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Impact of Deficit Irrigation on Soil Salinity and Cucumber Yield under Greenhouse Condition in an Arid Environment

A. M. Alomran[1*], I. I. Louki[1], A. A. Aly[1,2], and M. E. Nadeem[1]

ABSTRACT

Continuing agricultural expansion and urban development in Saudi Arabia, (located in an arid climate), together with an increased demands for more water supplies, calls for more efficient irrigation practices, and an increase in Crop Water Productivity (CWP). Throughout the present study, a deficit irrigation system was investigated for its impact on soil salinity, crop response factor (Ky), *CWP*, and a crop, namely cucumber's (*Cucumis sativus* L.) yield. Cucumber seeds were planted in a greenhouse equipped with drip irrigation system. The crop evapotranspiration (ETc) was assessed through Pan Evaporation method (PE) and estimation based upon Penman-Monteith equation (PM). The results revealed good agreement between PE and PM *ETc*. The irrigation treatments consisted of four levels of *ETc* (40, 60, 80, and 100% of ETc) in addition to the traditional one as practiced by local farmers. At the 60 and 80% *ETc* treatments, the deficit irrigation was tested at different growth stages (Initial, developmental, middle, and late stages of crop growth). Each of the treatments was carried out in three replicates. The results showed that soil salinity in general increased with decreasing level of applied water. The crop cucumber could tolerate shortage of water during the middle season growth stage, when the *Ky* values ranged between 0.57 and 0.76. The level of water used up in 100% *ETc* treatment was much lower than that in the traditional drip irrigation as practiced by farmers. In other words, the *CWP* values increased with water consumption being decreased. The results also indicated that the highest values for *CWP* were found for the most stressed treatment of 40% *ETc*, while on the other hand the overall crop productivity had decreased.

Keywords: Arid Environment Condition, Cucumber Water Productivity, Low Irrigation Limit, Water Use Efficiency, Yield Reduction Ratio.

INTRODUCTION

The Kingdom of Saudi Arabia, like other countries located in arid regions, suffers from water scarcity and in adequate renewable water resources. Water scarcity along with a continuous decrease in water resources, coupled with an increasing demand for water in agriculture and in other sectors, have forced the farmers to change their irrigation practices and governments to alter their water management strategies in an attempt to save the precious commodity. In Saudi Arabia, both farmers and governmental agencies started changing irrigation strategies by moving from open field to greenhouses and by using surface and subsurface drip irrigation. This could enhance irrigation water savings while maintaining a satisfactory production level (Al-Omran *et al.,* 2010, 2012; Costa *et al.,* 2007). One important method to save irrigation water and increase Water Use Efficiency (WUE) is Deficit Irrigation (DI) (Topcu *et al.,* 2007; Patanè and Cosentino, 2009; Kirda *et al.,* 2004, Cheng *et al.,* 2012),

[1] Department of Soil Sciences, Food Sciences and Agriculture, King Saud University, P.O. Box: 2460, Riyadh 11451, Saudi Arabia.
[*] Corresponding author; e-mail: rasoul@ksu.edu.sa
[2] Department of Soil and Water Science, Alexandria University, Egypt.

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in which crops are deliberately exposed to some degree of deficit irrigation through either the whole growth stages or at certain stages of the growth period (Kirda *et al.,* 2004). *DI* is also defined as an optimization strategy in which irrigation is applied during non-drought, sensitive growth stages of a crop (English, 1990). *DI* involves supplying the root zone with less water than the maximum Evapotranspiration (ETm) (Zegbe-Dominguez *et al.,* 2003). *DI* has been extensively studied on several crops (Sepaskhah and Akbari, 2005; Kirda *et al.,* 2004; Pereira *et al.,* 2002) and recommended for arid and semiarid regions (Kirda et al., 2004). Zegbe-Dominguez *et al.* (2003) studied *DI* on tomato produced in greenhouse and found that the dry mass yield did not decrease under *DI* compared with full irrigation. Moreover *DI* could save up to 50% of irrigation water and increase *WUE* by 200%, with satisfactory yield. Al-Mohammadi and Al-Zu'bi (2011) conducted an experiment under greenhouse conditions to evaluate some optimum combination of irrigation and fertilizer levels to attain the best yield and quality of tomato, concluding that the irrigation and fertilizer levels exerted significant effects on the number of flowers per plant; however, plant height was not significantly affected significantly by any of the treatments.

An adoption of *DI* requires the knowledge of crop evapotranspiration (ETc), crop response to water deficit, critical stages of growth under water deficit and the economic impacts on reduction in yield (Pereira *et al.,* 2002). Agele *et al.* (2011) concluded that seasonal crop *ET* values are greater during reproduction growth stage of the crop. Amer *et al.* (2009) concluded that cucumber yield significantly decreased in a linear relationship with increasing water deficit. However, no significant change was observed when water was applied above 100% *ETc*. Mao *et al.* (2003) studied the effect of deficit irrigation on yield and on water use of greenhouse grown cucumber in China. They reported that *WUE* decreased when increasing the level of irrigation water applied from fruiting to the end of the growth stages. However, *WUE* increased with on increase in irrigation water from cucumber fruit setting to the initial fruit repining stage.

Research on yield response factor (Ky) to water deficiency in different crops is well documented in literature (Kirda, 2000; Moutonnet, 2000; Ayas and Domirtas, 2009a). When crops are of *Ky* values lower than one, they are considered as tolerant to water deficit. On the contrary, crops of *Ky* values greater than one are considered as not tolerant to deficit irrigation. Ayas and Domirtas (2009b) reported that *Ky* values for cucumber, grown in Turkey, ranged between 0.196 and1.31, depending on the water stressed growth stage; while Amer *et al.* (2009) concluded that *Ky* values ranged between 0.71 and 0.85 in a field experiment in Egypt. Other *Ky* values reported in literature are 1.23 for green bean, and 0.97 and 1.37 for safflower and eggplant, respectively (Lovelli *et al.,* 2007).

Deficit irrigation strategy has received very little attention in the agricultural sector in Saudi Arabia. Therefore, the main objectives of this study were to: (i) to study the relationship between Pan Evaporation and Penman-Monteith ETcs (ii) to study the effect of Deficit Irrigation under greenhouse conditions on soil salinity, *CWP*, and on cucumber yield, to investigate the effect of *DI* on the crop at its different growth, and finally, (iii) determine the cucumber *Ky* for the crop.

MATERIALS AND METHODS

Field experiments were carried out at the greenhouse complex of Almohous Farm, 120 km northwest of Riyadh, Saudi Arabia (altitude: 722 m above mean sea level, latitude: 25° 17' 40" N and longitude: 45° 52' 55" E). From February, 2008 till April, 2011 a total of 12 treatments were conducted at different times of the year (Table 2). Soil samples were collected from each treatment representing the soil of the experimental

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area at vertical near emitter 0-30 and 30-50 cm depth and at horizontal 10 and 20 cm from emitter for both surface and subsurface soil samples. Soil salinity was determined the collected soil samples before the trial set and at the end of the crop cycle. Saturated soil paste extracts, the selected properties of the soil and irrigation water were determined through standard procedures (Page *et al.*, 1982). The pH and $CaCO_3$ content of the soil amounted to 7.9, and 18%, respectively. Sand and clay contents were 84 and 10%, respectively, while field capacity and wilting point respectively recorded as 0.17 and 0.09. The chemical properties of the groundwater used in irrigation are listed in Table 1.

The layout of the experiment was comprised of a completely randomized design of four replicates. Irrigation treatments consisted of four levels of *ETc* (40, 60, 80, and 100% of ETc) in addition to the traditional farmers' drip irrigation. The crop Evapotranspiration (ETc) in the greenhouse and open field conditions were assessed through two methods namely: Evaporation Pan and estimation based on Penman-Monteith equation (PM). A pan and adequate weather station equipments were

Table 1. Chemical properties of irrigation water.

EC (dS m^{-1})	pH	Cation and anion concentration (meq L^{-1})								*SAR*	Trace elements (mg L^{-1})		
		Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4		Fe	B	NO_3
1.43	7.1	4.2	2.4	7.3	0.13	0.0	2.0	7.2	5.0	4.1	0.20	0.81	7.0

Table 2. Irrigation treatment combinations of the each experiment.

Treatment	Initial stage[a]	Develop. stage	Mid. stage	Late stage	Description
T_1-100	1[b]	1	1	1	Full irrigation during the season (100% of ET_{max}).
T_2-80-0	1	1	1	1	80% of ET_{max} irrigation during the season has been given.
T_3-80-1	0[c]	1	1	1	A full irrigation up to the end of 1st stage, then 80% of ET_{max} for the other stages.
T_4-80-2	1	0	1	1	A full irrigation at the developmental stage, then 80% of ET_{max} restoration for the other stages.
T_5-80-3	1	1	0	1	A full irrigation at the mid stage, then 80% of ET_{max} restoration for the other stages.
T_6-80-4	1	1	1	0	A full irrigation at the late stage, then 80% of ET_{max} restoration for the other stages.
T_7-60-0	1	1	1	1	60% of ET_{max} irrigation during the season.
T_8-60-1	0	1	1	1	A full irrigation up to the end of the 1st stage, then 60% of ET_{max} for the other stages.
T_9-60-2	1	0	1	1	A full irrigation at the developmental stage, then 60% of ET_{max} restoration for the remaining stages.
T_{10}-60-3	1	1	0	1	A full irrigation at the mid stage, then 60% of ET_{max} restoration for the other stages.
T_{11}-60-4	1	1	1	0	A full irrigation at the late stage, then 60% of ET_{max} restoration for the other stages.
T_{12}-40	1	1	1	1	40% of ET_{max} irrigation during the season has been applied.
T_{13}-Trad.[d]	1	1	1	1	The traditional drip irrigation in greenhouse. Farmers do not comply with the scientific methods to found out the amount of applied water and add more than the required water (more than ET_{max}).

[a] Growth stage; [b] The growth stage took applied water as on treatment; [c] The growth stage took a 100% of *ETc* (ET_{max}), [d] Traditinal.

fixed inside and outside the greenhouse to obtain weather as well as pan evaporation data (Allen *et al.,* 1998). At 60 and 80% treatments, the deficit irrigation was applied at different growth stages (initial, developmental, mid., and late growth) for a total of 12 treatments (Table 2). The cultivar "Bazz" cucumber (*Cucumis sativus* L.) was grown for the experiments. The main irrigation line was 63 while the submain lines 16 mm in diameter. The length of submain lines was 17 m for each line with emitters spaced at 0.5 m and a distance between rows of 1 m. Furthermore, water meters were installed for recording the level of the applied water in each treatment. Irrigation scheduling was based upon Pan Evaporation, because it is easy to use, beside being available for open field, (Kirda *et al.,* 2004; Simsek *et al.,* 2005) and for greenhouse conditions (Abou-Hadid *et al.,* 1991; Tüzel *et al.,* 2001; Mahajan and Singh, 2006; Zhang *et al.,* 2003; Harmanto *et al.,* 2004). Crop evapotranspiration (ETc) was calculated using the following equation:

$$ETc=Ep\times Kp\times Kc \quad (1)$$

where *ETc* is maximum daily crop *ET* in mm, *Ep* standing for the daily evaporation from class A Pan in mm, *Kp* is the pan coefficient (ranging between 0.70 and 0.88) and *Kc* the crop coefficient (ranging between 0.57 and 1.26 depending on growth stages. *Kp* and *Kc* were found out according to the equations of Allen *et al.* (1998).

The Gross Water Requirement (GWR) was calculated by the use of the following equations (Cuenca, 1989):

$$GWR= ETc/(1-LR) \quad (2)$$

$$GWR= Kc\times Eo\times Kp/(1-LR)\times Ea \quad (3)$$

where, *GWR* is Gross Water Requirement in mm day^{-1}, E_a is irrigation efficiency and *LR* the leaching requirement. *LR* was calculated according to Ayers and Westcot (1985):

$$LR= EC_w\times(E_l/2\ EC_e\ max) \quad (4)$$

where, EC_w is salinity of irrigation water in dS m^{-1}, E_l is leaching efficiency, and EC_e *max* the maximum electrical conductivity of the extracted soil paste for zero yield in dS m^{-1}. The calculated *LR* in this experiment amounted to 0.06.

Crop Water Productivity (CWP), as reviewed by Kijne *et al.* (2003), is defined as the ratio of crop yield (kg) to volume of applied water (m^3) as follows:

$$CWP= Yield/Water\ applied \quad (5)$$

The relationship between crop yield and water application is generally denoted as crop Water Production Function (CWPF). *CWPF* becomes curvilinear as some of the excess applied water goes to drainage or loss. A useful way to express the water production function is on a relative basis, where actual yield (Ya) is divided by maximum yield (Ym) and actual evapotranspiration (ETa) is divided by reference crop evapotranspiration (ET_0). The relationship between evapotranspiration deficit [1–(ETa/ETc)] and yield depression [(1–(Ya/Ym)] is considered linear (Doorenbos and Kassam, 1986), with a slope called the yield response factor of the crop or Crop Response Factor (Ky) (Kirda *et al.,* 2004). This relationship is expressed as by the following equation:

$$[1-(Ya/Ym)] = Ky\ [1-(ETa/ETm)] \quad (6)$$

CWPF reflects the benefit of applied water in production of dry matter or yield. The quadratic polynomial function of Helweg (1991) is expressed as follows:

$$Y_a= b_0+b_1W+b_2W^2 \quad (7)$$

where, Y_a is crop production or yield, t ha^{-1}, *W* the applied irrigation water, m^3 ha^{-1} and while b_0, b_1 and b_2 the fitting coefficients.

[a] Growth stage; [b] The growth stage took applied water as on treatment; [c] The growth stage took a 100% of *ETc* (ET_{max}), [d] Traditinal.

When yield approaches its maximum, the slope of the Water Productivity Function against water applied goes to zero; therefore, the maximum applied water (W_{max}) being calculated by differentiating the *CWPF* (Equation 5) and equaling to zero, then the maximum predicted yield (Y_{max}) can be calculated by substituting W_{max} in Equation (5):

$$\partial Y/\partial W = +b_1+2b_2W= 0 \quad (8)$$

$$W_{max}= - b_1/2b_2 \quad (9)$$

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$$\mathbf{Y}_{\max} = b_0 + b_1 W_{\max} + b_2 W^2_{\max} \qquad (10)$$

Statistical Analyses

Data related to cucumber yield were statistically analyzed through one way Analysis of Variance (ANOVA) making use of SAS software. The differences between means were evaluated for the significance using LSD test (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Relationship between Pan Evaporation and Penman-Monteith *ETc*

Crop evapotranspiration (ETc) in the greenhouse in *vs.* in open field was calculated by use of two methods: (i) Pan Evaporation and (ii) estimation as based upon Penman-Monteith equation (PM) (Allen *et al.,* 1998). The results indicated that for both *ETc* measurements, there was a very good agreement observed between Pan Evaporation method and Penman-Monteith equation for both greenhouse and open field conditions. In most cases R^2 observed was over 80% (Figure 1). Therefore Pan Evaporation method can be utilized instead of relying on the method of Penman-Monteith which needs climatic data which may not be available to farmers in the field (Tiwari, 2000; Chartzoulakis and Drosos, 1997; Baille, 1994; Harmanto *et al.,* 2004). The results of greenhouse crop Evapotranspiration (ETc) are made use of in each treatment and the corresponding Applied Water (AW) presented in Table 3. A maximum amount of water applied to the crop was 355 mm for the T_1-100 treatment while a minimum applied was 147 mm for T_{12} treatment. The level of water applied by the farmer (traditional practice) amounted to 722 mm.

Soil Salinization under DI

The results (Figure 2) show that the soil salinity varied according to the irrigation regime. *ECe* in general increases when the amount of applied water undergoes a decrease. The increase was highly significant ($P \leq 0.05$) for cucumber cultivar. Figures 2-a and -b show that the traditional drip irrigation was more efficient in control of soil salinity or its removal, followed by T_1-100 treatment; while the T_{12}-40 treatment enhanced soil salt accumulation in the subsurface (30-50 cm) of the soil layer. The average final summer root zone *ECe* along the 30-50 cm depth near the emitter was 1.1 dS m^{-1} for T_{13}.Trad. However, it was approximately more than three times (3.6 dS m^{-1}) that for the T_{12}-40 treatment. Likewise the *ECe* in the winter season varied between 1.5 and 2.5 dS m^{-1} for T_{13}.Trad and T_{12}-40

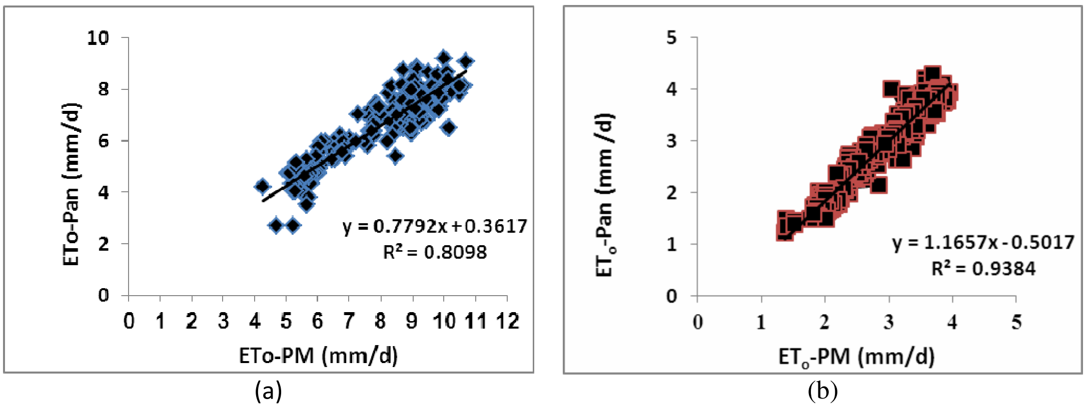

Figure 1. Correlations between *ETc* calculated through Penman-Monteith equation and pan: (a) Open field, (b) Greenhouse.

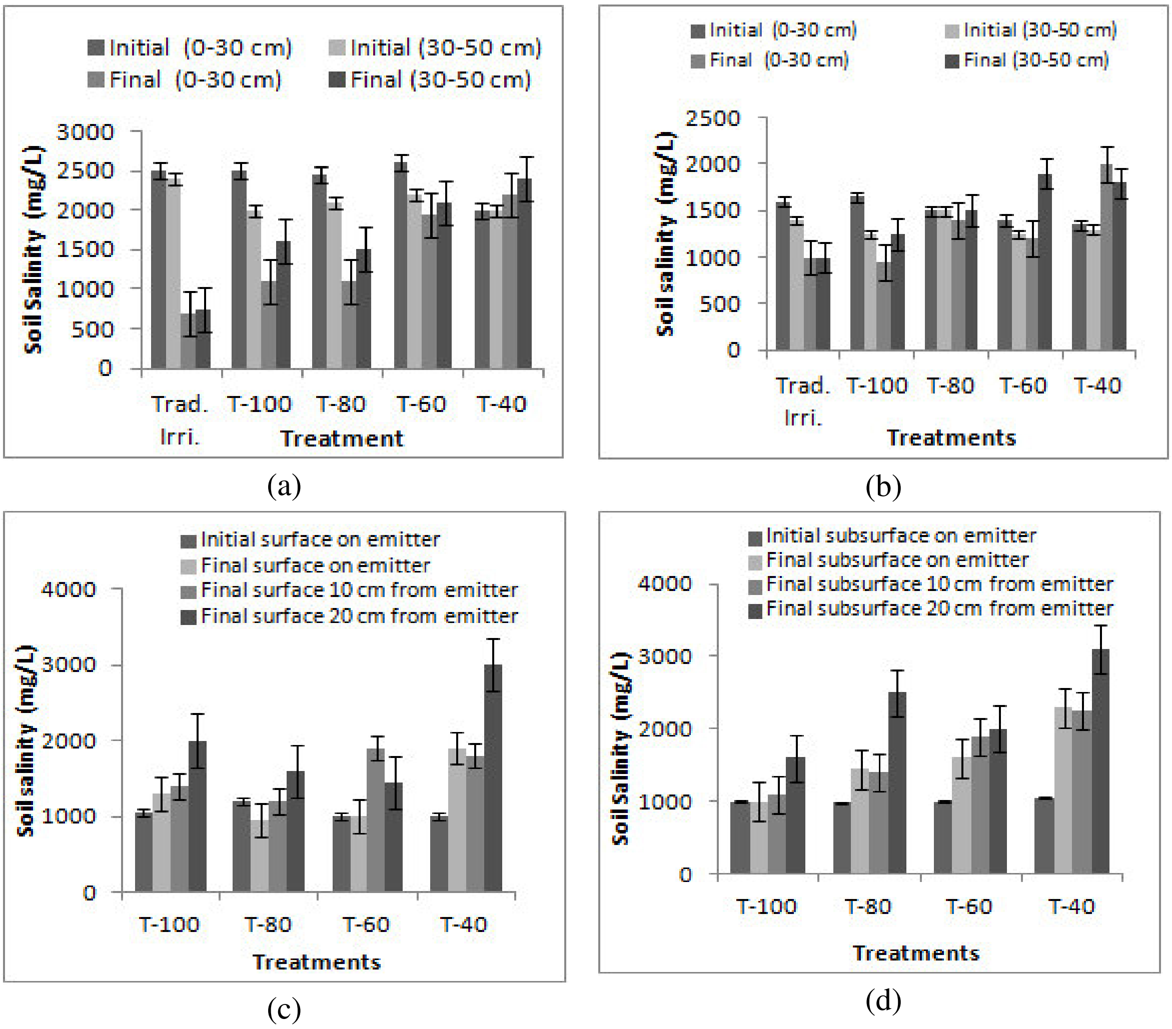

Figure 2. The effect of deficit irrigation on soil salinity: (a) and (b) are vertical salt distribution near emitter and at the depths of 0-30 and 30-50 cm for summer *vs.* winter seasons respectively, and (c) and (d) are horizontal salt distribution during the winter season for surface *vs.* subsurface soil samples

treatment respectively. In contrast, no surface (0-30 cm) salt accumulation was recorded under deficit irrigation for the different irrigation treatments (Kahlaoui *et al.,* 2011). Figures 2-c and -d show that the salt accumulation in the root zone increased away from the emitter and with decreasing quantity of applied water for both surface (0-30 cm) and subsurface (30-50 cm) soil layers. The average root zone *ECe* along the 20 cm distance from the emitter increased from 1.6 dS m^{-1} (in the initial state) to approximately 4.7 dS m^{-1} (by the end of the experiments) for both surface and subsurface soil layers in the T_{12}-40 treatment. On the other hand the *ECe* of the T_1-100 treatment increased from 1.6 to 3.1 dS m^{-1} for surface soil layers and from 1.6 to 2.8 dS m^{-1} for subsurface soil layers for the initial and final states respectively (Hanson *et al.,* 2009).

Crop Water Productivity

CWP expresses the productivity of water as related to yield. T_4-80 treatment was found to be the most acceptable one in terms of water productivity (Table 3), however the traditional irrigation led to a lower water productivity (19.7 kg m^{-3}). But, even though

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Table 3. Mean yield, Evapotranspiration (ETc), Applied Water (AW), and Water Productivity (WP) of different seasons as affected by deficit irrigation treatments at different growth stages of cucumber.

Treatments	Average days per season	Yield (kg m^{-2})	*ETc* (mm)	*AW* (mm)	*AW* (mm day^{-1})	*CWP* (kg m^{-3})
T_1-100	108	15.0 a [a]	307	355	3.3	42.3
T_2-80-0	108	13.8 bc	245	283	2.6	48.8
T_3-80-1	108	13.2 d	256	295	2.7	44.7
T_4-80-2	108	14.2 b	259	299	2.8	47.5
T_5-80-3	108	14.6 ab	269	309	2.9	47.2
T_6-80-4	108	13.5 cd	260	300	2.8	45.0
T_7-60-0	108	11.4 f	184	213	2.0	53.5
T_8-60-1	108	11.7 f	204	236	2.2	49.6
T_9-60-2	108	12.4 e	210	243	2.3	51.0
T_{10}-60-3	108	12.7 e	232	267	2.5	47.6
T_{11}-60-4	108	11.5 f	213	246	2.3	46.7
T_{12}-40	108	9.1 g	123	147	1.4	61.9
T_{13}-Trad	108	14.2b	307	722	6.7	19.7

[a] Treatment means marked with the same letters are not significant using LSD Test at 5% level.

decreasing irrigation water to 40% *ET* caused very high water productivity; however, it decreased ended up with a final yield. In general, *CWP* values increased with decreased irrigation water applied, a maximum value of *CWP* of 61.9 kg m^{-3} was recorded for T12-40 treatment, while it was 42.3 kg m^{-3} for full irrigation treatment (T1-100). Similar results have been reported by Ali *et al.* (2007); Oweis and Hachum (2004); and by Zhang *et al.* (2004). Several explanations as for the reason behind an increase in *CWP* with *DI* are presented, some of which are that *DI* can increase the ratio of yield over crop water consumption (evapotranspiration) by: (1) reducing water loss through unproductive evaporation; (2) Increasing the proportion of marketable yield to the total produced biomass (harvest index), (3) proper fertilizer uptake and prevention of such bad and adverse agronomic conditions as water logging, outbreak of pests and diseases, etc. (Geerts and Raes, 2009; Steduto and Albrizio, 2005; Pereira *et al.,* 2002).

The results of cucumber yield for different treatments (Table 3) indicated that the highest yield was obtained in the treatment T1-100 (15.0 kg m^{-3}) and the lowest one in the treatment T12-40 (9.1 kg m^{-3}). The yield in the traditional treatment was recorded to be lower than T_1-100 while higher than those in the other treatments (Mao *et al.,* 2003). A polynomial function was fitted between (Y) and (AW) for different seasons (Figure 3). According to the mathematical analysis of the crop water production function (CWPF), the predicted maximum yields were 19.49, 15.40, and 14.10 kg m^{-2} and the corresponding calculated applied water was 600, 582, and 573 mm for summer, winter, and autumn respectively (Table 4). These results were in agreement with those reported by Al-Harbi *et al.* (2008) and Zhang and Oweis (1999). However, Mao *et al.* (2003) reported a polynomial relationship between *ET* and yield. In this study, treatment T_1-100 had the highest yield, treatments $T_{3,\ 4,\ 5,\ 6}$-80 and T_{12}-40 gave fairly marketable yields, while economically saving water, fertilizers and pesticide. The results also indicated that *CWP* increased with decreasing level of applied water; the *CWP*s being 42.3 and 61.9 kg m-3 for T1-100 and T12-40 respectively. However the traditional irrigation treatment bore the lowest *WP* (19.7 kg m^{-3}). Although a low irrigation level, as in treatment T_{12}-40, led to high

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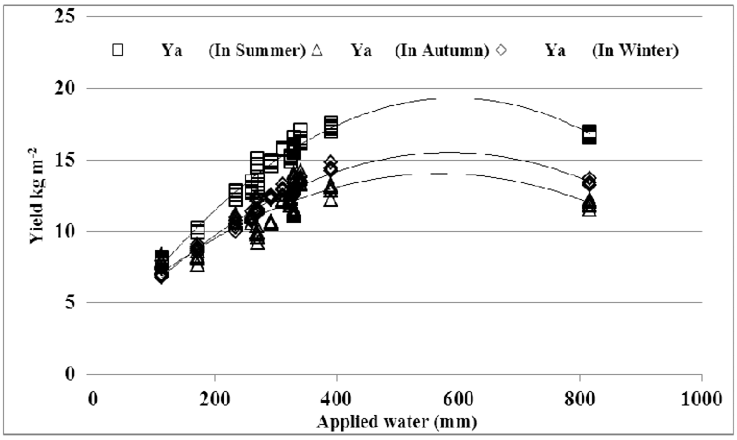


Figure 3. The relationship between marketable total cucumber yield and applied water within different seasons.

Table 4. Cucumber water production functions as based upon applied irrigation water.

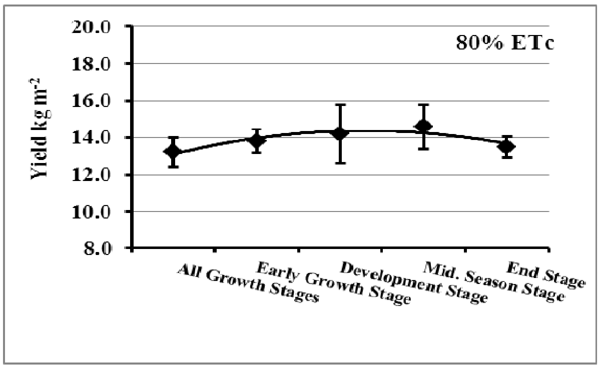
Season	Crop water production function	R^2	Maximum yield (kg m^{-2})	Applied water (mm)
Summer	$Y= -50E\text{-}06\ (AW)^2+0.0600\ (AW)+1.491$	0.9660	19.49	600
Winter	$Y= -39E\text{-}06\ (AW)^2+0.0454\ (AW)+2.1845$	0.9586	15.40	582
Autumn	$Y= -33E\text{-}06\ (AW)^2+ 0.0378\ (AW) + 3.2701$	0.7257	14.10	573

water productivity, it on the other hand led to poor crop quality and quantity of yield.

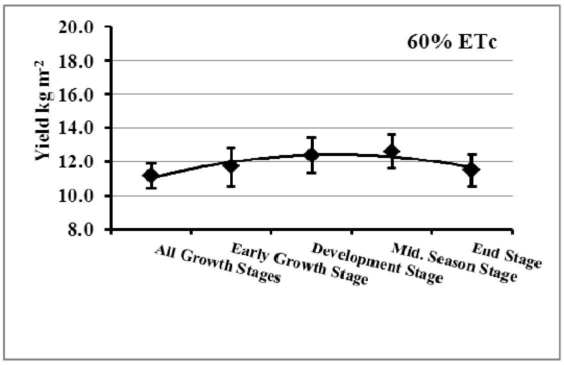
The results also indicated that deficit irrigation at 80% of *ETc* was more efficient in saving irrigation water and of a good marketable yield as compared with either traditional irrigation or 100% *ETc*. Moreover a deficit drip irrigation system helps in rationalization, preventing excessive use of pesticides and fertilizers, consequently reducing environmental pollution.

Deficit Irrigation at Crop's Different Growth Stages

Figures 4-a and -b show that the early and late growth stages of cucumber were the most sensitive stages to water stress. On the other hand, the developmental stage was the most tolerant stage to water deficiency. Cucumber yields were 14.2 and 14.6 kg m^{-2}



(a)



(b)

Figure 4. Effect of deficit irrigation on cucumber yield at its different growth stages.

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for T_4-80-2 and T_5-80-3 respectively. They amounted to 13.2 and 13.5 kg m^{-2} for T_3-80-1 and T_6-80-4 respectively. Same results were reported by Potop (2011). However Lauchli and Grattan (2007) studied the effect of salinity of different growth stages for different crops and concluded that most crops are salt tolerant at germination but sensitive during emergence and vegetative developmental stages. They also reported that the initial phase of growth reduction is due to an osmotic effect similar to the initial response to water stress.

Crop Yield Response Factor

Crop yield response factor (Ky) was determined for the different treatments of deficit irrigation (Moutonnet, 2000). *Ky* in general indicates a linear relationship between the relative reduction in water consumed and a correspondingly relative in yield (Lovelli *et al.,* 2007; Kidra *et al.,* 2004). Throughout the present experiments, the average crop response factor for different seasons throughout the cucumber growth stages was 0.6455 (Figure 5). This means that cucumber, when grown in greenhouse conditions (under Saudi Arabia climatic conditions), can be considered as a water stress tolerant crop. These results are similar to those reported by Amer *et al.* (2009); however Ayas and Demirta (2009a) recorded a *Ky* of 1.2 for cucumber (*Cucumis sativus* L. Maraton), grown in Turkey under unheated greenhouse conditions.

CONCLUSIONS

The management of water under water scarcity includes multiple policies. In general, policies should aim at reducing the non-beneficial water uses, particularly those related to water consumption and to the non-reusable fraction of the diverted water. However, fully exploring these concepts, mainly for farmers at field scales, requires appropriate procedures to be developed. Reduced water demand could be achieved through an adoption of improved farm irrigation systems, and using deficit irrigation. Throughout the present study, *DI* was tested for the crop cucumber. It was found that full irrigation at the early and late stages and then irrigation with 80% of *ETc* was the most approproate treatment in terms

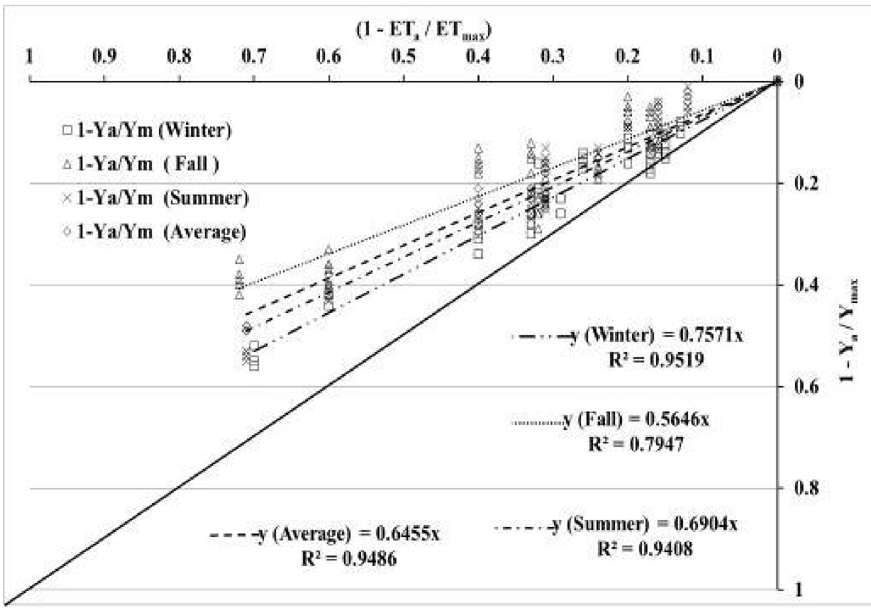

Figure 5. Relative decrease in cucumber yield as a function of relative decrease in evapotranspiration rate.

of crop water productivity (CWP) and final yield. A decrease irrigation water up to 40% *ETc* caused high *CWP* while a decrease in the final yield. The traditional irrigation led to lower *CWP*; however, the yield was lower than that of 100% *ETc* and as well higher than those for other treatments. In general and under experimental conditions both soil salinity and *CWP* increased with a decrease in the amount of applied water. A polynomial relationship was established between Yield (Y) and Applied Water (AW), however crop yield response factor (Ky) indicated a linear relationship between the relative reduction in water consumed *vs.* the relative reduction in yield with an average value of 0.6455 being recorded.

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REFERENCES

1. Abou-Hadid, A. F., El-Beltagy, A. S. and El-Khima, S. 1991. Pan Evaporation as Affected by Plastic House Microclimate. *Acta Hort.,* **287**: 35-46.
2. Agele, S. O., Iremiren, G. O. and Ojeniyi, S. O. 2011. Evapotranspiration, Water Use Efficiency and Yield of Rainfed and Irrigated Tomato. *Int. J. Agric. Biol.,* **13**: 469–476
3. Al-Harbi, A. R., Al-Omran, A. M. and El-Adgham, F. I. 2008. Effect of Drip Irrigation Levels and Emitters Depth on (*Abelmoschus esculentus*) Growth. *J. App. Sci.,* **8**: 2764-2769.
4. Ali, M. A., Hoque, M. R., Hassan, A. A. and Khair A. 2007. Effects of Deficit Irrigation on Yield, Water Productivity, and Economy. *Agric. Water Manag.,* **92**: 151-161.
5. Allen, R. G., Pereira, L. S., Raes., D. and Smith, M. 1998. Crop Evapotranpiration Guidelines for Computing Crop Water Requirements. Paper 56, FAO Irrigation and Drainage, Rome.
6. Al-Mohammadi1, F. and Al-Zu'bi1, Y. 2011. Soil Chemical Properties and Yield of Tomato as Influenced by Different Levels of Irrigation Water and Fertilizer. *J. Agr. Sci. Tech.,* **13:** 289-299.
7. Al-Omran, A. M., Al-Harbi, A. R., Wahb-Allah, M. A., Nadeem, M. and Eleter, A. 2010. Impact of Irrigation Water Quality, Irrigation Systems, Irrigation Rates and Soil Amendments on Tomato Production in Sandy Calcareous Soil. *Turk. J. Agric. For.,* **34**: 59 –73.
8. Alomran, A. M., Al-Harbi, M. A., Wahb-Allah, M. A., Alwabel, M., Nadeem, M. and Al-Eter, A. 2012. Management of Irrigation Water Salinity in Greenhouse Tomato Production under Calcareous Sandy Soil and Drip Irrigation. *J. Agri. Sci. Tech.,* **14(4):** 939-950.
9. Amer, K. H., Sally, A. M. and Jerry, L. H. 2009. Effect of Deficit Irrigation and Fertilization on Cucumber. *Agro. J.,* **101**: 1556–1564.
10. Ayas, S. and Demirta, C. 2009a. Deficit Irrigation Effects on Cucumber (*Cucumis sativus* L. Maraton) Yield in Unheated Greenhouse Condition. *Inter. J. Food Agric. Enviro.,* **7**: 645-649.
11. Ayas, S. and Demirta, C. 2009b. Deficit Irrigation Effects on Onion (*Allium cepa* L. E. T. Grano 502) Yield in Unheated Greenhouse Condition. *Inter. J. Food Agric. Enviro.,* **7**: 239-243.
12. Ayers, R. S. and Westcot, D. W. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage, No. 29, Roma.
13. Baille, A. 1994. Principles and Methods for Predicting Crop Water Requirement in GgreenhouseEnvironments. *INRA-CIHEAM, Cahiers Options Mediterraneennes*, **31**: 177-186.
14. Chartzoulakis, K. and Drosos, N. 1997. Water Requirements of Greenhouse Grown Pepper under Drip Irrigation. *Acta Hort.,* **449**: 175–180.
15. Cheng, F., Sun, H., Shi, H., Zhao, Z. h., Wang, Q. and Zhang, J. 2012. Effects of Regulated Deficit Irrigation on the Vegetative and Generative Properties of the Pear Cultivar 'Yali'. *J. Agr. Sci. Tech.,* **14:** 183-194.
16. Costa, J. M., Ortuno, M. F. and Chaves, M. M. 2007. Deficit Irrigation as a Strategy to

Save Water: Physiology and Potential Application to Horticulture. *J. Integ. Plant Bio.,* **49**: 1421–1434.

17. Cuenca, R. H. 1989. *Irrigation System Design: An Engineering Approach*. Prentice Hall, Inc., Englewood Cliffs, USA, PP. 552.
18. Doorenbos, J. and Kassam, A. H. 1986. Yield Response to Water. Paper No. 33, FAO Irrigation and Drainage, FAO, Rome, Italy, 193 PP.
19. English, M. 1990. Deficit Irrigation. I: Analytical Framework. *J. Irrig. Drain.,* **116**: 399-412.
20. Geerts, S. and Raes, D. 2009. Deficit Irrigation as an On-farm Strategy to Maximize Crop Water Productivity in Dry Areas. *Agric. Water Manag.,* **96**: 1275-1284
21. Hanson, B. R., Simnek, J., Jan, W. H. and Hutmacher, R. B. 2009. Drip Irrigation Provides the Salinity Control Needed for Profitable Irrigation of Tomatoes in the San Joaquin Valley. *California Agric.,* **63(3):** 131-136.
22. Harmanto, V., Babel, M. S. and Tantau, H. J. 2004. Water Requirement of Drip Irrigated Tomatoes Grown in Greenhouse in Tropical Environment. *Agric. Water Manag.,* **71**: 225-242.
23. Helweg, O. J. 1991. Functions of Crop Yield from Applied Water. *Agron. J.,* **83**: 769-773.
24. Kahlaoui, B., Hachicha, M., Rejeb, S., Rejeb, M. N., Hanchi, B. and Misle, E. 2011. Effects of Saline Water on Tomato under Subsurface Drip Irrigation: Nutritional and Foliar Aspects. *J. Soil Sci. Plant Nutr.,* **11**: 69–80.
25. Kijne, J. W., Barker, R. and Molden, D. 2003. Improving Water Productivity in Agriculture: Editor's Overview. In: "*Water Productivity in Agriculture: Limits and Opportunities for Improvement*", (Eds.): Kijne, J. W. and Barker, R. M. D.. International Water Management Institute, Colombo, Sri Lanka, PP. xi-xix
26. Kirda, C., Cetin, M., Dasgan, Y., Topcu, S., Kaman, H., Ekici, B., Derici M. R. and Ozguven, A. I. 2004. Yield Response of Greenhouse Grown Tomato to Partial Root Drying and Conventional Deficit Irrigation. *Agric. Water Manag.,* **69**: 191-201.
27. Kirda, C. 2000. Deficit Irrigation Scheduling Based on Plant Growth Stages Showing Water Stress Tolerance. In: "*Deficit Irrigation Practices*", (Eds.): Kirda, C., Moutonnet, P., Hera, C. and Nielsen, D. R.. Water Report #22, FAO, Rome, PP. 109.
28. Lauchli, A. and Grattan, S. R. 2007. Plant Growth and Development under Salinity Stress. In "*Advances in Molecular Breeding Toward Drought and Salt Tolerant Crops*", (Eds.): Jenks, M. A. Jenks, M. A., Hasegawa, P, Jain, S. Springer, PP. 1–32.
29. Lovelli, S., Perniola, M., Ferrara, A. and Tammaso, T. D. 2007. Yield Response Factor to Water (Ky) and Water Use Efficiency of *Carthamus tinctorius* L. and *Solaum melongeual*. *Agric. Water Mange.,* **92**: 73-80.
30. Mahajan. G. and Singh, K. G. 2006. Response of Greenhouse Tomato to Irrigation and Fertigation. *Agric. Water Manag.,* **84**: 202–206.
31. Mao, X., Liu, M., Wang, X., Hou, C. Z. and Shi, J. 2003. Effects of Deficit Irrigation on Yield and Water Use of Greenhouse Grown Cucumber in the North China Plain. *Agric. Water Manag.,* **61(3):** 219-228.
32. Moutonnet, P. 2000. Yield Response to Field Crops to Deficit Irrigation. In: "*Deficit Irrigation Practices*", (Eds.): Kirda, C., Moutonnet, P., Hera, C. and Nielsen, D. R.. Water Report #22 FAO, Rome, PP. 109.
33. Oweis, T. and Hachum, A. 2004. Water Harvesting and Supplemental Irrigation for Improved Water Productivity of Dry Farming System in West Asia and North Africa. *In Proceeding of the 4th Int. Crop Sci. Congress, Held at Brisbane, on the Theme "Crop Science for Diversified Planet"*, 2004, Brisbane, Australia.
34. Page, A. L., Miller, R. b. and Keeney, D. R. 1982. Methods of Soil Analysis. Part 2. "*Chemical and Microbiological Properties*". 2nd Edition. *Agron. Monogr.*, ASA and SSSA, Madison, WI, **9.**
35. Patanè, C. and Cosentino, S. L. 2009. Effects of Soil Water Deficit on Yield and Quality of Processing Tomato under a Mediterranean Climate. *Agric. Water Manag.,* **97**: 131-138.
36. Pereira, L. S., Oweis, T. and Zairi, A. 2002. Irrigation Management under Water Scarcity. *Agric. Water Manag.,* **57**: 175-206.
37. Potop, V. 2011. Assessment of Water Deficit and Surplus during Growing Period of Vegetable Crops in Polabi. Skalni mlyn, (Available On-line at: http://www.cbks.cz/SbornikSMlyn11/Potop2.pdf accessed on 16 April 2012).

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38. Sepaskhah, A. R. and Akbari, D. 2005. Deficit Irrigation Planning under Variable Seasonal Rainfall. *Biosyst. Eng.,* **92**: 97–106.
39. Simsek, M., Tonkaz, T., Kacira, M., Comlekcioglu, N. and Dogan, Z. 2005. The Effects of Different Irrigation Regimes on Cucumber (*Cucumbis sativus* L.) Yield and Yield Characteristics under Open Field Conditions. *Agric. Water Manag.,* **73**: 173-191.
40. Snedecor, G. W. and Cochran, W. G. 1980. *Statistical Method.* 7th Edition, The Iowa State University Press, Iowa, USA, PP. 476.
41. Steduto, P. and Albrizio, R. 2005. Resource Use Efficiency of Field-grown Sunflower, Sorghum, Wheat and Chickpea. II. Water Use Efficiency and Comparison with Radiation Use Efficiency. *Agric. Forest Meteorol.,* **130**: 269-281.
42. Tiwari, K. N., 2000. Plasticulture Development Centre, Agricultural and Food Engineering Department, IIT, Kharagpur, India.
43. Topcu, S., Kirda, C., Dasgan, Y., Kaman, H., Cetin, M., Yazici, A. and Bacon, M. A. 2007. Yield Response and N-fertiliser Recovery of Tomato Grown under Deficit Irrigation. *Euro. J. Agron.,* **26**: 64–70.
44. Tüzel, I. H., Tüzel, Y., Gül, A., Meriç, M. K., Yavuz, O. and Eltez, R. Z. 2001. Comparison of Open and Closed Systems on Yield, Water and Nutrient Consumption and Their Environmental Impact. *Proc. of the World Congress on Soilless Culture: Agriculture in the Coming Millenium. Acta Hort.,* **554**: 221- 228. http://www.actahort.org/books/554/554_23.htm
45. Zegbe-Domìnguez, J. A., Behboudian, M. H., Lang, A. and Clothier, B. E. 2003. Deficit Irrigation and Partial Rootzone Drying Maintain Fruit Dry Mass and Enhance Fruit Quality in 'Petopride' Processing Tomato (*Lycopersicon esculentum* Mill.). *Scientia Hortic.,* **98**: 505–510.
46. Zhang, H. and Oweis, T. 1999. Water-yield Relations and Optimal Irrigation Scheduling of Wheat in the Mediterranean Region. *Agric. Water Manag.,* **38**: 195–211.
47. Zhang, X., Dong, P. and Chunsheng, H. 2003. Conserving Groundwater for Irrigation in the North China Plain. *Irri. Sci.,* **21**: 159–166.
48. Zhang, Y., Kendy, E., Qiang, Y., Changming, L., Yanjun, S. and Hongyong, S. 2004. Effect of Soil Water Deficit on Evapotranspiration, Crop Yield, and Water Use Efficiency in the North China Plain. *Agric. Water Manag.,* **64**: 107-122.

تأثیر " کم آبیاری" بر شوری خاک و بازده محصول خیار تحت شرایط گلخانه در آب و هوای خشک

ا. م. آل عمران، ی. ی. لوکی، ا. ا. علی و م. ا . ندیم

چکیده

توسعه مداوم کشاورزی و وسعت یافتن زندگی شهری در عربستان سعودی (آب و هوای خشک) همراه با تقاضای روز افزون برای منابع بیشتر آب، مسئولین امر را بر آن وا داشته است که به دنبال شیوه‌هایی از آبیاری که دارای بازده بیشتری باشند و همچنین به دنبال برداشت میزان بیشتری از محصول در مقابل واحد مصرف آب Crop Water Productiuity (CWP) باشند. در خلال تحقیق حاضر تأثیر سیستمی از سیستمهای "کم آبیاری" (Deficit Irrigation (DIS)) بر روی شوری خاک، فاکتور عکس‌العمل محصول

Response Factor (ky) به مفهوم برداشت محصول بیشتر در قبال واحد مصرف آب و در ارتباط با محصول خیار (*Cucumis sativus* L.) برآورد گردید. بذر خیار در گلخانه‌ای که مجهز به سیستم آبیاری قطره‌ای بود کشت شد. تبخیر و تعرق گیاه Crop Evapotranspirtaion (Etc) از روش طشتک تبخیر ((Pan Evaporation (PE) و تخمین براساس فرمول پن‌من مون‌نیت Penman- Monteilh (Ph) مورد ارزیابی قرار گرفت. نتایج حاکی از مطابقت مطلوب محاسبه تبخیر و تعرق به روش طشتک تبخیر و پن‌من بود. رفتارهای آبیاری شامل چهار سط تبخیر و تعرق گیاه یعنی ۴۰ و ۶۰ و ۸۰ و ۱۰۰ درصد تبخیر و تعرق محصول به اضافه نحوهٔ آبیاری معمول در بین کشاورزان (قطره‌ای) بودند. در تیمارهای آبیاری ۶۰ و ۸۰ درصد تبخیر گیاه "کم آبیاری" در مراحل گوناگون رشد گیاه (اولیه، روبه رشد، رشد بینابین و مراحل آخر رشد گیاه) به محک آزمایش گذاشته شد. هر کدام از رفتارها در سه تکرار انجام شد. نتایج به طور کلی نشان داد که شوری خاک با کم شدن میزان آب آبیاری افزایش می‌یابد. محصول خیار تاب تحمل کمبود آب را در بخش‌های میانی فصل رشد گیاه (هنگامی که مقادیر ky (فاکتور عکس‌العمل محصول) بین ۰/۵۷ و ۰/۷۹ بود) دارا بود. سطح آب مصرفی در رفتار ۱۰۰ درصد تبخیر و تعرق گیاه خیلی پائین تر از سطح مورد استفاده در آبیاری قطره‌ای (مورد استفادهٔ معمول زارعین) بود، بدین مفهوم که بازده مطلوب محصول در برابر مصرف مقدار کمتری از آب عادی گردید. بازدهی محصول در قبال میزان مصرف آب (CWP) در رفتار ۴۰ درصد تبخیر و تعرق گیاه (رفتاری که در آن گیاه تحت بیشترین تنش خشکی قرار داشت) بالاترین سطح ولی تولید (در سطح کل) محصول مواجه با کاهش بود.

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