Atatürk Üniv. Ziraat Fak. Derg.
33 (4), 383-389, 2002

Growth and Yield Parameters of Bell Peppers With Surface and Subsurface Drip Irrigation Systems Under Different Irrigation Levels

Halil KIRNAK
Harran Üniversitesi Ziraat Fakültesi Tarımsal Yapılar ve Sulama Bölümü, ŞANLIURFA

Cengiz KAYA
Harran Üniversitesi Ziraat Fakültesi Bahçe Bitkileri Bölümü, ŞANLIURFA

Veli DEĞİRMENCİ
Köyhizmetleri Araştırma Enstitüsü, ŞANLIURFA

Geliş Tarihi : 20.02.2002

ABSTRACT : The aim of this study was to compare the effects of surface (SDI) and subsurface (SSDI) methods of drip irrigation on plant growth, water use efficiency (WUE), fruit yield and quality in bell pepper (Capsicum annuum L.) cv. 11B 14. Different irrigation amounts based on Class-A-Pan evaporation were applied to plants during 4 different growing periods at 4 different irrigation levels (A, B, C, D) on every other day. Water stress (treatment, A) using SDI caused reductions in all parameters compared with unstressed treatments (C, D and relatively B). The highest yield was obtained from the treatment D as 50.8 and 55.2 t ha^{-1} for both SDI and SSDI methods, respectively. The SSDI+A treatment had the highest water use efficiencies and was significantly better than the SDI+D treatment. Seasonal water use ranged from 715 to 1412 mm in SDI treatment; and 765 to 1475 mm in SSDI treatments. The research results revealed that SSDI system could be a better choice compared to SDI system under deficit irrigation in Harran plain. However, there was no significant yield changes between C and D irrigation levels under both irrigation systems. These results clearly indicate that subsurface drip irrigation relatively mitigates negative effects of water stress on plant growth and fruit yield in field grown bell pepper particularly in semi-arid regions with limited water resources.

Key Words: Subsurface drip irrigation, surface drip irrigation, water deficit, bell pepper.

Toprak Üstü ve Toprak Altı Damla Sulama Sistemlerinde Farklı Sulama Düzeylerinin Biber Bitkisinin Gelişim ve Verim Özelliklerine Etkisi

ÖZET: Araştırma, toprak altı ve toprak üstü damla sulama yöntemleriyle farklı düzeylerde sulanan biber bitkisinin (11B14) gelişimi, su kullanım randımanı, verim ve kalite özelliklerini karşılaştırmak amacıyla yürütülmüştür. A-sınıfı buharlama kabından yararlanılarak bitkilere dört farklı gelişme döneminde (I, II, III, IV), iki günde bir dört farklı düzeyde (A, B, C, D) sulama suyu uygulanmıştır. Su stresi (A konusu) toprak üstü damla sulamada incelenen tüm parametrelerde stressiz konulara göre (C, D ve nispeten B konusu) düşüşlere neden olmuştur. En yüksek verim D konusundan elde edilmiş olup toprak üstü damla sulamada 50.8 ton ha^{-1}, toprak altı damla sulama da ise 55.2 ton ha^{-1} dir. Toprak altı damla sulama sistemiyle sulanan A konusunda su kullanım randımanları, toprak üstü damla sulama sistemiyle sulanan D konusuna göre istatistiki olarak önemli olacak şekilde yüksek bir değere ulaşmıştır. Mevsimlik su kullanımı SDI konusunda 715-1412 mm, SSDI konusunda ise 765-1475 mm arasında degişmiştir. Araştırma sunuçları Harran ovasında kısıntılı sulama koşullarında SSDI sisteminin SDI sistemine göre daha iyi bir seçenek olduğunu göstermiştir. Her iki sulama sisteminde de C ve D konuları arasında önemli verim farklılığı bulunmamıştır. Bu sonuçlar özellikle sınırlı su kaynaklarına sahip yarı-kurak bölgelerde, toprak altı damla sulama sisteminin su stresi altındaki biber bitkisinin gelişimi ve verimi üzerine olan olumsuz etkiyi nispeten azalttığını ortaya koymuştur.

Anahtar Kelimeler: Toprak altı damla sulama, toprak üstü damla sulama, su kısıntısı, biber.

Introduction

Irrigation is an increasingly important practice for sustainable agriculture in arid and semi-arid regions of the world as well as in Turkey. Applying the correct amount of water is particularly critical for crops such as bell pepper, which are sensitive to water stress. Irrespective of the irrigation system used, frequent water shortages outside the control of the grower will occur at times critical to vegetable growth. This leads to plant water stress and hence there is need for an efficient system which optimises use of applied water (James, 1993).

Yields of many drought sensitive vegetable crops have been reduced substantially when the soil water tension was greater than -50 kPa. Since a close correlation exists between water use and yield in annual field crops, water stress should be avoided at all stages of development of the crops. Reduced canopy development (e.g., shoot growth and leaf expansion) is one of the earliest responses to water stress before stomatal closure and reduction of photosynthesis (Smittle et al. 1994). Although total amount of water applied to plants during the whole growing period was important, the timing of the applied irrigation water was more critical. Goldberg et al. (1976) stated the positive effect of a regulated deficit irrigation at the early growth stage of the plants. Çevik et al. (1996) concluded the importance of regulated deficit irrigation for the eggplant production. They mentioned that the regulated irrigation practiced at the first growth stage (period between transplanting to flowering) increased the plant growth.

Application of surface drip irrigation (SDI) to field crops is difficult because of the potential for surface installed drip tubing interfering with cultural operations. In order to alleviate this difficulty, the use of subsurface drip irrigation (SSDI) has been proposed and used by many farmers and researchers. The design of the subsurface drip irrigation is the same as for surface systems except the tubing is buried. The main advantages of SSDI over SDI are: (1) more efficient use of water and fertilizer since application is in the effective part of the root zone (2) strike out the effect of infiltration variability on irrigation uniformity and (3) to reduce the evaporation from soil surface. Disadvantages of SSDI are: (1) high initial cost (2) potential root intrusion in the drip lines (3) salt accumulation between drip lines (4) bed size and spacing of crops should conform to lateral spacing of drip lines (Hansen et al. 1997).

There has been an increasing usage of SSDI for vegetable production in the World especially in arid and semi-arid regions due to advantages mentioned above. The bell pepper is one of the important vegetables consumed in Şanlıurfa. In our country, the usage of the SSDI is very limited and there is no sufficient information about the effectiveness of this system over the SDI system. Links between irrigation and fruit yield in bell pepper under SDI are well established (Wierenga and Saddiq, 1985; Madramootoo and Rigby, 1991; Smittle et al. 1994; Çevik et al. 1996). However, the effect of the limited water use in combination with surface and subsurface drip irrigation on the plant growth, water use efficiency and yield components of bell pepper has not been studied in Harran Plain and is the aim of the present investigation.

Materials and Methods

This experiment was carried out on a clay textured soil during the growing seasons of 1999 and 2000, at a farm near Koruklu located 27 km SE of Sanliurfa, Harran Plain, Turkey. The 1999-2000 growing season climatic conditions were typical of the conditions that prevail in the GAP region. Table 1 summarizes the montly climate data for Harran plain where the experiments were carried out. Average values for field capacity, permanent wilting point, dry bulk density, pH, and EC of the soil at the site for 0-60 cm soil depth were 31.85%, 21.35%, 1.35 g/cm^3, 7.45, and 0.75 dS/m, respectively. The water quality at the site was good (EC = 0.60 dS/m and pH = 7.0). Flat field beds, 5.0 m long and 2.50 m wide, were prepared. Forty plants per replicate were planted with an inter-plant spacing of 0.45 m and an inter-row spacing of 0.55 m. There was 2.5 m space among treatments. There were total four rows in each bed in the transplanting, but two central rows were used in the yield and growth analysis. The surface and subsurface drip irrigation systems with single laterals were centered between rows. The laterals were placed on the soil surface and at 20 cm depth for surface and subsurface drip irrigation systems, respectively. Spacing of the drippers with a constant discharge of 2.0 L/h at 100 kPa for both irrigation systems was 45 cm. Each plot had a separate flow meter to monitor water input. There was no rainfall during the experimental period.

Seeds of bell pepper (*Capsicum annuum L.*, cv. '11B 14') were germinated in fine sand during the first week of April in both years and at the first true leaf stage (10 days after germination), seedlings were transplanted into plastic tubs containing previously washed sand. At the second true leaf stage, seedlings were again selected and transplanted to the field. The plants were sprinkler irrigated at 4 mm/h from 10:00 am to 3:00 pm for a week to promote root establishment without stress in both years. In this study, vegetative period was separated into 4 parts; (I): Periods between transplanting of seedlings to the field and 50% of flowering, (II): Periods between flowering and 50% of fruit formation, (III): Periods between fruit formation and beginning of harvest, (IV): Periods between beginning of harvest and end of harvest. The amount of irrigation water applied to plants was calculated from the product of cumulative class-A-pan evaporation and Kpc. The Kpc coefficients were given in Table 1 for different growth stages. The Kpc coefficient in plant growth stage I was held low (Kpc = 0.3) due to reasons mentioned by Goldberg et al. (1976) and Çevik et al. (1996). In order to

Table 1. Monthly average climatic data for 1999-2000 growing season in the experimental area

Climatic parameters	*April*	*May*	*June*	*July*	*August*	*September*
Minimum air temperature (°C)	8.1	9.9	17.5	23.2	22.2	18.6
Maximum air temperature (°C)	31.6	35.8	40.4	43.0	42.9	36.8
Average temperature (°C)	17.8	21.1	28.5	32.9	30.4	27.5
Rainfall (mm)	59.9	0.6	-	-	-	-
Relative humidity (%)	60.6	37.9	38.7	42.9	50.5	49.2
Wind speed (m/s)	2.4	2.3	3.0	2.8	2.7	2.0
Evaporation (mm)	138.9	281.5	341.5	385.6	310.5	275.6

see the effects of water deficit on plant growth and yield, Kpc value for all growth stages in irrigation level A was kept as a lowest. Hence, the irrigation treatment A was assumed as water stress treatment.

Water use (ET) was calculated according to the one-dimensional water balance approach using gravimetric soil-water measurements (Doorenbos and Kassam 1979):

$$ET = I + P - D_r - R_f \pm \Delta_s$$

where ET is evapotranspiration, I is irrigation water applied during the growth period, P is effective rainfall during the growth period thus capillary rise, D_r is amount of drainage water, R_f is amount of runoff, Δ_s is change in the soil moisture content determined by gravimetric sampling.

In order to determine actual ET, soil moisture content between 0 and 90 cm was measured gravimetrically at the planting, prior to each irrigation and at harvest. Since there was no observed runoff during the experiment and the water table was in 7 m depth, capillary flow to root zone and runoff flow were assumed to be negligible in the calculation of ET. Drainage below 90 cm, after a number of soil-water content measurements, was considered as negligible.

Table 1. Kpc values under the different irrigation level and plant growth stage.

Plant growth stage	Irrigation levels			
	A	B	C	D
I	0.3	0.3	0.3	0.3
II	0.5	0.5	0.6	0.7
III	0.5	0.7	0.8	0.9
IV	0.5	0.9	1.0	1.1

All treatments received the same amount of total N (18 kg/da), P (2.4 kg/da) and K (5.5 kg/da) fertiliser based on soil analysis. All of the P, K and 40% of the N fertilisers were applied prior to planting and thoroughly mixed into the soil. The remaining 60% of N was added equally at weekly intervals through the drip irrigation system starting two weeks after transplanting until the first harvest. A regular spray program for disease and insect control was followed throughout the growing period. Measurements of height from cotyledonary node to the base of the petiole at the tallest growing point (Madramootoo and Rigby, 1991) and canopy and stem diameters from five plants in each treatment were taken immediately prior to first harvest. Fully sized green peppers were harvested every week starting from mid-July until mid-September. The fruit was then sorted, counted, and weighted as marketable or unmarketable. All measurements were made in two central rows. Peppers that were misshapen, rotten, or soft were classified as unmarketable. The experiment was arranged in a randomized split-block design with 3 replications. Irrigation systems were in the main plots while irrigation levels in the subplots. All data were analyzed using a statview computer program. Means were separated by Duncan's multiple range test ($P < 0.05$).

Fruit yield and water use efficiency

The values for fruit yield (kg/plant) and fruit number per plant are the means of twenty plants per treatment. Individual fruit weight was calculated from 25 randomly chosen fruits per treatment at each harvest. Number of fruit per plant is the means of fruits of twenty plants per treatment. Irrigation water use efficiency (IWUE) was calculated from the marketable fruit yields and amount of water applied to the plants for the treatments during the growing season. Total water use efficiency (TWUE) was computed as the ratio of marketable fruit yields to water use. Water use was the total of seasonal water depletion (planting to harvest) plus rainfall and irrigation during the same period.

Plant dry weight determination

Total dry matter accumulation was estimated at the end of the experiment using whole plant minus fruit and drying them at 70 ^{o}C for 48 hours to a constant weight. Five plants from each treatment were used for this purpose. In the root analysis, 60 cm effective root depth along with a 45×55 cm planting area were considered. The plant stem was cut at the soil level and roots were extracted and analyzed according to Chapman and Pratt, (1982).

Leaf relative water content

Leaf relative water content (LRWC) was calculated based on the methods from Yamasaki and Dillenburg (1999). LRWC analysis was done periodically with 30 day intervals after planting till harvest. Four leaves of four randomly chosen plants per treatment were always collected from mid section of plant in order to minimize age effects; individual leaves were removed and weighed to obtain fresh mass (FM). In order to determine the turgid mass (TM), leaves were floated in distilled water inside a closed petri dish. During the imbibition period, leaf samples were weighed periodically, after gently wiping the water from the leaf surface with tissue paper. At the end of the imbibition period, leaf samples were placed in a pre-heated oven at 80°C for 48 h, in order to obtain dry mass (DM). All mass measurements were made using an analytical balance, with precision of 0.0001 g. Values of FM, TM and DM were used to calculate LRWC using the equation:

$$LRWC (\%) = [(FM-DM)/(TM-DM)] \times 100$$

RESULTS and DISCUSSION

Plant Growth

Interactions between irrigation systems and irrigation levels were found significant at $p<0.05$ level and differences among the treatments were separated by Duncan test. The A treatment at both irrigation methods reduced both dry matter and LRWC in bell pepper due to reduced water application (Table 2). The SSDI+D treatment produced the highest dry matter and LRWC. In our experiment, root growth was less inhibited than shoot growth under water stress according to root/shoot ratio (Table 2). This is in agreement with other previous research results. Sharp (1996) has shown that some roots continue to elongate at low soil water potential and that completely inhibits shoot growth. The LRWC values decreased based on reductions in irrigation water application.

Table 2. Dry weights (g) and LRWC (%) of bell pepper irrigated by surface and subsurface drip systems under different irrigation levels

Treatments		1999			2000		
		Root	Shoot	LRWC	Root	Shoot	LRWC
SDI	A	3.4 a[1]	15.5 a	58 a	3.5 a	13.1 a	60 a
	B	3.9 bc	19.5 b	75 c	4.0 bc	20.1 b	76 c
	C	4.4 d	24.6 c	86 ef	4.5 d	23.5 bc	86 e
	D	4.5 de	26.7 cde	90 fg	4.5 d	27.4 d	89 ef
SSDI	A	3.8 ab	16.9 ab	62 b	3.9 ab	15.5 a	65 b
	B	4.2 cd	26.5 cd	79 d	4.4 cd	24.5 cd	80 d
	C	4.9 ef	28.7 de	89 fg	5.1 e	32.5 e	89 ef
	D	5.0 f	30.5 e	92 g	5.2 e	32.6 e	90 f

[1]: Within each column, means followed by the same letter indicate no significant difference between treatments (p>0.05).

Using subsurface drip irrigation (SSDI+A) treatment resulted in increases in dry matter and LRWC compared to plants grown under the (SDI+A) treatment. This beneficial effect of SSDI on reducing water stress is probably due to minimising the water loss from the soil surface. The values for the (SDI+C or D) treatment were similar to those (SSDI+D) treatment.

The plant height, canopy and stem diameter were reduced by SDI+A treatment significantly at $P<0.05$ level compared to SDI+D treatment. The SSDI+A treatment increased these parameters and values obtained were very close to the (SDI+B) treatment (Table 3). Plant height and canopy diameter were the highest in the SSDI+D treatment. The results show that SSDI has potential benefit over SDI under both unstressed and stressed conditions. However, advantages of SSDI over the SDI was more obvious in stressed treatment (A) in terms of growth parameters.

Table 3. Effects of irrigation level on plant height (cm), canopy diameter (cm) and stem diameter (mm) of bell pepper irrigated by surface and subsurface drip irrigation

Treatments		1999			2000		
		Plant height	Canopy diameter	Stem diameter	Plant height	Canopy diameter	Stem diameter
SDI	A	58.2 a[1]	18.5 a	16.5 a	60.2 a	19.1 a	16.1 a
	B	67.5 bc	22.2 b	18.5 c	68.3 b	23.8 b	18.9 b
	C	71.1 cd	27.6 d	20.1 d	70.5 bc	28.1 c	21.5 d
	D	71.5 cd	28.5 d	21.0 e	71.9 bc	28.8 c	21.9 d
SSDI	A	61.2 a	21.5 b	17.5 b	62.4 a	22.2 b	18.8 b
	B	69.2 cd	24.9 c	20.3 d	70.5 bc	28.6 c	20.8 c
	C	73.1 d	32.4 e	23.2 g	74.1 c	32.9 d	22.8 e
	D	73.9 d	32.9 e	22.9 f	73.8 c	33.1 d	23.1 e

[1]: Within each column, means followed by the same letter indicate no significant difference between treatments (p>0.05).

Fruit yield, quality and WUE

Yield was reduced by 42% for SDI+A treatment compared to SDI+D treatment. Fruit weights and fruit number per plant were also significantly reduced by the stressed SDI+A treatment. Similar results were obtained by Smittle et al. (1994) in bell peppers that reported that water stress reduced fruit yield under SDI system. The use of subsurface drip irrigation (SSDI) mitigated the detrimental effects of water stress on fruit yield to some extent (Table 4). Plants in the SSDI+A treatment produced marketable fruit yield similar to those of the unstressed SDI values, but marketable yield was still lower. These data are in broad agreement with a number of other workers who reported a positive effect of subsurface drip irrigation on both yield and quality; Hansen et al. (1997) for lettuce and Phene et al. (1987) for processing tomato.

The irrigation levels both in SDI and SSDI plots significantly increased both fruit quality and yield. However, C and D treatment in both SDI and SSDI systems were similar to each other. The highest yield, averaging 55.2 t ha^{-1}, was measured in SSDI plots with D treatment, followed by SSDI+C plots with 54.4 t ha^{-1}. The highest yield in SDI plots was obtained in D treatment with an average value of 50.7 t ha^{-1}, followed by C treatment with 48 t ha^{-1}. As the amount of irrigation water decreased, marketable yield was also decreased. Marketable yields in SSDI plots in this study were comparable with the fruit yield of bell pepper from previous experiments in the Harran plain. However, the yields from SSDI irrigated plots were significantly higher than those from the previous experiments utilizing surface irrigation methods (Degirmenci and Sözbilici, 1995; Karakuş and Anlagan, 1996).

The SSDI+A treatment had the highest IWUE (0.053 t/ha/mm) and was significantly better than the SDI+A

(0.043 t/ha/mm) treatments. The highest TWUE, averaging 0.046 t/ha/mm, was obtained in SSDI+A treatment. In general, TWUE values decreased with increasing water use. IWUE were slightly higher than the TWUE values in both irrigation systems. Since there was no rainfall during the growing season, these slight differences between the two values can be attributed to water used from soil storage. The greater IWUE and TWUE for subsurface drip irrigation treatments were probably due to virtually nil losses due to soil evaporation for the SSDI treatments compared to the surface drip irrigation treatments (Table 5). Since surface evaporation with subsurface drip irrigation is minimal, water losses must originate mainly from transpiration. It is likely that the increased transpiration improved cooling of the crop canopy. This would result in increased WUE and photosynthesis. The study conducted by Hutmacher et al. (1996) with alfalfa using SSDI methods stated that increases in WUE were mainly due to reduced water application not increased yield. However, increases in the WUE with SSDI treatments compared to SDI treatments in our study were the result of both improved yields and reduced water application together.

The SDI and SSDI plots received irrigation water varying from a low of 666 mm in heavy stress plot (A) to a high of 1351 mm in non-stress plot (D). The seasonal water use by bell pepper varied from a low of 715 mm in SDI+A to a high of 1412 mm in SDI+D. In SSDI plots, water use changed from 765 mm in A to 1475 mm in D treatment. Water use in SDI+B was almost the same as those in SSDI+B treatment.

Table 4. Fruit number and total fruit yield per plant (kg plant^{-1}), mean fruit weight (g fruit^{-1}) and marketable fruit yield (t ha^{-1}) for bell pepper irrigated by surface and subsurface drip irrigation under different irrigation levels

Treatments		1999				2000			
		Yield per plant	Fruit number per plant	Fruit weight	Marketable yield	Yield per plant	Fruit number per plant	Fruit weight	Marketable yield
SDI	A	0.85 a[1]	28 a	26.3 a	30.1 a[1]	0.97 a	26 a	27.9 a	29.2 a
	B	1.20 b	33 b	33.1 b	37.9 b	1.15 a	35 bc	34.9 b	39.1 b
	C	1.65 cd	40 cd	37.5 cd	47.8 cd	1.70 bc	42 d	38.3 c	48.1 cd
	D	1.72 d	42 de	39.5 d	50.2 de	1.68 bc	43 d	40.1 c	51.4 d
SSDI	A	1.35 bc	32 b	32.7 b	35.5 b	1.26 ab	34 b	34.2 b	36.4 b
	B	1.75 d	37 c	36.5 bcd	44.0 c	1.60 b	38 c	38.3 c	44.5 c
	C	1.90 d	44 e	43.5 e	53.7 ef	2.00 d	45 d	44.8 d	55.2 de
	D	1.95 d	44 e	44.0 e	54.5 f	1.90 cd	43 d	45.1 d	55.9 e

[1]: Within each column, means followed by the same letter indicate no significant difference between treatments ($p>0.05$)

Table 5. Applied water (AW, mm) and water use efficiency (t fruit / ha per mm of applied water) of bell pepper under surface and subsurface drip irrigation

Treatments		1999				2000			
		AW	ET	IWUE	TWUE	AW	ET	IWUE	TWUE
SDI	A	666	715	0.045 c[1]	0.042 cd	683	746	0.043 b	0.039 bc
	B	846	945	0.044 bc	0.040 b	885	968	0.044 b	0.040 cd
	C	1066	1115	0.044 bc	0.043 d	1101	1178	0.044 b	0.041 d
	D	1307	1405	0.038 a	0.036 a	1351	1412	0.038 a	0.036 a
SSDI	A	666	765	0.053 e	0.046 f	683	788	0.053 d	0.046 f
	B	846	1000	0.051 d	0.044 de	885	1012	0.050 c	0.044 e
	C	1066	1214	0.050 d	0.044 de	1101	1250	0.050 c	0.044 e
	D	1307	1474	0.042 b	0.037 a	1351	1475	0.039 a	0.038 b

[1]: Within each column, means followed by the same letter indicate no significant difference between treatments $p<0.05$

Seasonal maximum water use and irrigation water requirements of pepper under Harran plain conditions has been reported to be 1766 and 1643 mm under surface irrigation conditions (Degirmenci and Sözbilici, 1995). As the amount of water applied with SSDI system in this study is considered, water saving is possible in comparison to the results from furrow irrigation studies carried out at the same location.

Significant linear relationships were found between yield of pepper and water use in SDI and SSDI treatments as shown in Figure 1. The yield of pepper increased with increasing water use in both irrigation systems. The slopes of the relationships between relative reduction and relative ET deficit are termed as yield response factor (ky) by Doorenbus and Kassam (1979) and was found to be 1.12 and 1.28 for SDI and SSDI treatments, respectively.

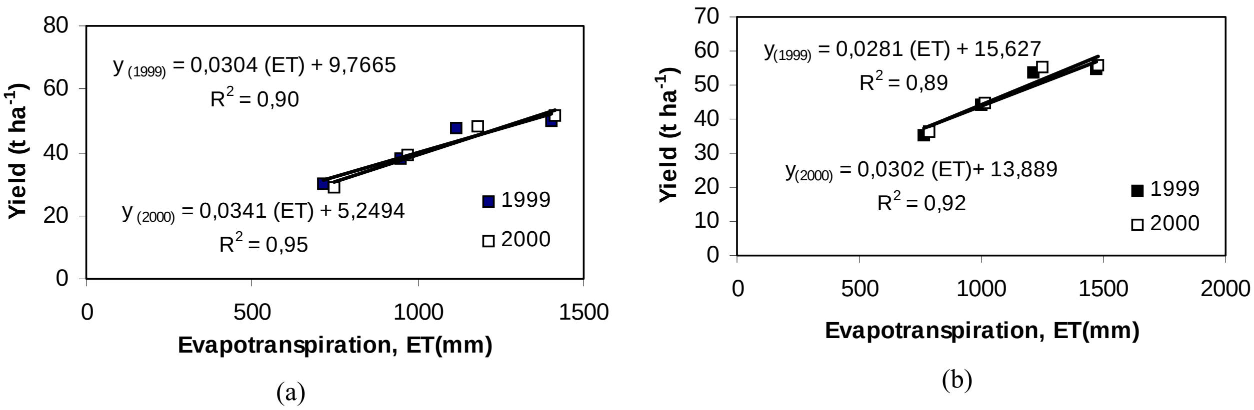

Figure 1. The relationship between yield of pepper and water use for SDI (a) and SSDI (b) treatments.

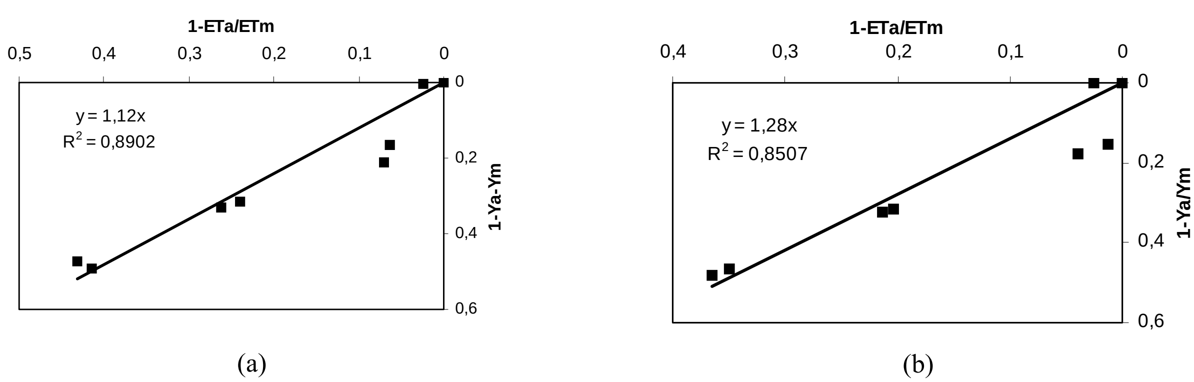

Figure 2. Relative yield reduction vs. relative ET deficit relationships for SDI (a) and SSDI (b) treatments.

CONCLUSIONS

Water stress (treatment A) using surface drip irrigation in the cultivation of bell pepper adversely affected its growth, yield and physiological development. The treatments in SSDI relatively mitigated the adverse effects of water stress on field-grown bell pepper restoring most of the growth and yield to levels similar or close to those in unstressed plants. SSDI has potential advantages over SDI in terms of increased yield and water use efficiencies under water stress (A) conditions. In the conditions of enough water, there is no significant yield and fruit quality changes between SSDI and SDI treatments (C or D). Hence, SSDI+C or SDI+D treatment can be suggested for pepper production due to higher yield in Harran plain in the conditions of enough water for irrigation. However, in the conditions of limited water sources, SSDI along with A or B irrigation level could be a better choice compared to SDI system. A higher water use efficiencies (IWUE and TWUE) in the SSDI methods compared to SDI indicated that significant water conservation in semi-arid regions could be obtained without significant yield reductions using SSDI method. This research revealed that SSDI system can be used successfully for the irrigation of bell pepper under the climatic conditions of Harran plain.

Acknowledgements

Authors would like to acknowledge Goktepe Ldt. Co. for supplying some parts of irrigation system.

REFERENCES

Bar-Yosef, B., B. Sagiv and T. Markovitch. 1989. Sweet corn response to surface and subsurface trickle phosphorus fertigation. Agronomy Journal 81(3), 443-447.

Chapman, H.D. and P.F. Pratt. 1982. Method of plant analysis. In: Methods of Analysis for soils, plants and water, pp. 60-193. (Chapman Pub. California)

Çevik, B., N. Baytorun, Ç. Tanrıverdi, K. Abak and N. Sarı. 1996. Effects of different irrigation water applications on yield and quality of eggplant grown in glasshouse. Tr. J. Of Agriculture and Forestry, 20:175-181.

Degirmenci, V and Y. Sözbilici. 1995. Furrow irrigation of pepper in Harran plain of GAP region. Şanlıurfa rural research institute, no: 98, pp. 270-280, Şanlıurfa.

Doorenbos, J., A.H. Kassam, 1979. Yield Response to Water. FAO, irrigation and drainage paper no:33, Rome, 193.

Goldberg, D., B. Gornat and D. Rimon. 1976. Drip irrigation-principles design and agricultural practices. Drip irrigation scientific publications, Israel.

Hansen, B.R., L.J. Schwanki, K.F. Schulbach and G.S. Pettygrove. 1997. A comparison of furrow, surface drip and subsurface drip irrigation on lettuce yield and applied water. Agricultural Water Management 33, 139-157.

Horton, R., F. Beese and P.J. Wierenga. 1982. Physiology response of chilli peppers to trickle irrigation. Agronomy Journal 74, 551-555.

Hutmacher, R.B., R.M. Mead and P. Shouse. 1996. Subsurface drip : Improving alfalfa irrigation in the west. Irrigation Science 45, 48-52.

James, L.G., 1993. Principles of Farm Irrigation System Design. Krieger publishing company, p. 543, Florida-USA.

Karakus,L and M. Anlagan. 1996. N fertilization of pepper in Harran plain conditions. Şanlıurfa rural research institute, no: 102, pp. 545-553, Şanlıurfa.

Lavon, R., R. Salomon and E.E. Goldschmid. 1999. Effect of potassium, magnesium and calcium deficiencies on nitrogen constituents and chloroplast components in citrus leaves. Journal of The American Society for Horticultural Science 124 (2), 158-162.

Madramootoo, C.A. and M. Rigby. 1991. Effects of trickle irrigation on the growth and sunscald of bell peppers (Capsicum annuum L.) in southern Quebec. Agricultural Water Management 19, 181-189.

Phene, C.J., K.R. Davis, R.B. Hutmacher and R.L. McCormick. 1987. Advantages of subsurface drip irrigation for processing tomatoes. Acta Horticulture 200, 101-103.

Sharp, R.E. 1996. Regulation of plant growth responses to low soil water potential. HortScience 31(1), 36-38.

Smittle, D.A., W.L. Dickens and J.R. Stansell. 1994. Irrigation regimes affect yield and water use by bell pepper. Journal of American Soiety of Horticultural Science 119(5), 936-939.

Wierenga, P.J. and M.H. Saddiq. 1985. Optimum soil water tension for trickle irrigated chilli peppers. Proc. Third Int. Drip/Trickle Congress, 1, 93-197.

Yamasaki, S. , L.R. Dillenburg, 1999. Measurements of leaf relative water content in araucaria angustifolia. Revista Brasilleira de Fisiologia Vegetal, 11(2): 69-75.