Agricultural Water Management 148 (2015) 10–15

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Effects of different irrigation regimes on yield and water use efficiency of cucumber crop

M.H. Rahil[a,*], A. Qanadillo[b]

[a] Palestine Technical University-Kadoorie, Tulkarm, Palestine
[b] Palestinian National Agriculture Research Center, Jenin, Palestine

ARTICLE INFO

Article history:
Received 17 April 2014
Accepted 4 September 2014

Keywords:
Cucumber
Greenhouse
Evapotranspiration
Tensiometer
Dry matter

ABSTRACT

This study was conducted to investigate the effects of four irrigation regimes on yield, growth parameters and water use efficiency of cucumber crop under greenhouse cultivation. A field experiment was carried out at the experimental farm of Palestine Technical University Kadoorie, located at Tulkarm, Palestine. Cucumber seedlings were planted on 14 February 2012 in greenhouse at a rate of 1500 seedlings per 1000 square meters. Four irrigation regimes were examined during the growing period as follows: farmer irrigation (FI), tensiometer based irrigation (TI), irrigation at full ET_c data (ET_c), and irrigation at 70% of ET_c (70% ET_c). Plant data were collected during the growing period for evaluating the total yield, plant height, number of harvested fruits per plant, weight of harvested fruits per plant, dry matter of above and under ground parts.

The results indicated that the 70% ET_c treatment obtained the highest crop yield followed by ET_c, FI, and TI treatments, respectively. On average, cucumber yield under 70% ET_c treatment was 24%, 6% and 4% higher than that under TI, FI and ET_c treatments, respectively. At the end of harvesting stage plant height, above-ground dry matter obtained by 70% ET_c treatment was higher than the other treatments. The smallest plant height and dry matter was obtained under TI treatment. Results also indicated that, when using scheduled irrigation methods large amount of water were saved and found to be 139, 104 and 26 mm for TI, 70% ET_c and ET_c treatments, respectively, compared to FI treatment. The highest water use efficiency (WUE) was obtained under 70% ET_c treatment followed by ET_c, TI and FI treatments, respectively.

1. Introduction

Water availability is generally the most important factor limiting the development of agriculture in arid and semiarid regions (Deng et al., 2006; Zhou, 2003; Kashyap and Panda, 2003; Ferreira and Carr, 2002; Panigrahi et al., 2001). New innovations for saving irrigation water and thereby increasing water use efficiency (WUE) are especially important in water-scarce regions (Gencoglan et al., 2006). WUE relates to how much yield is obtained per unit of applied water (Howell, 2003). This can be represented as an incremental gain in dry matter per unit of water taken up and transpired by the plant (Draycott, 2006). WUE was identified as one of the key water use indicators derived in the study of sustainable irrigated agriculture. The definition focuses farmer's attention on both water use and production and provides an indication of whether the resource has been used effectively.

Drip irrigation with its ability to provide small and frequent water application directly in the vicinity of the plant root zone has proved to be a success in terms of water and increased yield in a wide range of crops (Rahil and Antonopoulos, 2007; Janat, 2003; Bhardwaj, 2001). Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduce production. However, it is necessary to make efficient use of irrigation water and bring more area under irrigation through available water resources for improving food security. This can be achieved by introducing advanced methods and devices of irrigation and improving water management practices (Deng et al., 2006; Zaman et al., 2001). Among the water management practices for increasing water use efficiency and saving large amount of irrigation water throughout the growing season is tensiometer device. Despite the existence of information about the effect of tensiometer on irrigation water saving, little literature available on tensiometer and its influence as a tool to improve yield and water use efficiency under several soil textures.

In Palestine, water for irrigation is both scarce and expensive and necessitates to be utilized in a scientific manner. Water

* Corresponding author. Tel.: +970 599097842; fax: +970 92677922.
E-mail addresses: mrahail@yahoo.com, mrahail@ptuk.edu.ps (M.H. Rahil).

http://dx.doi.org/10.1016/j.agwat.2014.09.005
0378-3774/

is an important limiting factor in the production and quality of cucumber because it has a sparse root system; approximately 85% of the root length is concentrated in the upper 30 cm top of soil layer (Janoudi and Widders, 1993). Cucumber is one of the major vegetable crops cultivated in Palestine under greenhouse conditions, which constitutes 14.4% of the total area planted with vegetable crops in the Palestinian Territories. It is a subtropical vegetable crop that grows successfully under conditions of high light, humidity, soil moisture, temperature and fertilizers in greenhouse (El-Aidy et al., 2007). Crops grown in open field of a semi arid climate are subjected to direct sunlight, high temperature and wind, resulting in high crop evapotranspiration (ET_c), therefore, demanding large amount of water. In contrast, shade greenhouses favor plant growth; since plant are less subjected to water stress, direct sunlight was avoided, wind speed reduced, and ET_c is low.

Availability of adequate amount of soil moisture at critical stages of plant growth not only optimizes the metabolic process in plant cells but also increases the effectiveness of the mineral nutrients applied to the crop. Consequently any degree of water stress may produce deleterious effects on growth and yield of the crop (Saif et al., 2003). Deficit water budgets lead to numerous physiological changes such as altered root to shoot ratio, reduced leaf area or number of leaves and finally reduce plant growth and yield. Several studies found that fresh fruit yield of cucumber were highly affected by the total amount of irrigation water at all growth stages (Hasandokht, 2005; Wang and Zhang, 2004; Mao et al., 2003; Hao and Papadopoulos, 2003; Castilla et al., 1991).

The objectives of this study were to investigate the effects of four irrigation regimes on the vegetative growth, yield and water use efficiency of cucumber crop under greenhouse cultivation. The study examined the optimum irrigation regime of drip irrigated cucumber plants as well as the water savings.

2. Materials and methods

2.1. Site description and experimental data

A field study was conducted at the experimental farm of Palestine Technical University-Kadoorie located at Tulkarm, Palestine, from February to the end of June 2012. A greenhouse with an area of 1000 square meters was used for the experiment. The soil of the experimental farm can be classified as clay texture with bulk density in the upper 30 cm of 1.2 g cm^{-3}. Commercial organic fertilizer at a rate of 200 kg per 1000 square meters was applied prior to planting and mixed into the soil. A drip irrigation system with emitter discharge at a rate of 4 l h^{-1} and with spacing between emitters of 40 cm was installed at spacing between laterals of 120 cm.

2.2. Seedlings cultivation

Cucumber (*Cucumis sativus* L.), Nasim variety, were planted at a rate of 1500 seedlings per 1000 square meters on 14 February 2012. All treatments received the same amount of fertilizers. Compound fertilizer (13:13:13) at a rate of 13 kg per 1000 square meters was applied at three days intervals through drip irrigation system, during the first growth period which elongated for two weeks starting from transplanting. Also another compound fertilizer (11:8:20) at a rate of 460 kg per 1000 square meters was applied during the second and third growth periods which elongated for 15 weeks. The amount of compound fertilizers was applied according to the NPK requirement of cucumber crop during the growth periods as given in Table 1.

Table 1
Nutrient requirements of cucumber crop cultivated in greenhouse.

Plant growth stages	Nutrient requirements		
	N	P_2O_5	K_2O
Transplanting—14 days	100	100	100
14–35 days	200	100	100
35–118 days	250	100	350

2.3. Irrigation treatments

Four irrigation regimes: farmer irrigation (FI), tensiometer based irrigation (TI), crop evapotranspiration (ET_c) and 70% of crop evapotranspiration (70% ET_c) were investigated during the growth periods of cucumber crop under greenhouse cultivation.

The amount of irrigation water to be applied for farmer irrigation treatment (FI) was measured as traditionally applied by the farmers in the experiment area; according to plant observation and growth development stages. Irrigation water was applied for a period of 30 min every two days during the first growth period which was elongated for two weeks. During the second growth period, the time of water application was increased up to 45–60 min every three days for a period of one month, and the time of water application reached up to 80–100 min every three to four days for a period of two months.

Tensiometer based irrigation treatment (TI) was scheduled using two tensiometers which placed at 15 and 30 cm soil depths closed to the root system. The locations selected for the tensiometers were representative for the general condition. The tensiometer placed at 15 cm depth was used for the beginning of irrigation, while the tensiometer placed at 30 cm depth was used for ending of irrigation. Irrigation decision was made when the average tensiometer reading reached up to 50–60 kPa.

The amount of irrigation water to be applied for the crop evapotranspiration treatment (ET_c) was estimated using modified FAO Penman–Monteith method (Allen et al., 1998); using a CRPWAT Software version 7.0 (Smith, 1992) as follows:

$$ET_c = K_c \frac{0.408\varDelta(R_n - G) + \gamma\left(900/T_{\text{mean}} + 273\right)u_2(e_s - e_a)}{\varDelta + \gamma(1 + 0.34u_2)} \quad (1)$$

where ET_c is the crop evapotranspiration under standard condition (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2--} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T_{mean} is the mean daily air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m s^{-1}), $(e_s - e_a)$ is the vapor pressure deficit (kPa), $\varDelta$ is the slope of vapor pressure curve (kPa °C^{-1}), γ is the psychrometric constant (kPa °C^{-1}) and K_c is the crop coefficient (between 0.6 and 1.15) which is affected by several factors such as crop type, crop height, albedo of the crop-soil surface, aerodynamic properties, leaf and stomata properties and crop stages. Data of crop coefficient of cucumber during different growth periods are given in Fig. 1.

The 70% of crop evapotranspiration treatment (70% ET_c) was estimated according to Harmanto et al. (2005) who found that, the actual crop evapotranspiration inside the greenhouse was about 25–30% lower than the actual water applied to the crop in the open field.

A set of climatic data, air temperature, relative humidity, wind speed and solar radiation outside the greenhouse were obtained from a meteorological station located adjacent to the experimental field and used to estimate the ET_c data.

Water use efficiency (WUE) is defined as the ratio of the crop yield to irrigation water applied (Al-Jamal et al., 2001). WUE can be increased by practicing deficit irrigation, improving irrigation technology, irrigation scheduling and improving agronomic

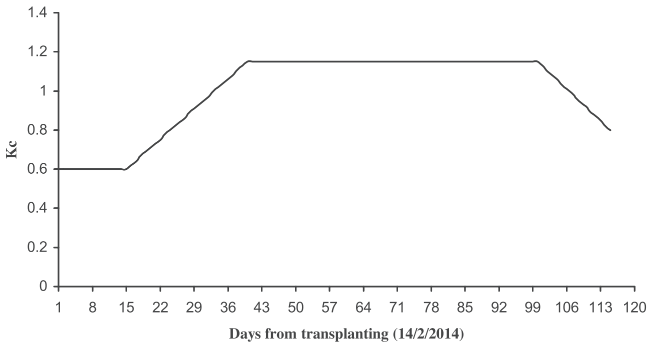

Fig. 1. Crop coefficient (K_c) of cucumber plants during growth periods.

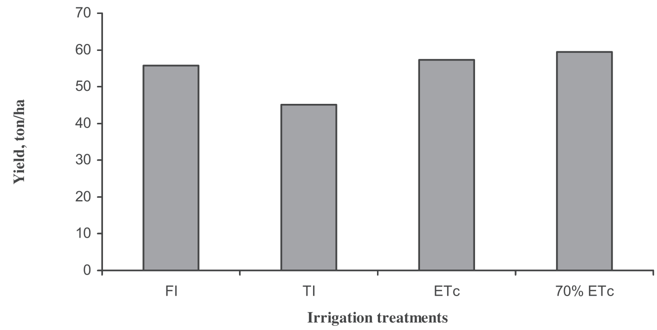

Fig. 2. Average yield of cucumber crop under four irrigation regimes (FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration).

practices that lead to yield increase. WUE was calculated according to FAO (1982) as follows:

$$WUE = \frac{\text{yield (kg)}}{\text{total water applied } (m^3)} \quad (2)$$

2.4. Soil and plant measurements

Soil samples' analyses for the experimental site were performed before planting (Table 2). Samples were collected from different sites at soil depths of 0–15 and 15–30 cm for evaluating the physical and chemical properties of the soil. Soil samples were analyzed for gravimetric soil moisture content, soil pH and electrical conductivity by saturation past, soil particle size distribution by hydrometer method, soil bulk density by core method, phosphorus content was determined using spectrophotometer according to Wantanabe and Olsen (1965), potassium content was determined photo-metrically using flame photometer as described by Chapman and Pratt (1961). Physical and chemical properties of the soil were described by Piper (1950), Jackson (1967) and Black (1969). The soil of the experimental site had no salinity problem with saturation extract EC_e of 0.9–1.3 dS m^{-1}. The results indicated a soil pH of 8.3.

Plant data were collected during the growing period of cucumber crop for evaluating the total yield, plant height, number of harvested fruits per plant, weight of harvested fruits per plant and dry matter of above and under ground parts. Total dry matter was determined after fruit harvesting using three plants from each replicate (whole plants minus fruits). Leaves, roots and stems were separated and weighed to obtain root and shoot (leaves and stem) dry weight after drying at 65 °C for one week to constant weight. Harvesting was done manually from 40 to 117 days after transplanting. The total cucumber fruits produced were weighed using a digital balance.

Table 2
Some selected soil chemical and physical properties.

Parameters	Unit	Soil depth (cm)	
		0–15	15–30
Texture		Clay	Clay
Sand	%	12	10
Silt	%	29	32
Clay	%	60	58
FC	%	36	36
PWP	%	16	16
Bulk density	g cm^{-3}	1.2	1.2
pH		8.3	8.3
ECe	dS m^{-1}	1.3	0.9
Ca^{2+}	ppm	103.6	93.1
Mg^{2+}	ppm	50.1	37.4
Na^{+}	ppm	83.8	57.0
K^{+}	ppm	6.4	6.7
Cl^{-}	ppm	242.3	177.5
HCO_3^{-}	ppm	27.5	68.6
CO_3^{-}	ppm	7.5	3.8
$CaCO_3^{-}$	%	18.2	14.4
NO_3–N	ppm	33.6	37.9
PO_4^{-}	ppm	11.5	8.7

2.5. Statistical analysis

The effects of four irrigation regimes on yield, growth parameters and water use efficiency of cucumber crop cultivated in greenhouse were analyzed using a randomized complete block design, using four treatments with five replicates per each treatment. Collected data in this study were analyzed and examined statistically using analysis of variance (ANOVA) from the Statistical Analysis System (SPSS) appropriate for a randomized complete block design. Means were compared by LSD test at 5% level of significance. The mean values of each treatment were designated by letters (a, b, c) which represent the significance degree of the difference between the means. Means represented by two letters in common indicate that the difference is not significant or weakly significant.

3. Results and discussion

3.1. Yield and its components

The effects of irrigation regimes on cucumber yield are shown in Fig. 2. The average yield of different treatments indicated that the 70% ET_c treatment obtained the highest crop yield of 59.52 t ha^{-1}, while the yield for ET_c, FI, and TI treatments were 57.27, 55.81 and 45.10 t ha^{-1}, respectively. The results also indicated that the yield of cucumber was reduced under TI treatment. Statistical analysis given in Table 3 indicated that, the yield obtained under TI treatment was significantly less than the other treatments, while there was no significant difference in yield between FI, ET_c and 70% ET_c treatments according to LSD at 0.05 level. On average, cucumber yield under 70% ET_c treatment was 24%, 6% and 4% higher than that under TI, FI and ET_c treatments, respectively. These results might be due to highly uniform delivery of water and efficient moisture availability in the root zone that achieved under 70% ET_c treatment which might had decreased the water leaching, and increased various physiological processes, better plant nutrient uptake, higher rate of photosynthesis, which might reflected on more number of fruits and higher fruit weight.

The yield components of cucumber crop are given in Table 3. The 70% ET_c obtained the highest average number of harvested fruit per plant followed by ET_c, FI, and TI treatments, respectively. The average number of harvested fruit for each treatment is given in Table 4. Statistical analysis given in Table 3 revealed that the vegetative parameters, i.e., plant height, above-ground dry matter of

Table 3
Yield components of cucumber crop under four irrigation treatments.

Yield components	Treatments			
	FI	TI	ET_c	70% ET_c
Total yield ($t\,ha^{-1}$)	55.81^b	45.10^a	57.27^b	59.52^b
Average plant yield ($kg\,plant^{-1}$)	4.03^b	3.19^a	4.30^b	4.52^b
Average number of harvested fruit per plant	2.8^b	2.4^a	3.0^b	3.1^b
Maximum plant height (cm)	161^{ab}	138^a	180^b	185^b
Above-ground dry matter at last stage ($g\,plant^{-1}$)	77^b	53^a	67^{ab}	84^b
Under-ground dry matter at last stage ($g\,plant^{-1}$)	2.25^a	1.35^a	1.51^a	1.65^a

Within rows means followed by the same letters are not significantly different according to LSD at 0.05 level. FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration.

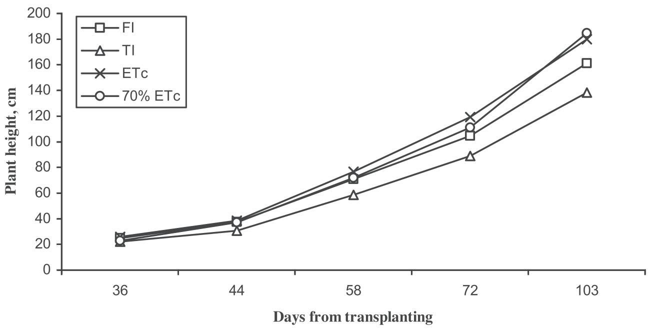

Fig. 3. Average plant height of cucumber plants under four irrigation regimes (FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration).

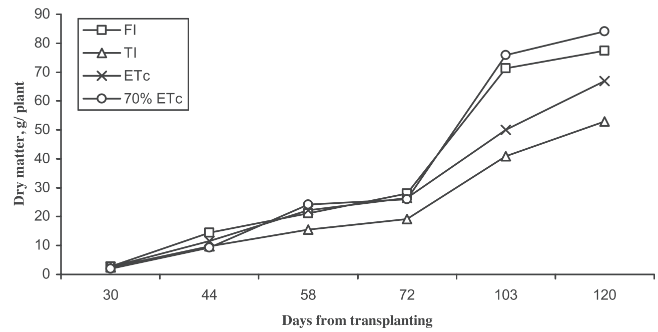

Fig. 4. Average above-ground dry matter of cucumber under four irrigation regimes (FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration).

cucumber plants under TI treatment were significantly less than that under FI, ET_c and 70% ET_c treatments.

3.2. Plant height

The effect of irrigation regimes on plant height was analyzed and compared statistically within treatments. Fig. 3 shows the effect of irrigation regimes on crop height after 36 days from transplanting until the end of growing period. The plants attained higher heights for ET_c and 70% ET_c treatments compared to the TI and FI treatments. The ET_c treatment gave the highest plant height compared to the other treatments during the growing period from the days 36 to 72 from transplanting. At the end of experiment, the 70% ET_c treatment obtained the highest plant height. The smallest plants height was observed for the TI treatment followed by the FI treatment. This gives an idea that either over or low irrigation amounts were not given the maximum plant growth for cucumber. These results agree with the findings of Harmanto et al. (2005) who found that, the 70% of ET_c gave the highest plant height of tomato plant cultivated in greenhouse. In contrast, Hashem et al. (2011) stated that, the vegetative parameters of cucumber plant was increased with the irrigation level of 100% ET_o followed by 80% and 120% irrigation levels during two growing seasons. Ngouajio et al. (2007) mentioned that, increased vegetative parameters under 100% ET_o irrigation level was attributed to the suitable irrigation quantity especially in the early stages of crop growth which enhanced a deeper and more extensive root system.

Table 4
Average number of harvested fruit of cucumber under four irrigation regimes during harvesting events.

Harvesting events	Treatments			
	FI	TI	ET_c	70% ET_c
Week 1	1.9 ± 0.4	1.4 ± 0.2	2.3 ± 0.5	2.4 ± 0.2
Week 2	3.9 ± 0.6	3.1 ± 0.6	3.4 ± 0.5	3.6 ± 1.3
Week 3	2.1 ± 0.3	2.3 ± 0.6	3.3 ± 1.0	3.6 ± 0.9
Week 4	3.4 ± 1.1	1.9 ± 0.3	2.8 ± 0.9	2.6 ± 1.1
Week 5	4.1 ± 1.1	3.4 ± 1.0	3.5 ± 1.1	3.5 ± 0.4
Week 6	2.6 ± 0.6	2.8 ± 0.6	2.8 ± 1.0	3.0 ± 0.4
Week 7	3.1 ± 0.3	2.3 ± 0.7	2.8 ± 1.0	3.0 ± 0.6
Week 8	2.1 ± 0.4	2.4 ± 0.3	3.6 ± 0.4	3.5 ± 1.0
Week 9	2.4 ± 0.5	2.4 ± 0.3	3.3 ± 1.0	3.3 ± 1.3
Week 10	2.7 ± 0.4	1.9 ± 0.2	2.8 ± 0.2	2.9 ± 0.3
Mean	2.8 ± 0.2	2.4 ± 0.2	3.0 ± 0.5	3.1 ± 0.4

FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration.

3.3. Plant dry matter

Plant dry matter was measured for both above and underground organs. Concerning the above ground dry matter (Fig. 4); the plants gave similar dry matter for FI, ET_c and 70% ET_c treatments at 62 days from transplanting. At the end of harvesting stage, plant dry matter obtained under 70% ET_c treatment was higher than the other treatments. The smallest plant dry matter was obtained under TI treatment. It is observed that the root and shot growth was inhibited under TI treatment (Figs. 4 and 5). Moreover, results of this study indicated that the dry matter of underground organs was higher for FI treatments comparing to the other treatments. Statistically, there is no significant difference in under-ground dry matter between the four irrigation treatments.

3.4. Water applied and water saving

Different amounts of irrigation water were applied every irrigation event through the growing period under four irrigation regimes as presented in Fig. 6. The amount of irrigation water applied in FI treatment was determined according to plant observation and plant growth stages. Crop water requirements in ET_c treatment were estimated using CROPWAT model from climatic data outside the greenhouse. The FI treatment used the higher amount of water than the other irrigation treatments. When using

Table 5
Irrigation depth, WUE, water saved and yield of cucumber crop under four irrigation treatments.

Treatments*	Irrigation events	Water saved (mm)	WUE ($kg\,m^{-3}$)	Yield ($t\,ha^{-1}$)	Irrigation depth (mm)
FI	44	–	19[b]	55.8[b]	287
TI	26	139	30[a]	45.1[a]	148
ET_c	42	26	22[a]	57.3[b]	261
70% ET_c	42	104	33[b]	59.5[b]	183

* Within columns means followed by the same letters are not significantly different according to LSD at 0.05 level. FI: Farmer Irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration.

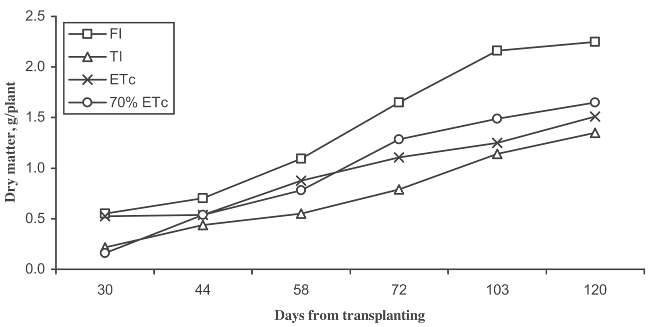

Fig. 5. Average under-ground dry matter of cucumber under four irrigation regimes (FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration).

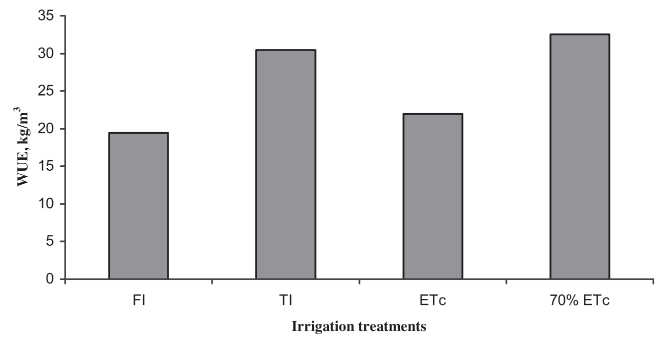

Fig. 7. Water use efficiency (WUE) of cucumber plants under four irrigation regimes (FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration).

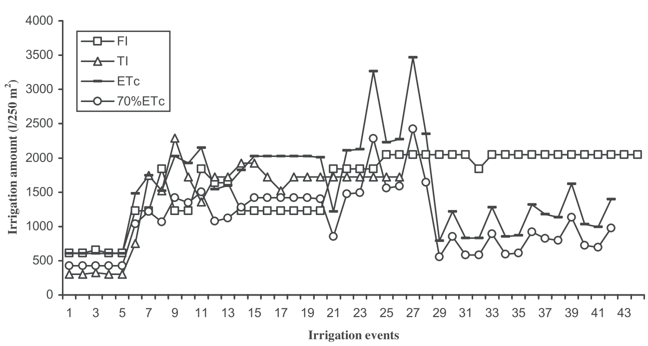

Fig. 6. Amount of irrigation water applied every irrigation event under four irrigation regimes (FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration).

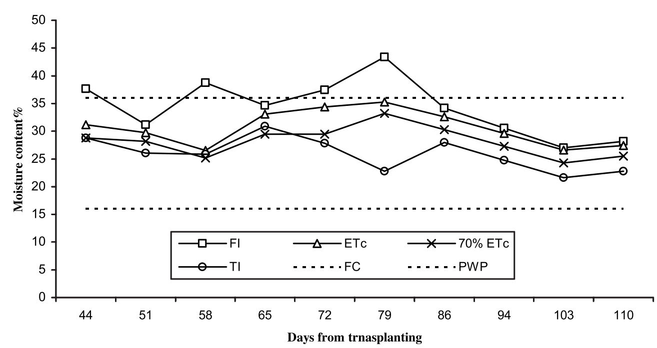

Fig. 8. Gravimetric soil moisture content during the growing period of cucumber under four irrigation regimes (FI: farmer irrigation; TI: tensiometer irrigation; ET_c: crop evapotranspiration; 70% ET_c: 70% of crop evapotranspiration).

scheduled irrigation methods, large amount of water were saved and found to be 139, 104 and 26 mm for TI, 70% ET_c and ET_c treatments, respectively compared to FI treatment. Results of this study indicated that although large amount of water was saved under TI treatment, but the yield was reduced by 24% compared with the 70% ET_c treatment.

3.5. Water use efficiency (WUE)

Water use efficiency (WUE) was calculated as the ratio of cucumber yield (kg) to total crop water use (m^3). Data on WUE for all treatments are presented in Table 5, and shown in Fig. 7. It is indicated that the WUE of cucumber plants investigated under 70% ET_c treatment was higher than that under FI, TI, and ET_c treatments. Data given in Table 5 showed that, there was a significant difference in WUE between 70% ET_c and TI treatments according to LSD at 0.05 level. Hashem et al. (2011) found that, the highest WUE was obtained by 80% ET_o of cucumber cultivated in greenhouse. It is indicated that although TI treatment had higher WUE than that under FI and ET_c treatments, but the yield of TI treatment was the lowest one compared to the other treatments. These results indicated that there was no consistent relationship between plant production and WUE. These results agree with the findings of Condon et al. (2002). In another field experiment, Douh et al. (2013) stated that soil water status assessed through criteria like soil water content, volume of water supply, humidity, or soil water potential constitute an imperfect parameter to characterize real plant water status, and it leads consequently to variability in WUE. The lowest WUE (19 $kg\,m^{-3}$) was found under FI treatment. This can be ascribed to the fact that, large amount of irrigation water was applied under FI treatment in improper way.

3.6. Soil moisture content

The soil moisture content under four irrigation treatments is presented in Fig. 8. Soil moisture content increased after irrigation and decreased between two successive irrigations. This decrease became more rapidly as the climate became hotter and the crop reached a more advanced vegetative stage. It is observed that the soil moisture content of the FI treatment was higher than the field capacity in some days during the growing period. This indicated unscheduled irrigation system under FI treatment. In TI treatment, it is observed that the soil moisture content was lower than the other treatment during the whole growing period.

4. Conclusions

Under the conditions of present study, effects of four irrigation regimes on yield and water use efficiency of cucumber crop were investigated. The statistical analysis of the treatments indicated that, the irrigation regimes had significantly affected the cucumber yield, irrigation water use efficiency and water saving. The results of the study demonstrated that, the growth parameters (plant height, plant dry matter, fruit number per plant) and fruit yield of cucumber were increased by using 70% of crop evapotranspiration throughout the growing season, which stimulated and encouraged plant growth.

Results also indicated that, the highest amount of water saved was observed under TI treatment, even though; the yield production of cucumber plant was reduced by 24% under this treatment. This may be explained by the fact that, the tensiometer device usually not functioning well under heavy textured soil; or further research may be required to explain the lower yield production under tensiometer based irrigation.

This study indicated that, the highest water use efficiency (33 kg m^{-3}) of cucumber crop was obtained under 70% of ET_c followed by TI, full ET_c and FI treatments, respectively. The lowest water use efficiency (19 kg m^{-3}) was found under FI treatment. This can be ascribed to the fact that, large amount of water was applied under FI treatment in improper way.

References

Al-Jamal, M.S., Ball, S., Sammis, T.W., 2001. Comparison of sprinkler, trickle and furrow irrigation efficiencies for onion production. Agric. Water Manage. 46, 253–266.
Allen, R.G., Pereira, L., Raes, D., Smith, M., 1998. Crop evapotranspiration guidelines for computing crop water requirements. In: FAO Irrigation and Drainage Paper 56. UN-FAO, Rome, Italy.
Bhardwaj, S.K., 2001. Importance of drip irrigation in Indian agriculture. Kissan World 28, 32–33.
Black, C.A., 1969. Methods of Soil Analysis. Amer. Soc. of Agron. Inc., Madison, USA.
Castilla, N., Bretones, F., Lopez-Galvez, J., 1991. Cucumber growth and yield in an unheated plastic greenhouse. Agric. Med. 121, 166–172.
Chapman, H.D., Pratt, F., 1961. Methods of Analysis for Soils, Plants and Water. Univ. of Calif., USA.
Condon, A.G., Richards, R.A., Rebetzke, G.J., Farquhar, G.D., 2002. Improving intrinsic water use efficiency and crop yield. Crop Sci. 42, 122–131.
Deng, X.P., Shan, L., Zhang, H., Turner, N.C., 2006. Improving agriculture water use efficiency in arid and semi-arid areas of China. Agric. Water Manage. 80, 23–40.
Douh, B., Mguidiche, A., Bhouri-Khila, S., Mansour, M., Harrabi, R., Boujlben, A., 2013. Yield and water use efficiency of cucumber (*Cucumis sativus* L.) conducted under subsurface drip irrigation system in a Miditerranean climate. J. Environ. Sci., Toxicol. Food Technol. 2 (4), 46–51.
Draycott, A.P., 2006. Sugar Beet. Blackwell Publishing, Oxford, UK, pp. 474.
El-Aidy, F., El-Zawely, A., Hassan, N., El-Sawy, M., 2007. Effect of plastic tunnel size on production of cucumber in delta of Egypt. Appl. Ecol. Environ. Res. 5 (2), 11–24.
FAO, 1982. Crop water requirements. In: Irrigation and Drainage Paper No. 24. FAO, Rome, Italy.
Ferreira, T., Carr, M., 2002. Response of potatoes (*Solanum tuberosum* L.) to irrigation and nitrogen in a hot, dry climate: I. Water use. Field Crops Res. 78, 51–64.
Gencoglan, C., Altunbey, H., Gencoglan, S., 2006. Response of green bean (*P. Vulgaris* L.) to subsurface drip irrigation and partial rootzone-drying irrigation. Agric. Water Manage. 84 (3), 274–280.
Hao, X., Papadopoulos, A.P., 2003. Effects of supplemental lighting and cover materials on growth, photosynthesis biomass partitioning, early yield and quality of greenhouse cucumber. Sci. Hortic. 80, 1–18.
Harmanto, Salokhe V.M., Babel, M.S., Tantau, H.J., 2005. Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment. Agric. Water Manage. 71, 225–242.
Hasandokht, M., 2005. Greenhouse Management (Production Technology of Greenhouse Products). Marz Danesh Press, Tehran, Iran, pp. 320.
Hashem, F.A., Medany, M.A., Abd El-Moniem, E.M., Abdallah, M.M., 2011. Influence of greenhouse cover on potential evapotranspiration and cucumber water requirements. Ann. Agric. Sci. 56, 49–55.
Howell, T.A., 2003. Irrigation efficiency. In: Stewart, B.A., Howell, T.A. (Eds.), Encyclopedia of Water Science. Marcel Dekker, New York, pp. 467–472.
Jackson, M.L., 1967. Soil Chemical Analysis. Prentice-Hall Inc., Englewood Cliffs, NJ, USA.
Janat, M., 2003. Effect of drip fertigation on improvement of potato yield and water use efficiency. AECS-A/RRE, vol. 126., pp. 1–38.
Janoudi, A.K., Widders, I.E., 1993. Water deficits and fruiting affect carbon assimilation and allocation in cucumber plants. Hortic. Sci. 28, 98–100.
Kashyap, P., Panda, R., 2003. Effect of irrigation scheduling on potato crop parameters under water stressed conditions. Agric. Water Manage. 59, 49–66.
Mao, X., Liu, M., Wang, X., Liu, C., Hou, Z., Shi, J., 2003. Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. Agric. Water Manage. 61 (3), 219–228.
Ngouajio, M., Wang, G., Goldy, R., 2007. Withholding of drip irrigation between transplanting and flowering increases the yield of field-grown tomato under plastic mulch. Agric. Water Manage. 87, 285–291.
Panigrahi, B., Panda, S., Raghuwanshi, N.S., 2001. Potato water use and yield under furrow irrigation. Irrig. Sci. 20, 155–163.
Piper, C.S., 1950. Soil and Plant Analysis. Inter Science Publisher Inc., NY, USA.
Rahil, M.H., Antonopoulos, V.Z., 2007. Simulating soil water flow and nitrogen dynamics in a sunflower field irrigated with reclaimed wastewater. Agric. Water Manage. 92, 142–150.
Saif, U., Maqsood, M., Farooq, M., Hussain, S., Habib, A., 2003. Effect of planting patterns and different irrigation levels on yield and yield component of maize (*Zea mays*, L.). Int. J. Agric. Biol. 1, 64–66.
Smith, M., 1992. CROPWAT: a computer program for irrigation planning and management. In: FAO Irrigation and Drainage Paper 46. UN-FAO, Rome, Italy.
Wang, S., Zhang, F., 2004. Effect of different water treatment on photosynthesis characteristics and leaf ultra structure of cucumber growing in solar green-house. Acta Hortic. 633, 397–401.
Wantanabe, F.S., Olsen, S.R., 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. Proc. 29, 677–678.
Zaman, W.U., Arshad, M., Saleem, A., 2001. Distribution of nitrate nitrogen in the soil profile under different irrigation methods. Int. J. Agric. Biol. 2, 208–209.
Zhou, W.B., 2003. Review on the study of water resources utilization efficiency in irrigation district in arid and semiarid areas of China. J. Arid Land Res. Environ. 17, 91–95.