectively, and the crop coefficients (K_c) of initial, mid and end stages were 0.6, 1 and 0.75, respectively, according to Allen et al. (1998). The amount of irrigation water applied to each treatment during the irrigation regime was determined by using the following equation:

$$IWA = \frac{A \times ET_c \times I_i \times K_r}{E_a \times 1000 \times (1 - LR)} \tag{3}$$

where IWA is the irrigation water applied (m^3), A is the (m^2), ET_c is the crop water requirements (mm day^{-1}), I_i is the irrigation intervals (day), E_a is the application efficiency (%) (E_a = 85), K_r covering

Table 1
Monthly weather data at Fayoum, Egypt during 2013 summer and fall growing seasons.

Month	[a]$T_{\min}$ (°C)	$T_{\max}$ (°C)	T_{avg} (°C)	RH_{avg} (%)	U_2 m s^{-1}	R_s MJ m^{-2} d^{-1}	ET_o mm d^{-1}	E_p mm d^{-1}
May	20.8	38.5	29.65	42.0	1.90	14.36	10.16	7.8
June	22.6	39.0	30.8	43.0	1.50	15.35	10.74	8.3
July	24.6	37.1	30.9	46.0	2.0	14.26	10.66	7.5
August	25.2	38.1	31.6	49.5	1.60	12.65	9.90	6.8
September	23.6	36.6	30.1	43.7	2.1	11.38	8.64	5.8
October	19.54	30.79	25.11	43.03	2.0	8.61	6.61	4.18
November	17.47	29.13	23.32	40.53	2.2	7.81	4.63	2.54
December	10.3	24.1	17.2	53.05	2.3	6.8	3.49	2.0

[a] T_{avg}, $T_{\max}$, and $T_{\min}$ are average, maximum, and minimum temperatures, respectively, RH_{avg} is average relative humidity, U_2 is average wind speed, R_s is average solar radiation, ET_o is average potential evapotranspiration (Allen et al., 1998), and E_p is average of measured pan evaporation class A.