

A comparative study of the impact of deficit irrigation on cucumber yields planted in a greenhouse and an open field in an arid environment

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Abstract

In this study, a deficit irrigation program was investigated for its impact on cucumber crop yield (*Cucumis sativus L.*) planted in an open field and a greenhouse using a drip irrigation system during 2008–2011 growing seasons. The irrigation treatments were four levels of ET_c (40, 60, 80 and 100%) in addition to the traditional practice of local farmers. At 60 and 80% ET_c treatments, the deficits of irrigation were tested at different growth stages (development, middle and late stages of growth) for a total of 12 treatments in each experiment; furthermore, three replicates for each treatments were carried out. The data showed that the cucumber could tolerate a shortage of water during the middle season growth stage for both the greenhouse and the open field, and the crop response factor (K_y) values ranged between 0.57–0.76 and 0.96–1.02 for the greenhouse and the open field respectively. The amount of water used in 100% ET_c was much lower than that of the traditional drip irrigation used by farmers, moreover the crop water productivity (CWP) values increased when the water amount decreased. The results also indicated that the highest values for CWP were found in the most stressed treatments of 40% ET_c, and on the other hand the overall productivity decreased.

Keywords: deficit irrigation, crop response factor, water use efficiency, drip irrigation.



1 Introduction

The ecosystem of the arid regions of Saudi Arabia is impoverished by scarcity of water resources and of predominance of sandy soil, which consists more than 45% of the cultivated soils (Bashour *et al.* [1]). Sandy soils are particularly critical for water management due to their low water-holding capacity, high infiltration rate and low organic matter, which may induce low water use efficiency (Al-Omran *et al.* [2]). The water shortage and increasing demand for water in agriculture and other sectors compel the need to adoption of irrigation strategies in Saudi Arabia. This may allow saving irrigation water for agricultural sector (Al-Harbi *et al.* [3], Al-Omran *et al.* [4]). An approach to attain the objective of saving water and increasing water use efficiency (WUE) is through using deficit irrigation program (DI) in which crops are deliberately allowed some degree of deficit irrigation through the whole growth stage or at certain stages of the growth (Topcu *et al.* [5], Patanè and Cosentino [6], Kirda *et al.* [7]). Deficit irrigation has been extensively studied on several crops (Sepaskhah and Akbari [8], Kirda *et al.* [7], Pereira *et al.* [9]) and was recommended for arid and semiarid regions (Kirda *et al.* [7]). Zegbe-Dominguez *et al.* [10] studied DI on tomato and found that the dry mass yield did not decrease under DI compared with full irrigation. Moreover DI can save up to 50% of irrigation water and increased WUE by 200%, with satisfactory yield. The adoption of deficit irrigation requires the knowledge of crop evapotranspiration (ET_c), crop response to water deficit, critical stages of growth under water deficit and economic impacts of yield reduction (Pereira *et al.* [9]). Agele *et al.* [11] concluded that seasonal crop ET values were greater during reproduction growth stage of the crop. Amer *et al.* [12] 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% ET_c. Mao *et al.* [13] studied the effect of deficit irrigation on yield and water use of grown cucumber in China and reported that the WUE decreased when increasing the irrigation water applied from stem fruiting to the end of the growth stages. However, the WUE increased with the increase of irrigation water from cucumber fruit setting to first fruit repining. The work on yield response factor (K_y) to water for many crops have been documented in the literature (Kirda [14], Moutonnet [15]) where crops has a value of K_y lower than 1 can tolerate the water deficit. On the contrary, crops showing a K_y greater than one show a yield decrease more than proportional to the applied ET decrease, which means that the crop might not tolerate any irrigation deficit. Ayas and Demirta [16] reported that K_y value for cucumber grown in Turkey ranged between (0.196-1.31) depend of the water stress growth stage, while Amer *et al.* [12] concluded that these values ranged between 0.71–0.85 in field experiment in Egypt. The value of K_y for green bean was 1.23, while the values for Safflower and eggplant were 0.97 and 1.37, respectively (Lovelli *et al.* [17]). The deficit irrigation strategy has received very little attention in agricultural sector in Saudi Arabia; therefore, the objectives of this study were: i) determine the cucumber water requirement under drip irrigation. ii) Compare and study the effect of deficit irrigation at different stages of cucumber growth on yield and water use efficiency on open field and greenhouse.



2 Materials and methods

Greenhouse and field experiments were carried out at the complex at Almohous Farm, 120 km northwest of Riyadh, Saudi Arabia (altitude: 722 m above sea level, latitude: 25° 17' 40"N and longitude: 45° 52' 55"E), between February 2008 and April 2011, and a total of 12 experiments were designed. Selected properties of the soil and irrigation water were determined by standard procedure (Page *et al.* [18]). The soil electrical conductivity, pH, CaCO₃, sand%, and clay% were 3.6 dS/m, 7.9%, 18%, 84%, and 10%, respectively. The irrigation water chemical characteristics were determined; the EC_w was 1.43 dS/m, the sodium adsorption ratio SAR was 4.1, and the classification of water was (C2-S1) according to Richards [19]. The layout of the experiment was completely randomized design with four replicates. Irrigation treatments consist of four level of ET_c (40, 60, 80, and 100%) in addition to traditional practice by farmers. At 60 and 80% treatments, deficits irrigation tested at different growth stages (development, mid., and late stages of the growth) for a total of 13 treatments at each experiment as shown in Table 1. The cultivar of "Bazz" of cucumber (*Cucumis sativus* L.) was used for the experiments. The main line is 63 mm in diameter. The sub-main lines tubing is 16 mm in diameter, the length of each line is 17 m with emitters built at 0.5 m spacing with distance between rows of 1 m. Furthermore, water meters were installed for measuring the exact amount of water applied for each treatment (Figure 1). Irrigation scheduling methods based on pan evaporation are widely used at different ET_c percentage due to its availability and easy to use (Kirda *et al.* [7], Simsek *et al.* [20]).

Crop evapotranspiration (ET_c) calculated from the following equation:

$$ET_c = E_o * K_p * K_c \quad (1)$$

where ET_c is the maximum daily ET in mm; E_o is the evaporation from class A pan in mm; K_p is the pan coefficient, calculated according to Allen *et al.* [21], and ranged from (0.70–0.88); K_c is the crop coefficient, ranging between (0.40–1.26) for different stages of the growth.

The gross water requirement (GWR) was calculated by the following equation (Cuenca, 1989):

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

$$GWR = K_c E_o K_p / (1 - LR) \text{ Effirr} \quad (3)$$

where: GWR is the gross water requirement in mm/day, Effirr is the irrigation efficiency and LR is the percentage of leaching requirement.

Water use efficiency or crop water productivity as reviewed by Molden [22] is generally defined as the ratio crop yield (Kg) to volume of water applied (m³) to produce the yield:

$$WUE = \text{Yield} / \text{water applied} \quad (4)$$



Table 1: Irrigation treatments combinations for each run of the experiment.

Treatment	Initial St. ¹	Develop. St.	Mid. St.	Late. St.	Description
T ₁ -100	1*	1	1	1	Full irrigation during the season (100% of ET _m).
T ₂ -80-0	1	1	1	1	80% of ET _m irrigation during the season has been given.
T ₃ -80-1	0**	1	1	1	A full irrigation up to the end of 1 st stage, then 80% of ET _m for the other stages.
T ₄ -80-2	1	0	1	1	A full irrigation at the development stage, then 80% of ET _m restoration for the other stages.
T ₅ -80-3	1	1	0	1	A full irrigation at the mid stage, then 80% of ET _m restoration for the other stages.
T ₆ -80-4	1	1	1	0	A full irrigation at the late stage, then 80% of ET _m restoration for the other stages.
T ₇ -60-0	1	1	1	1	60% of ET _m irrigation during the season.
T ₈ -60-1	0	1	1	1	A full irrigation up to the end of the 1 st stage, then 60% of ET _m for the other stages.
T ₉ -60-2	1	0	1	1	A full irrigation at the development stage, then 60% of ET _m restoration for the remaining stages.
T ₁₀ -60-3	1	1	0	1	A full irrigation at the mid stage, then 60% of ET _m restoration for the other stages.
T ₁₁ -60-4	1	1	1	0	A full irrigation at the late stage, then 60% of ET _m restoration for the other stages.
T ₁₂ -40	1	1	1	1	40% of ET _m irrigation during the season has been given.
T ₁₃ -Trad.	1	1	1	1	The traditional drip irrigation in greenhouse. The farmer does not depend at scientific methods to calculate the amount of applied water and adds more than the required water (more than ET _m).

*= The growth stage took same amount of applied water as mentioned on the treatment.

**= The growth stage took a 100% level of ET.

The relationship between crop yield and water application is called water production function (WPF). The WPF becomes curvilinear as more of applied water goes to drainage or loss. A useful way to express the water production function is on a relative basis, where actual yield (Y_a) is divided by maximum yield (Y_m) and actual evapotranspiration (ET_a) is divided by crop evapotranspiration (ET_c). The relationship between evapotranspiration deficit ($1 - (ET_a/ET_c)$) and yield depression ($1 - (Y_a/Y_m)$) is always linear (Doorenbos and Kassam [23]), the slope called yield response factor of the crop (k_y). This relationship is expressed by the following equation:

$$(1 - (Y_a/Y_m)) = K_y (1 - (ET_a/ET_m)) \quad (5)$$

3 Results and discussion

3.1 Yield and water productivity

3.1.1 Open field

The results found that the highest value of CWP was at the highest stressed treatment (T_{12}) which recorded 12.7 kg m^{-3} . Moreover, decreasing irrigation water to level of 80% of ET_c did not affect the growth and yield (table 2). An attempt was made to establish a relationship between water consumed and yield (Figure 1). According to the mathematical analysis of the crop water production function (WPF), the predicted maximum yields were 7.58 and 8.96 kg/m^2 and the corresponding predicated applied water of 1290 and 980 mm for summer and fall respectively (Table 3). These results were in agreement with those reported by Al-Harbi *et al.* [3] and Zhang and Oweis [24]. However, Mao *et al.* [13] reported a polynomial relationship between ET and yield. The study also concluded that, the treatment T_1 -100 had the highest yield; however, treatments $T_{2, 3, 4, 5, 6}$ -80, and also T_{12} -40 gave fairly good marketable yield while economically saving water, fertilizers, and pesticide. The result indicated that the water productivity (WP) increased with decreasing the amount of applied water; the increased values were from 9.9 to 12.7 kg m^{-3} for T_1 -100 and T_{12} -40 respectively. On the other hand, the WP of the traditional irrigation treatment recorded lowest value (3.7 kgm^{-3}). It was evident that over irrigation as of traditional method lead to lower water productivity, however lack of irrigation as of treatments T_{12} -40 lead to very high water productivity but yield quantity and quality decreased to be unacceptable. Similar results were reported by Ali *et al.* [25], Oweis and Hachum [26] and Zhang *et al.* [27]. Many explanations for the reason of increasing WP with DI, some of them are that the DI can increase the ratio of yield over crop water consumption (evapotranspiration) by the following: (1) reducing the water loss by unproductive evaporation, (2) increasing the proportion of marketable yield to the totally produced biomass (harvest index), (3) adequate fertilizer application and avoiding bad agronomic conditions during crop growth such as water logging in the root zone, pests and diseases, etc. (Geerts and Raes [28], Steduto and Albrizio [29], Pereira *et al.* [9]).

3.1.2 Greenhouse

The T4-80 treatment was found to be the best treatment in terms of water productivity (Table 3); however the traditional irrigation led to lower water productivity (19.7 kg m^{-3}). Moreover, decreasing irrigation water to 40% ET caused very high water productivity; however, it decreased the final yield. Generally the crop water productivity (CWP) values increased when water amount decreased, the maximum value of CWP was 61.9 kg/m^3 for T₁₂-40 treatment, and it was 42.3 kg/m^3 for full irrigation treatment (T₁-100). Similar results were reported by Ali *et al.* [25], Oweis and Hachum [26] and Zhang *et al.* [27].

Table 2: Yield, evapotranspiration (ET_c), applied water (AW), water use efficiency (WUE) and water productivity (WP) as affected by deficit irrigation treatments at different growth stages of cucumber planted in open field.

Treatment	Average days per season	Yield kg m^{-2}	ET _c mm	AW mm	AW mm day^{-1}	WUE kg m^{-3}	WP kg m^{-3}
T ₁ -100	91	7.2	617	727	8.0	11.7	9.9
T ₂ -80-0	91	6.3	494	581	6.4	12.8	10.8
T ₃ -80-1	91	6.2	520	611	6.7	11.9	10.1
T ₄ -80-2	91	6.1	520	613	6.7	11.7	10.0
T ₅ -80-3	91	6.5	538	631	6.9	12.1	10.3
T ₆ -80-4	91	6.1	519	615	6.8	11.8	9.9
T ₇ -60-0	91	4.9	370	436	4.8	13.2	11.2
T ₈ -60-1	91	4.8	424	495	5.4	11.3	9.7
T ₉ -60-2	91	5.2	424	500	5.5	12.3	10.4
T ₁₀ -60-3	91	5.4	458	535	5.9	11.8	10.1
T ₁₁ -60-4	91	4.9	420	504	5.5	11.7	9.7
T ₁₂ -40-0	91	3.4	223	267	2.9	15.2	12.7
T ₁₃ -Traditional	91	5.8	617	1562	17.2	9.4	3.7



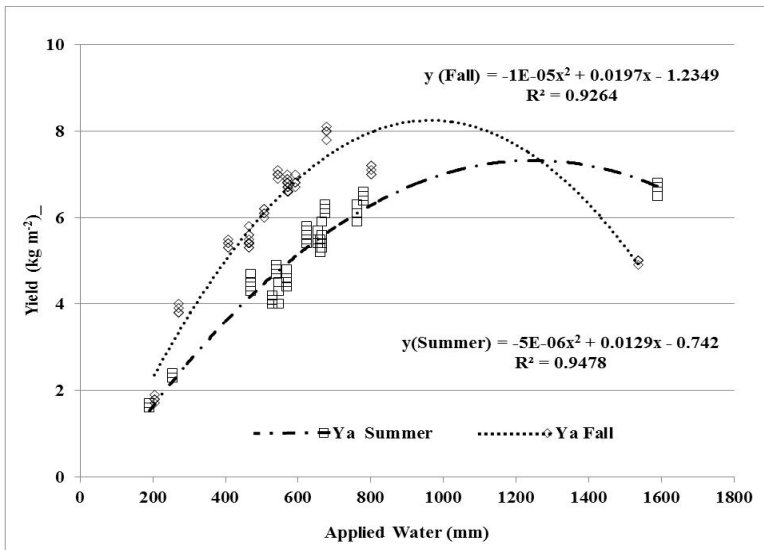


Figure 1: Yield as a function of applied water for two seasons of cucumber (open field).

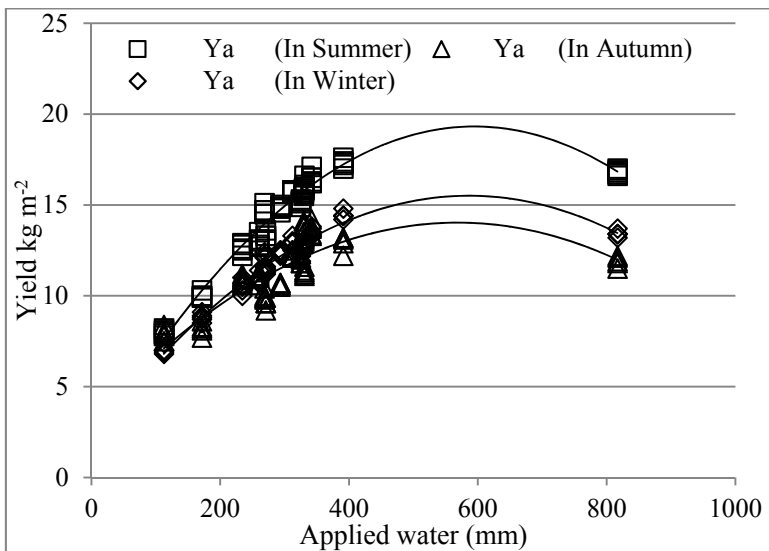


Figure 2: The relationship between marketable total cucumber yields planted on greenhouse and applied water at different seasons.

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 planted on greenhouse.

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*	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

*Treatment means with the same letter are not significant using LSD Test at 5% level.

A polynomial function was fitted between (Y) and (AW) for different seasons (Fig. 2). 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/m² and the corresponding calculated applied water was 600, 582, and 573 mm for summer, winter, and autumn respectively. These results were in agreement with those reported by Al-Harbi *et al.* [3] and Zhang and Oweis [24]. However, Mao *et al.* [13] reported a polynomial relationship between ET and yield. In this study, treatment T₁-100 had the highest yield, treatments T₃, 4, 5, 6-80 and T₁₂-40 gave fairly good marketable yield while economically saving water, fertilizers and pesticide. The result also indicated that the CWP increased with decreasing amount of applied water; the CWP were 42.3 and 61.9 kg m⁻³ for T₁-100 and T₁₂-40 respectively. However the traditional irrigation treatment has the lowest value of WP (19.7 kg m⁻³). Although less irrigation, as in treatment T₁₂-40, led to very high water productivity, it also led to poor quantity and quality of yield.

The results also indicated that the deficit irrigation at 80% of E_{Tc} was more efficient in saving irrigation water with a good marketable yield compared to traditional irrigation and 100% E_{Tc} . Moreover the deficit drip irrigation helps in rationalization and preventing excessive use of pesticides and fertilizers consequently reducing and environmental pollution.

3.1.3 Crop yield response factor

The crop yield response factor (K_y) was determined for the different treatment of deficit irrigation. K_y indicates a linear relationship between the relative reduction in water consumed and relative reduction in yield (Lovelli *et al.* [17] and Kidra *et al.* [7]). Seasonal crop response factor K_y for different treatment through the open field growth were ranged between 0.96 to 1.02 for fall and summer respectively (Fig. 3). This means that cucumber (*Cucumbissativus L.*) grown in open field under Saudi Arabia arid conditions, cannot tolerate high severe water stress. These results were similar to those reported by Ayas and Demirta [16] who recorded a K_y value of 1.2 for cucumber (*Cucumissativus L. Maraton*) grown in Turkey. On the other hand, the K_y in greenhouse ranged between 0.57 and 0.76 for fall and winter respectively (Figure 3). This means that cucumber, grown in green house under Saudi Arabia arid conditions, can be considered as a water stress tolerant crop. These results were similar to those reported by Amer *et al.* [12].

4 Conclusions

The management of water under water scarcity includes multiple policies. In general, policies should aim to reduce 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 can be achieved by adopting improved farm, irrigation systems, and deficit irrigation. In this study DI was tested for cucumber (*Cucumbis sativus L.*) in the green house and open field. It was found that full irrigation at the early and late stage and then irrigation with 80% of E_{Tc} was the best treatment in terms of water productivity and final yield; however decreasing irrigation water to 40% E_{Tc} caused very high water productivity while decreasing the final yield. Generally, under Saudi Arabian conditions, water use efficiency (WUE) and water productivity (WP) values increased when amount of applied water decreased. A polynomial relationship was determined between yield (Y) and applied water (AW) however, crop yield response factor (K_y) indicated a linear relationship between the relative reduction in water consumed and relative reduction in yield with an average of 0.65 and 0.99 for greenhouse and open field, this means that cucumber can be considered as a water stress tolerant crop if planted under greenhouse ; on the other hand the cucumber will not tolerate high water stress at open field arid conditions.



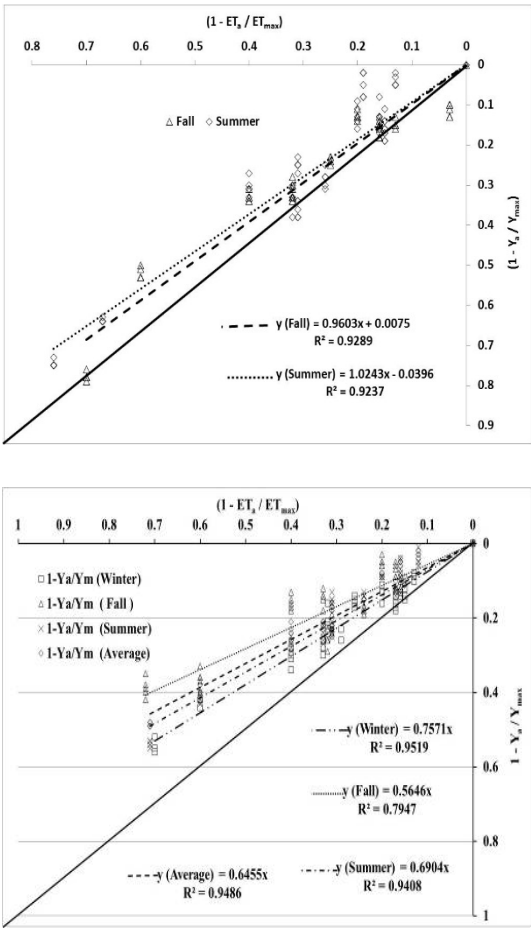


Figure 3: Relative cucumber yield decrease as function of relative evapotranspiration decrease.

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