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Effect of summer-fall deficit irrigation on morpho-physiological, anatomical responses, fruit yield and water use efficiency of cucumber under salt affected soil

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ABSTRACT

Agriculture has been adversely affected by low water availability due to climate change, creating abiotic stress conditions for economically important crops such as cucumber. Two on-field seasons study (summer and fall) were conducted consecutively in 2016/17 to investigate the effect of deficit drip irrigation at three levels ($DI_{0\%}$ = 100%, $DI_{20\%}$ = 80%, and $DI_{40\%}$ = 60% of crop evapotranspiration) on cucumber's growth and productivity, water use efficiency (WUE), osmo-protectants, leaf photosynthetic pigments and chlorophyll *a* fluorescence, plant water status, and leaf anatomy. Results showed that, fall season exceeded summer season in growth characteristics and fruit yields, WUE, soluble sugars, leaf photosynthetic pigments, plant water status (RWC and MSI), and leaf anatomy characteristics, while harvest index (HI), free proline and chlorophyll fluorescence were higher in summer than fall. For DI, with some exceptions all the aforementioned parameters were similar, approximately, under both $DI_{0\%}$ and $DI_{20\%}$. Under $DI_{40\%}$, values of all aforesaid parameters showed significant reductions compared to those recorded under $DI_{0\%}$ and $DI_{20\%}$, except for WUE, which was increased as DI increased. Therefore, intensive cultivation of cucumber in fall season will save more water with application of $DI_{20\text{-}40\%}$ according to the availability of water in the region, total fruit yield, and fruit price from which a decision to select either $DI_{20\%}$ or $DI_{40\%}$ of irrigation water applied (IWA) will be made.

1. Introduction

Cucumber (*Cucumis sativus* L.) is one of the most important vegetable crops cultivated worldwide. In arid and semiarid areas including Egypt, water scarcity is the major limiting factor in agricultural production. Sustainable agricultural practices, including better understandings of water productivity are considered to be a successful management tool under water-limited environments (Bacon, 2004; Howell, 2001). Deficit irrigation (DI), irrigation by water amounts less than the optimum crop water requirements, is a common sustainable practice in many regions of the world (Pereira et al., 2002). The potential benefits of DI derive from two major factors: increased water use efficiency and reduced costs of irrigation either by reducing the amount of irrigation water or by reducing the number of irrigation events (Igbadun et al., 2012; Patane et al., 2011). Effects of deficit irrigation on many vegetables and field crops growth and productivity have been reported by several researchers (Abd El-Mageed et al., 2016a, 2016b; Badal et al., 2013; Ballester et al., 2011; Karam et al., 2011). DI increased water productivity with no severe yield reduction to be caused for different crops (Geerts and Raes, 2009; Semida et al., 2017). On the other hand, it has been reported that cucumber yield decreased in linear relationship with the increase of DI (Amer et al., 2009). Cucumber yield was significantly affected by irrigation water amount at all growth stages. The least productive irrigation regimes were those that had water deficiencies during fruiting stages (Mao et al., 2003). In hydroponically cultivated zucchini, marketable fruits and total yields as well fruit number and weight plant^{-1} were considerably affected by growing season and irrigation system but not by their interaction. They added that lower yield observed in summer and/or fall growing season was attributed to a decrease in fruits weight and number (Rouphael and Colla, 2005). In another study on summer and fall squash, water productivity was affected by deficit irrigation and growing seasons. Water use efficiency was higher under fall season when compared with summer season (Abd El-Mageed and Semida et al., 2015a). In addition, Al-Omran et al., (2005) reported that squash yield were considerably affected by increasing the amounts of irrigation water. They added,

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WUE was increased in general with a reduction in the amount of irrigation water, but it was decreased at full irrigation level. WUE increased linearly as irrigation water applied increased; however, the various effects of deficit irrigation are crop-specific. Thus, to adapt a given crop to a specific location it is essential to assess the effect of different deficit irrigation strategies through multi-years open field experiments, before generalizing the most appropriate irrigation scheduling method (Abd El-Mageed and Semida et al., 2015b). Therefore, the main objective of the current study was to evaluate the effect of 20 and 40% deficit irrigation on growth, yields, water use efficiency, and physio-chemical attributes of cucumber plants grown in two (summer and fall) seasons. Results could provide a useful tool for developing a sustainable management strategies for cucumber production with reduced irrigation water.

2. Materials and methods

2.1. Lay out and experimentation

Two on-field seasons (summer and fall) experiments were conducted consecutively in 2016/17 in a private farmer's field, Fayoum, Egypt (latitudes 29° 02´ and 29° 35´ N and longitudes 30° 23´ and 31° 05´ E). The soil, 0.90 –1.0 m deep, is saline loamy sand and defined as Typic Torripsamments, siliceous, hypothermic (Soil Survey Staff USDA, 1999). The chemical and physical characteristics of the soil were: pH 7.79 (1:2.5 soil/water extract), Kjeldahl total N 1.38 g kg^{-1}, Olsen extractable P 524.7 mg kg^{-1}, ammonium acetate extractable K 44.3 mg kg^{-1}, organic C 8.0 g kg^{-1}, total carbonate 191.7 g kg^{-1}, electrical conductivity (EC_e; soil paste extract) 8.23 dS m^{-1}, bulk density 1.62 kg dm^{-3}, and water content at field capacity and wilting point 24 and 11%, respectively. Based on the EC value (8.23 dS m^{-1}), the soil is classified as being saline according to Dahnke and Whitney (1988).

Three irrigation levels of evapotranspiration (ETc) were investigated in both (summer and fall) season. They were: $DI_{0\%}$ = irrigation at 100% of ETc (control), $DI_{20\%}$ = deficit irrigation water was 80% compared to the control irrigation regime, and $DI_{40\%}$ = deficit irrigation water was 60% compared with the control regime. The total amounts of irrigation water applied during summer season were 3970, 3176 and 2382 m^3 ha^{-1}, and were 2920, 2336 and 1752 m^3 ha^{-1} for fall season for $DI_{0\%}$, $DI_{20\%}$, and $DI_{40\%}$, respectively. The experimental lay out was a Randomized Split Plot design with three replicates for each treatment.

The area of each experimental plot was 13.2 m^2; 12 m length × 1.10 m row width and about 0.3 m between plants within rows. Seeds of Cucumber hybrid Hayl® were sown 0.05 m away from the drip line at a depth of 0.04 m, drip irrigated with one line and one dripper per plant giving 4.0 L h^{-1}. Treatments were separated by 1 m non-irrigated area. Cucumber seeds were planted on May 20th and October 3rd, and terminated on August 6th and January 1st in the 2016/17 summer and fall seasons, respectively. One week after full germination different irrigation treatments were initiated. Fertilizers rate of application and other agricultural practices were according to the recombination of the Agricultural Research Center, Cairo, Egypt.

Cucumber plants were irrigated at 2 d intervals by different amounts of irrigation water treatments. According to the assessments with class A pan equation (ETo), Irrigation water applied (IWA) was determined as a percentage of the potential evapotranspiration representing one of the following three treatments: $DI_{0\%}$ = 100%, $DI_{20\%}$ = 80% and $DI_{40\%}$ = 60% of ETc. Daily ET_0 was computed using the pan equation as follows:

$$ET_o = E_{pan} \times K_{pan} \tag{1}$$

Where: ET_O is the reference evapotranspiration (mm/day), E_{pan} is the evaporation from the Class A pan (mm. d^{-1}), and K_{pan} is the Pan Coefficient (FAO pp. No. 24).

The crop water requirements (ETc) were estimated using the crop coefficient according to the following equation:

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

Where etc is the crop water requirement (mm. d^{-1}) and Kc is the crop coefficient. The duration of the different crop growth stages were 20, 30, 40, and 15 d for initial, crop development, mid-season and late season stages, respectively and the crop coefficients (Kc) of initial, mid and end stages were 0.60, 1.00 and 0.95, respectively, according to Allen et al. (1998).

The quantification of IWA for each treatment was done during the irrigation regime by using the following equation:

$$IWA = \frac{A \times ETc \times Ii \times Kr}{Ea \times 1000 \times (1 - LR)} \tag{3}$$

Where IWA is the irrigation water applied (m^3), A is the plot area (m^2), etc is the crop water requirements (mm. d^{-1}), Ii is the irrigation intervals (d), Ea is the application efficiency (%) (Ea = 85), Kr is the covering factor and LR is the leaching requirements.

2.2. Observation

Soil water content was recorded every 2 days at 0–15 and 15–30 cm depth using digital moisture meter sensors (HH2 type, Cambridge, CB5 0 EJ, UK). Five plants from each experimental plot were randomly chosen, at the end of each season, to determine plant growth characteristics, physio-chemical attributes and leaf anatomy. All plants of each experimental unit were used to measure yield and its components.

Plant leaf area was measured using Planix 7 Planometer (Tamaya Technics Incorporated). Shoots of plants were weighed for their fresh weights. For dry weight, shoot were placed in an oven at 70 ± 2 °C until a constant weight was recorded. Chlorophyll *a* fluorescence was measured using a handy PEA chlorophyll fluorometer (Hansatech Instruments Ltd, UK). F_v/F_m, the maximum quantum yield of PS II, was calculated from the equation: $F_v/F_m = (F_m - F_o)/F_m$ (Maxwell and Johnson, 2000). PI, performance index of photosynthesis based on the equal absorption, was calculated as illustrated by Clark et al., (2000). Third fully expanded leaves sample from top were chosen randomly from each treatment to conduct the physiological measurements i.e., free proline, total soluble sugar, and leaves relative water content (LRWC). Free proline concentrations was determined using the colorimetric method of Bates et al., (1973). The ethanolic method described by Irigoyen et al., (1992) was used to determine the concentration of total soluble sugar in leaves.

Plant water status was evaluated by measuring leaves relative water content (LRWC) as described by (Hayat et al., 2007). Leaf tissue samples (0.2 g) of fully-expanded leaves were used to determine the membrane stability index (MSI) as described by Rady, (2011). Harvest index (HI) was determined as a ratio of total fruit yield to the plant total biomass on a dry mass basis. The ratio of fruit yield (kg) to respective water use (m^3) was calculated and expressed as water use efficiency (WUE) in kg $ha^{-1}mm^{-1}$ (Jensen, 1983).

2.3. Statistical tests

Data collected during the two seasons (summer and fall, 2016/17), and a combined analyses were run over seasons. A simple analysis of variance (ANOVA) was carried out by Genstat statistical package (VSN International Ltd, Oxford, UK). Means multiple comparisons were done by least significant difference (LSD) test at 0.05 and 0.01 probability.

3. Results

Regarding climatic data of the two experimental seasons shown in Table 1 and Fig. 1 maximum daily temperatures during summer season averaged between 33.1 and 29.4 °C, and maximum daily temperatures during fall season averaged between 30.1 and 23.3 °C. The air relative