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EFFECT OF DRIP IRRIGATION REGIMES ON YIELD AND QUALITY OF FIELD GROWN BELL PEPPER

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SUMMARY -This study examines the effects of different irrigation regimes on yield and water use of bell pepper irrigated with a trickle system under field conditions in 2002 and 2003 growing seasons in the Mediterranean region of Turkey. Irrigation regimes consisted of three irrigation intervals (I_1:18-22 mm, I_2:38-42 mm and I_3:58-62 mm of cumulative pan evaporation from Class A pan) and three plant-pan coefficients (Kcp_1=0.50, Kcp_2=0.75 and Kcp_3=1.00) were evaluated. Irrigation intervals varied from 3-6 days in I_1, 6-11 days in I_2 and 9-15 days in I_3 treatments. Both Kcp and irrigation intervals (I) influenced significantly pepper yields. Maximum and minimum yields were obtained from the I_1Kcp_3 and I_3Kcp_1 treatments as 33140 kg ha^{-1} and 21620 kg ha^{-1} in the first experimental year and 35298 kg ha^{-1} and 21010 kg ha^{-1} in the second experimental year, respectively. As the Kcp value decreased the total yields each irrigation interval also decreased. However, with the lower irrigation frequency (I_3), lower yields were obtained with all Kcp coefficients. Seasonal water use values in the treatments varied from 365 mm in I_2Kcp_1 to 528 mm in I_1Kcp_3 in the first experimental year and 309 mm in I_3Kcp_1 to 511 mm in I_1Kcp_3 in the second experimental year. Significant second degree polynomial relations were found between pepper yield and total water use for each irrigation interval in 2002 and 2003 growing seasons. Irrigation intervals resulted in similar water use in the treatments with the same Kcp value. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) values were significantly influenced by the irrigation intervals and plant-pan coefficients. WUE ranged from 4.7 kg m^{-3} in I_3Kcp_2 to 7.6 kg m^{-3} in the I_1Kcp_1 in the 2002 growing season and ranged from 6.4 kg m^{-3} in I_3Kcp_3 to 7.9 kg m^{-3} in the I_2Kcp_2 in the 2003 growing season. Maximum IWUE was observed in I_1Kcp_1, and minimum IWUE was in I_3Kcp_3 treatment in the 2002 and 2003 growing seasons. Both Kcp coefficients (irrigation amounts) and irrigation frequencies had significantly different effects on quality parameters such as the first and second quality yield, number of fruit, mean fruit weight, pepper length and width, as well as stem diameter and plant height at harvest. In conclusion, I_1Kcp_3 irrigation regime is recommended for field grown bell pepper in order to attain higher yields with improved quality.

Key words: deficit irrigation, bell pepper, water use efficiency, quality, drip irrigation, free surface evaporation.

RESUME – *Cette étude, menée en 2002 et 2003 en Turquie, en région méditerranéenne, concerne les effets de différents régimes d'irrigation sur la production et la consommation en eau du poivron à farcir en culture irriguée de plein champ. On a utilisé trois différents régimes d'irrigation (Les valeurs d'évaporation cumulative de classe A Pan étaient de I_1:18-22 mm, I_2:38-42 mm et I_3: 58-62 mm) et trois coefficients plante-pan(kcp_1=0.50, kcp_2 =0.75, kcp_3 = 1.00). Les intervalles d'irrigation étaient de 3-6 jours dans le traitement I_1, 6-11 jours dans le traitement I_2, 9-15 jours dans le traitement I_3. Le coefficient kcp et l'intervalle d'irrigation joue un rôle significatif sur la production des poivrons. La première année, les productions maximale et minimale de 33140 kg ha^{-1} et de 21620 kh ha^{-1} ont été obtenues avec les traitements I_1kcp_3 et I_3kcp_1. La deuxième année, ces valeurs étaient respectivement de 35298 kg ha^{-1} et de 21010 kg ha^{-1}. Pour chaque intervalle d'irrigation, lorsque la valeur kcp décroît, la production totale diminue. Toutefois, avec la fréquence d'irrigation la plus basse (I_3), on a obtenu les plus faibles productions quel que soit le coefficient kcp. Les valeurs de consommation d'eau saisonnière(ET) varient de 365 mm dans le traitement I_2kcp_1 à 528 mm dans le traitement I_1kcp_3 durant la première année et de 309 mm dans le traitement I_1kcp_3 à 511 mm dans le traitement I_1kcp_3 la deuxième année. Des relations polynomiales significatives de second degré ont été trouvées entre la production de poivrons et la consommation totale d'eau utilisée pour chaque intervalle d'irrigation dans les essais de 2002 et 2003. Les intervalles d'irrigation résultent en une* *consommation d'eau totale similaire dans les traitements avec la même valeur de kcp. Le rendement de consommation d'eau (WUE) et le rendement d'utilisation d'eau d'irrigation (MWUE) ont des valeurs influencées significativement par les intervalles d'irrigation et les coefficients plante-pan. Le WUE varie de 4.7 kg* m^{-3} *avec le traitement* I_3kcp_2 *à 7.6 kg* m^{-3} *avec le traitement appliqué au cours de l'année 2002 et de 6.4 kg* m^{-3} *avec le traitement* I_3kcp_3 *à 7.9 kg* m^{-3} *avec le traitement* I_2kcp_2 *appliqué en 2003. La valeur maximale IWUE a été observée avec* I_1kcp_1*, et minimale avec* I_3kcp_3 *. Les coefficients kcp et fréquences d'irrigation ont des effets significativement différents sur des paramètres de qualité tels que la première et seconde qualité de production, le nombre de fruits, le poids moyen des fruits, la longueur et la largeur des poivrons, aussi bien que le diamètre et la hauteur de la plante à la récolte. En conclusion, le régime d'irrigation* I_1kcp_3 *est recommandé pour la production de poivron en plein champ pour obtenir la meilleure production et avec la meilleure qualité.*

***Mots clé**: déficit d'irrigation, poivron à farcir, efficience de l'utilisation d'eau, qualité, irrigation goutte à goutte, évaporation à surface libre.*

INTRODUCTION

Water supply is a major constraint to crop production in the Mediterranean region of Turkey. The increased competition for water between agricultural, industrial, and urban consumers creates the need for continuous improvement in irrigation practices in commercial vegetable production in the region. The economy of the region relies heavily on irrigated crop production. However, surface irrigation method is commonly used in the area resulting in low irrigation efficiencies as well as salinity and drainage problems. Efficient use of water by irrigation is becoming increasingly important, and alternative water application methods such as drip and sprinkler, may contribute substantially for making the best use of water for agriculture and improving irrigation efficiency.

The trend in recent years has been towards conversion of surface to drip irrigation, which is considered to be a more efficient delivery system. 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 reduces production. On the other hand, the intensity of the operation requires that the soil water supply be kept at the optimal level to maximize returns to the farmer. High-frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant, and maintains a high soil matric potential in the rhizosphere to reduce plant water stress (Phene and Sanders, 1976; Nakayama and Bucks, 1986).

Annual bell pepper production of Turkey is about 390000 metric tons of which 28.8 % is produced in the Mediterranean region (DIE, 2000). Bell pepper has been classified as susceptible to very susceptible to water stress, with blossom stage being the most sensitive period (Bruce *et al.*, 1980). For high yields, an adequate water supply and relatively moist soils are required during the total growing period. Reduction in water supply during the growing period in general has an adverse effect on yield and the greatest reduction in yield occurs when there is a continuous water shortage until the time of first picking. The period at the beginning of the flowering period is most sensitive to water shortage and soil water depletion in the root zone during this period should not exceed 25 percent. Water shortage just prior and during early flowering reduces the number of fruits. The effect of water deficit on yield during this period is greater under conditions of high temperature and low humidity. Controlled irrigation is essential for high yields because the crop is sensitive to both over and under irrigation (Doorenbos and Kassam, 1986). Water management in bell pepper is extremely important at all stages of plant development due to its influence on stand establishment, fungal problems and fruit set and quality. For this reason, the crop must be supplied with adequate water to ensure vigorous growth. Irrigation is important for its plant and fruit growth (Smittle *et al.*, 1994; Costa and Gianquinto, 2002).

Common irrigation methods practiced for bell pepper production in this region are wild flooding, furrow and basin. In general, the farmers over irrigate, resulting in high water losses and low irrigation efficiencies, and thus creating drainage and salinity problems (Tekinel *et al.*, 1989). With the drip irrigation systems, water and nutrients can be applied directly to the crop at the root level, having positive effects on yield and water savings and increasing the irrigation performance (Phene and

Howell, 1984). For these reasons, drip irrigation systems have seen widespread use in the world in recent years.

Pan evaporation incorporates the climatic factors influencing evapotranspiration into a single measurement (Hansen *et al.*, 1980) and has been used to schedule irrigation for several crops (Jensen and Middleton, 1970). Irrigation scheduling methods based on pan evaporation are widely used because of their easy applications (Elliades, 1988). With available pan coefficient in hand, pan evaporation (Class-A Pan) can be used in the arrangement of irrigation programs. Shmueli and Goldberg (1972) compared different pan coefficients under arid conditions in Israel and concluded that a pan coefficient of 1.33 resulted in greater yield than pan coefficients of 0.83, 0.95 and 1.75 for trickle irrigated bell pepper.

Üstün (1993) studied the effect of irrigation methods, irrigation frequency and pan coefficients on bell pepper under Ankara conditions and highest yield of 27861 kg ha^{-1} was obtained with trickle irrigation applied using an 6 day interval and pan coefficient of 0.50. Drip irrigation resulted in similar yield with surface irrigation, but 2.4 folds as compared to furrow method of irrigation reduce the amount of irrigation water applied.

The dependence of crop yields on water supply is a critical issue because of the increasing limited water resources for irrigation. The objectives of this study are to: (i) determine the effect of water stress occurring during the growing season on yield and quality of field grown bell pepper irrigated by a trickle system and (ii) evaluate the water use efficiency of bell pepper (*Capsicum annuum sp.*) in the Mediterranean region of Turkey.

MATERIALS AND METHODS

The field experiment was conducted at Tarsus Research Institute of Village Affairs (37°01'N and 35°01'E and altitude 60.0 m above sea level), in Tarsus, Turkey. Mediterranean climate prevails in the experimental area. *Table 1* summarizes the monthly mean climatic data compared with the long-term mean climatic data for the city of Tarsus. The 2002 growing season temperatures were typical of long-term means at Tarsus. However, the 2002 and 2003 growing season (July-December) rainfalls were less than the long-term mean.

Table 1. monthly mean climatic data compared with the long-term mean climatic data

Climatic Parameters		Months				
		Aug.	Sept.	Oct.	Nov.	Dec.
2002	Mean Maximum Temperature (°C)	32.7	31.7	29.6	23.9	13.9
	Mean Minimum Temperature (°C)	22.0	18.6	13.9	9.6	2.8
	Average Temperature (°C)	26.8	24.5	21.2	16.1	8.2
	Relative humidity, (%)	83.6	78.7	63.8	71.6	73.1
	Precipitation, (mm)	8.8	12.5	3.8	62.7	61.7
2003	Mean Maximum Temperature (°C)	34.3	31.0	28.0	22.8	16.3
	Mean Minimum Temperature (°C)	22.9	18.3	14.9	8.1	5.2
	Average Temperature (°C)	28.2	24.5	21.1	15.0	10.5
	Relative humidity, (%)	81.7	77.0	77.7	68.0	78.1
	Precipitation, (mm)	0.1	60.5	3.6	27.3	92.0
Long Term Means	Mean Maximum Temperature (°C)	32.7	31.6	28.1	22.1	16.2
	Mean Minimum Temperature (°C)	21.7	18.3	13.6	9.1	5.6
	Average Temperature (°C)	26.7	24.1	20.0	14.7	10.3
	Relative humidity, (%)	75.5	68.9	63.9	64.9	72.0
	Precipitation, (mm)	2.3	9.8	36.6	81.7	142.0

The soil of experimental site is classified as Arikli silty-clay-loam with relatively high water holding capacity (Dinç *et al.*, 1990). Some physical and chemical properties of the experimental soil are given in *Table 2*.

Table 2. Some chemical and physical properties of the experimental soil

Soil depth (cm)	Field capacity (g g^{-1})	Wilting point (g g^{-1})	Bulk density (g cm^{-3})	ECe (dS m^{-1})	$CaCO_3$ (%)	Organic matter (%)	pH
0-30	28.95	14.68	1.59	2.15	22.1	2.3	7.7
30-60	32.50	17.14	1.55	1.66	16.4	1.8	7.8
60-90	36.21	19.08	1.51	1.67	19.0	1,11	8.0

Water is obtained from an open channel irrigation system in the experimental area, and its quality is classified as "C_2S_1", and pH is 8.3, and the average electrical conductivity is 0.89 dS m^{-1}.

Commercial farm equipment was used for agronomic practices. Experimental field was planted with double row in a bed spacing of 60 cm and with row spacing of 20 cm on the bed. Four-week old "11-B-14" bell peppers (*Capsicum annuum sp.*) were transplanted on August 02, 2002, and August 01, 2003, respectively on the first and second year of the study.

Fertilizer applications were based on soil analysis recommendations. All treatment plots received the same amount of total fertilizer. A compound fertilizer of (15-15-15) was applied at a rate of 50 kg N per hectare prior to planting on July 29, 2002; The rest of N was applied to the experimental plots in the form of compound fertilizer (18-18-18) at a rate of 30 kg ha^{-1} on August 16, and 50 kg ha^{-1} on September 12, 50 kg ha^{-1} on October 07, 2002. In the second year, a compound fertilizer of (15-15-15) was applied at a rate of 50 kg N per hectare prior to planting on July 15, 2003; The rest of N was applied to the experimental plots in the form of compound fertilizer (18-18-18) at a rate of 30 kg ha^{-1} on August 19, and 50 kg ha^{-1} on September 07, 50 kg ha^{-1} on October 01, 2003.

Yield was determined by hand harvesting the 6 m sections of the three adjacent centre rows in each plot depending on the physiological maturity of plants. The harvest area in each plot was 14.4 m^2 (three rows, each 6 m long). Occurrence of the different phenological growth stages and harvesting time were recorded as number of days after transplanting (DAT) accordingly.

Yield quality parameters such as the first and second quality yields, number of pepper fruit, weight of pepper fruit, bell pepper length and width, plant height and diameter of stem at last harvesting were determined in each harvest period. Peppers are classified in two classes according to the Turkish Standards (TSE, 1974). The first quality peppers should be firm, crisp, smooth fairly well shaped in normal mature green colour, and free from various injuries.

The experimental design was split plots four replications. In this research, three irrigation intervals based on three levels of cumulative pan evaporation values (I_1: 18-22 mm, I_2: 38-42 mm, and I_3: 58-62 mm), and three irrigation levels as plant-pan coefficients (Kcp_1=0.50, Kcp_2=0.75 and Kcp_3=1.00) were evaluated. Main plots and subplots were assigned to cumulative evaporation from Class A Pan (I_1, I_2, and I_3), irrigation levels or plant–pan coefficients (Kcp_1, Kcp_2 and Kcp_3), respectively. Each subplot had dimensions of 8 m long and 5 rows in width. Details of an experimental sub-plot are shown in Fig. 1.

A trickle irrigation system was designed for the experiment. Laterals were laid for each plant row, and inline emitters with discharge rate of 2 L/h were spaced at 20 cm intervals on the lateral line. The system was operated at 100 kPa throughout the growing season. The control unit of the system consisted of a pump, gravel and disk filters, a flow meter, control valves, fertilizer tank, and pressure gauges.

Soil water content was measured at 0.3 m increments down to 0.9 m, using a neutron probe before irrigations throughout the growing season. The access tubes were installed in the centre of the experimental plots. The neutron probe was calibrated against the soil water content determined gravimetrically. Surface soil layer (0-30 cm) was sampled gravimetrically.

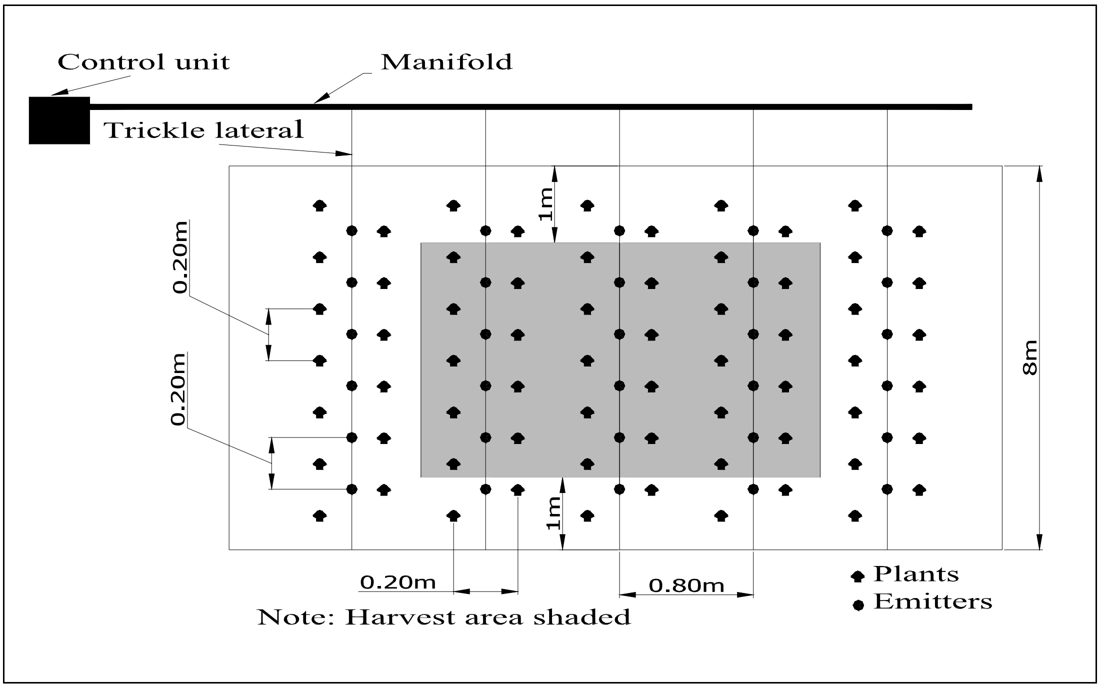

Fig. 1. Details of an experimental sub-plot

Evapotranspiration (ET) was calculated with the water balance equation (Eq. 1) (James, 1988).

$$ET=I+P\pm\Delta SW-Dp-Rf \tag{1}$$

Where;
ET: evapotranspiration (mm),
I: the amount of irrigation water applied (mm),
P: the precipitation (mm), ΔSW changes in the soil water content (mm)
Dp: the deep percolation (mm), and Rf amount of runoff (mm). Since the amount of irrigation water was controlled, deep percolation and run off were assumed to be zero.

The amount of irrigation water was calculated using Eq. (2):

$$I=A\ E_{pan}\ K_{cp} \tag{2}$$

Where;
I is the amount of irrigation water (L)
A: is plot area (m^2)
E_{pan}: is the amount of cumulative evaporation during an irrigation interval (mm)
K_{cp}: is plant-pan coefficient. Class A Pan is located at the meteorological station next to the experimental plots. A totalizing flow meter was installed at the control unit to measure total flow distributed to all replications in each treatment.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated as fresh bell pepper yield divided by seasonal ET and total seasonal irrigation water applied, respectively (Tanner and Sinclair, 1983; Howell *et al.*, 1990).

MSTATC program (Michigan State University) was used to carry out statistical analysis. Treatment means were compared using Duncan’s Multiple Range Test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Applied irrigation water amount (I) and water use (ET)

Table 3 presents the informative data about irrigation treatments. In the first year, in order for good plant stand, a total of 102 mm of irrigation water was applied equally to all treatment plots in seven different applications. On August 16, soil water deficit in the 60 cm profile depth was replenished to the field capacity in all treatments. The first treatment irrigation was applied on August 23, and final application was made on November 30, 2002. Number of irrigations varied from 7 in the lowest frequency (I_3) treatment to 21 in the high frequency treatment (I_1). Total amount of irrigation water applied varied from 296 mm to 489 mm depending on the Kcp coefficients (*Table 3*). Irrigation intervals varied from 3-5 days in I_1, 6-10 days in I_2, and 12-13 days in I_3 treatments in the first year. In the second year, a total of 163 mm of irrigation water was applied equally to all treatment plots in seven different applications. On August 19, soil water deficit in the 60 cm profile depth was replenished to the field capacity in all treatments. The first treatment irrigation was applied on August 22, and final application was made on November 30, 2003. Number of irrigations varied from 7 in the lowest frequency (I_3) treatment to 22 in the high frequency treatment (I_1). Total amount of irrigation water applied varied from 355 mm to 570 mm depending on the Kcp coefficients. Irrigation intervals generally varied from 3 to 6 days in I_1, 6 to 11 days in I_2, and 9 to 15 days in I_3 treatments in the second year.

Table 3. Yield, irrigation, water use and WUE data of bell pepper in different treatments

Years	Treatments	Yield (kg/ha)	Seasonal irrigation (mm)	Water use (mm)	WUE (kg/m^3)	IWUE (kg/m^3)
2002	I_1Kcp_1	28120 (bc)*	295.5	371	7.6	9.5
	I_1Kcp_2	30170 (b)	392.4	465	6.5	7.7
	I_1Kcp_3	33140 (a)	489.0	528	6.3	6.8
	I_2Kcp_1	22290 (d)	293.6	365	6.1	7.6
	I_2Kcp_2	26690 (c)	389.4	455	5.9	6.9
	I_2Kcp_3	26710 (c)	485.1	518	5.2	5.5
	I_3Kcp_1	21620 (d)	295.5	378	5.7	7.3
	I_3Kcp_2	21900 (d)	392.3	463	4.7	5.6
	I_3Kcp_3	25330 (c)	489.0	505	5.0	5.2
2003	I_1Kcp_1	26730 (e)	367.3	360	7.4	7.3
	I_1Kcp_2	32965 (b)	468.6	437	7.5	7.0
	I_1Kcp_3	35298 (a)	570.4	511	6.9	6.2
	I_2Kcp_1	23763 (f)	364.4	313	7.6	6.5
	I_2Kcp_2	30488 (c)	464.7	385	7.9	6.6
	I_2Kcp_3	32958 (b)	565.1	465	7.1	5.8
	I_3Kcp_1	21010 (g)	354.5	309	6.8	5.9
	I_3Kcp_2	26490 (e)	450.3	364	7.3	5.9
	I_3Kcp_3	29593 (d)	545.8	460	6.4	5.4

* Duncan grouping at %1 level

Seasonal water used by bell pepper varied from 365 mm in I_2Kcp_1 to 528 mm in I_1Kcp_3 treatment plots in the 2002 growing season; and 309 mm in I_3Kcp_1 to 511 mm in I_1Kcp_3 treatment plots in the 2003 growing season (*Table 3*). Water use values increased with increasing Kcp coefficient in each irrigation frequency. Üstün et al (1993) reported trickle irrigated bell pepper water use varying from 575 to 663 mm in suggested treatments (6 day irrigation interval and Kcp=0.50) in Central Anatolia of Turkey. Çelik (1991) evaluated the effect of various irrigation regimes on surface-irrigated bell pepper yields in the North-central Anatolia, and reported water use of 825 mm and seasonal irrigation water of 654 mm; and recommended irrigating at 40% of available water in the 90 cm profile depth.

In order to clarify the effects of irrigation on water use, regression analysis was carried out. There was a significant second-degree polynomial relationship between the irrigation water applied and seasonal water use each experimental year (Fig. 2).

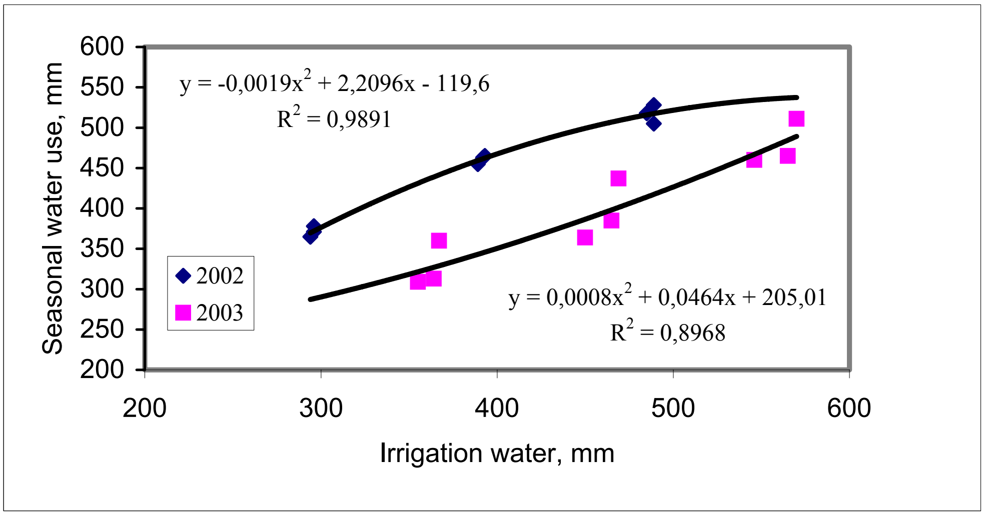

Fig. 2. The relationship between seasonal water use and irrigation water

WUE and IWUE values were significantly influenced by the irrigation intervals and plant-pan coefficients (*Table 3*). WUE values ranged from 4.7 kg m^{-3} in I_3Kcp_2 to 7.6 kg m^{-3} in the I_1Kcp_1 in the 2002 growing season and ranged from 6.4 kg m^{-3} in I_3Kcp_3 to 7.9 kg m^{-3} in the I_2Kcp_2 in the 2003 growing season. IWUE values varied from a minimum of 5.2 kg m^{-3} in I_3Kcp_3 to a maximum of 9.5 kg m^{-3} in I_1Kcp_1 treatment plots in the first experimental year; and varied from a minimum of 5.4 kg m^{-3} in I_3Kcp_3 to a maximum of 7.3 kg m^{-3} in I_1Kcp_1 treatment plots in the second experimental year. IWUE values decreased with increasing irrigation interval at the same Kcp coefficients. Dukes *et al.* (2003) reported IWUE values for trickle irrigated bell pepper ranging from 16.0 to 52.6 kg m^{-3} for marketable yields in Florida, USA.

Yield and some quality parameters

Data on yield and some quality parameters of bell pepper are presented in *Table 4.* A total of 8 picking was done starting from Sept. 16, 2002 ended on Dec. 11, 2002. In the second year, a total of 7 picking was done starting from September 23, 2003 through December 04, 2003.

Both the irrigation frequencies and irrigation levels significantly affected bell pepper yield and some quality parameters (*Table 4*). Highest yield averaging 33140 kg ha^{-1} was obtained in I_1Kcp_3 treatment plots, followed by I_1Kcp_2 plots with 30170 kg ha^{-1} and minimum yield was obtained from the I_3Kcp_1 treatments as 21620 kg ha^{-1} in the 2002 growing season. In the 2003 growing season, maximum and minimum yields were obtained from the same treatments as in the first year. In 2003, highest yield averaging 35298 kg ha^{-1} was obtained in I_1Kcp_3 treatment plots, followed by I_1Kcp_2 plots with 32965 kg ha^{-1} and minimum yield was obtained from the I_3Kcp_1 treatments as 21010 kg ha^{-1}.

Variance analysis of total yield data of 2002 growing season is given in *Table 5.* As the irrigation interval increased (I_3), bell pepper yields decreased significantly. The treatment with largest irrigation interval (I_3) resulted in minimum yields at lower Kcp coefficients (Kcp_1, Kcp_2) along with I_2Kcp_1 treatment. Thus, lower irrigation amounts with longer frequency resulted in significantly reduced yields.

Duncan grouping of pepper yields from the treatments indicated that yield from the most frequently irrigated treatment (I_1) with higher Kcp_3 coefficient was in the first group. As the amount of irrigation water applied decreased yield also decreased. Thus, an irrigation interval of 9-15 days was not suitable with lower Kcp values for drip irrigated bell pepper in the region. Üstün et al (1993) have reported trickle irrigated bell pepper yield varying from 20654 to 26556 kg ha^{-1} in Central Anatolia region of Turkey.

Table 4. Yield and some quality parameters of bell pepper in different treatments

Treat.	First Quality Yield (kg ha^{-1}) (1%)**	Second Quality Yield (kg ha^{-1}) (1%)**	Fruit number, 1000 per ha (1%)**	Mean Fruit weight, g (1%)**	Fruit width, mm (5%)**	Fruit lenght, mm (1%)**	At Harvest	
							Stem diameter, (mm) (1%)*	Plant Height, (cm) (1%)*
				2002				
I_1Kcp_1	21980 (c)	614 0(a)	1067.2 (ab)	26.4 (b)	42 (b)	66 (de)	101 (b)	44 (b)
I_1Kcp_2	2564 0(b)	454 0(b)	1035.3 (b)	29.2 (b)	43 (ab)	69 (ab)	103 (b)	45 (ab)
I_1Kcp_3	28800 (a)	4340 (b)	1098.4 (a)	30.0 (a)	45 (a)	71 (a)	112 (a)	51 (a)
I_2Kcp_1	17610 (d)	4670 (a)	898.3 (cde)	24.8 (b)	41 (b)	64 (e)	97 (b)	43 (b)
I_2Kcp_2	23040 (c)	3650 (b)	937.1 (cd)	28.5 (b)	41 (ab)	67 (cd)	103 (b)	47 (ab)
I_2Kcp_3	22130 (c)	4580 (b)	934.9 (cd)	28.6 (a)	42 (a)	68 (bc)	98 (b)	48 (a)
I_3Kcp_1	16710 (d)	4920 (a)	869.7 (e)	24.9 (b)	40 (b)	64 (e)	97 (b)	43 (b)
I_3Kcp_2	17910 (d)	3990 (b)	811.8 (f)	26.9 (b)	40 (ab)	66 (de)	103 (b)	46 (ab)
I_3Kcp_3	20980 (c)	4350 (b)	886.0 (de)	28.6 (a)	41 (a)	68 (bc)	95 (b)	48 (a)
				2003				
I_1Kcp_1	19920 (g)	6815 (a)	974.8 (b)	27.4 (e)	42.3(cde)	61 (c)	103 (de)	51 (c)
I_1Kcp_2	26910 (c)	5948 (b)	1149.5 (a)	31.1 (b)	45.0 (ab)	65 (b)	107 (cd)	57 (b)
I_1Kcp_3	30830 (a)	4468 (d)	1091.3 (a)	32.4 (a)	46.0 (a)	68 (a)	120 (a)	65 (a)
I_2Kcp_1	16480 (h)	7285 (a)	879.3 (b)	27.0 (e)	41.5 (de)	59 (c)	107 (cd)	50 (c)
I_2Kcp_2	24600 (d)	5890 (b)	1003.3 (a)	30.4 (bc)	43.5 (bc)	65 (b)	109 (c)	56 (b)
I_2Kcp_3	27780 (b)	5178 (c)	1050.5 (a)	31.4 (ab)	44.5 (ab)	67 (a)	114 (b)	63 (a)
I_3Kcp_1	14830 (i)	6180 (b)	831.5 (b)	25.3 (f)	40.8 (e)	60 (c)	100 (e)	49 (c)
I_3Kcp_2	20930 (f)	5563 (bc)	929.5 (a)	28.5 (d)	42.5 (cd)	64 (b)	101 (e)	52 (b)
I_3Kcp_3	23860(e)	5230 (c)	1006.3 (a)	29.4 (cd)	43.5 (bc)	65 (a)	102 (e)	58 (a)

Letters indicate significant differences at *P<0.05 and **P<0.01

Table 5. Analysis of variance table for total yield from different treatments (2002)

Variation source	d.f.	Sum of Squares	Mean Square	F value	Table F 0.01
Replication (R)	3	33137386.1	11045795.4	4.6594	9.78
I	2	357768088.9	178884044.4	75.4582**	10.92
Error (I)	6	14223822.2	2370637.0		
Kcp	2	87866155.6	43933077.8	23.4589**	6.01
I * Kcp	4	49051377.8	12262844.4	6.5480**	4.58
Error (Kcp)	18	33709866.7	1872770.4		
Total	35	575756697.2			

d.f.: Degrees of freedom
**P<0.01

Water–yield relationships

The relationships between irrigation water and yield of bell pepper are best described by a quadratic function each irrigation frequency for the first and second experimental years (Figs 3a-b).

There were second-degree polynomial relationships between seasonal water use (ET) and yield of bell pepper in each experimental year (Figs 4a-b). Regression equations fit for seasonal water use (ET) versus yields showed the same increase in ET would induce a different improvement on bell pepper yields for different irrigation intervals.

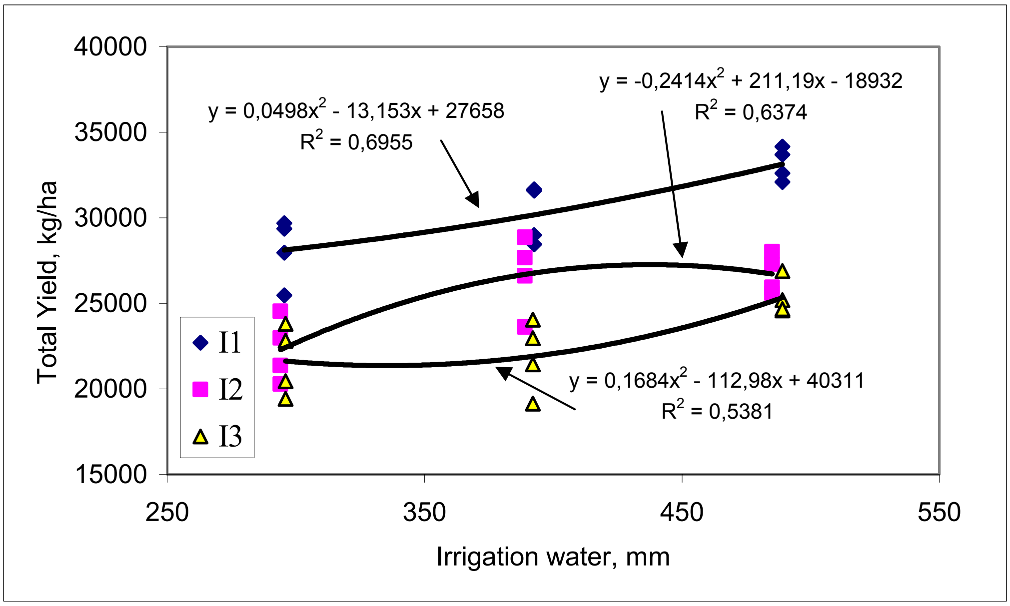

Fig. 3a. The relationship between seasonal irrigation water (I) and total yield (Y) for all irrigation frequencies (2002)

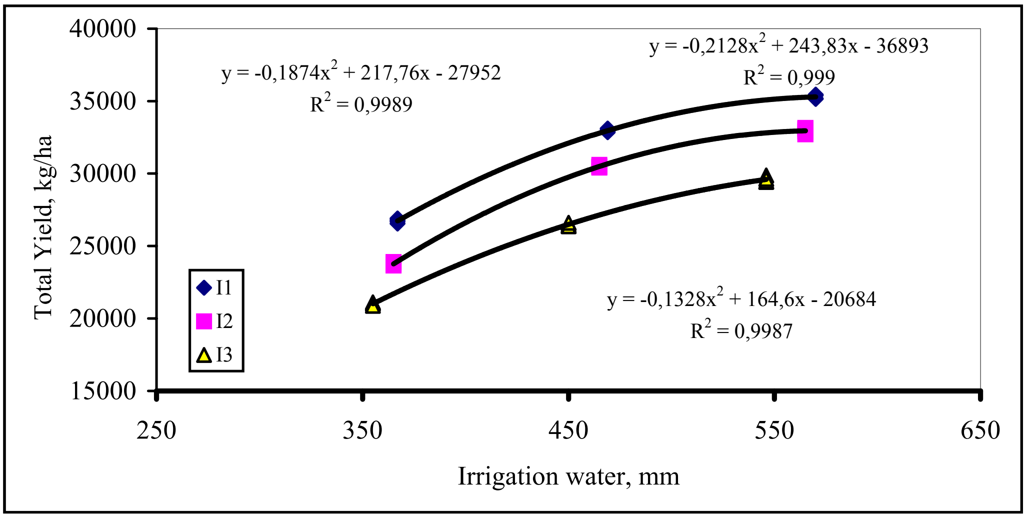

Fig. 3b. The relationship between seasonal irrigation water (I) and total yield (Y) for all irrigation frequencies (2002)

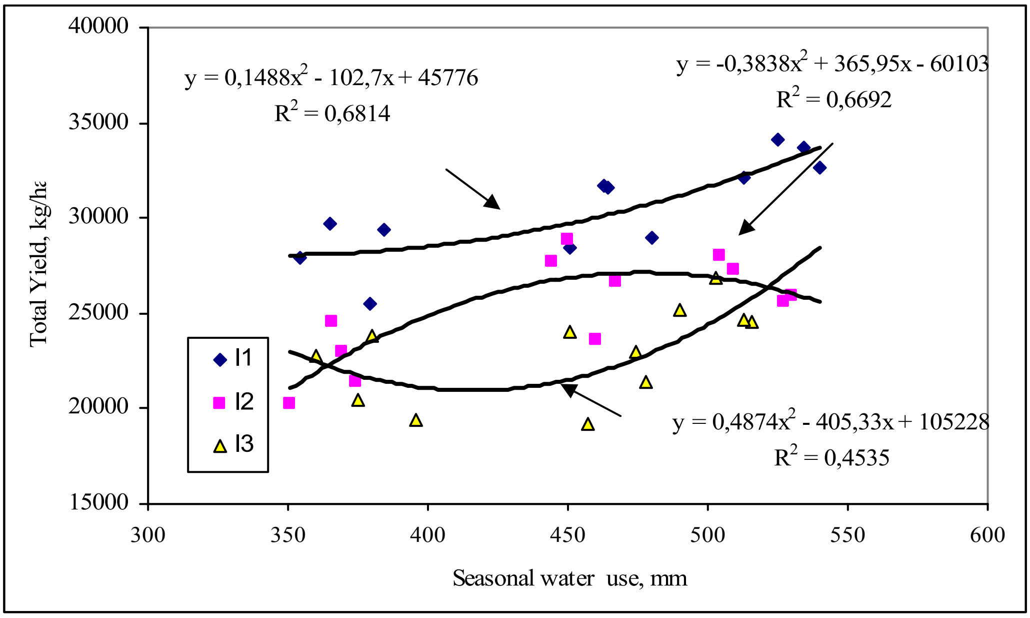

Fig. 4a. The relationship between seasonal water use (ET) and total yield (Y) for all irrigation frequencies (2002)

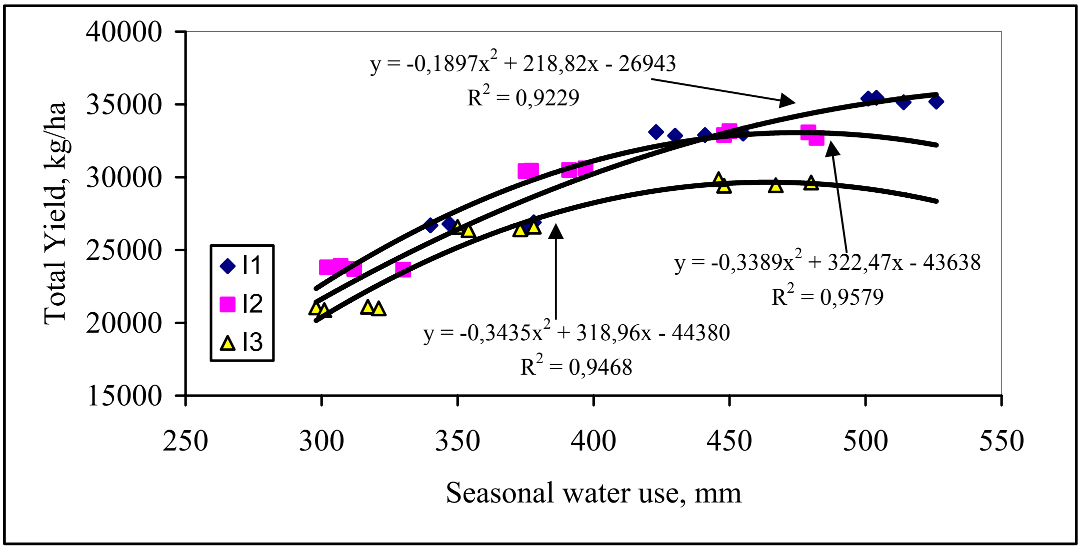

Fig. 4b. The relationship between seasonal water use (ET) and total yield (Y) for all irrigation frequencies (2003)

Fruit quality

First and second quality yield

Some bell pepper quality data in relation to different treatments are presented in the *Table 4*. I_1Kcp_3 treatment resulted in the significantly higher first quality peppers in both experimental years. Minimum first quality yields were obtained from the low frequency treatments (I_3) at lower Kcp values along with I_2Kcp_1 treatment in the first year. In the second year, I_3Kcp_1 resulted in the minimum first quality yield. Water stress reduced first quality pepper yield significantly. Thus, higher frequency and higher Kcp coefficients improve the first quality yield amounts. Treatments with Kcp_1 coefficient at each irrigation interval generally resulted in highest second quality yields.

Fruit number

Highest fruit number was obtained from the I_1Kcp_3 treatment in the first year; and Kcp_2 and Kcp_3 coefficients resulted in the higher fruit number in each irrigation interval in the second year as shown in *Table 4*. Increase in fruit number is the most important factor in yield increase. Moreover, a uniform supply of soil water throughout the growing season is needed to prevent poor fruit size and shape and to increase yield.

Fruit weight

In the first year, Kcp_3 coefficient in each irrigation interval resulted in highest mean fruit weight; and in the second year, highest mean fruit weight was obtained from the I_1Kcp_3 treatment (*Table 4*). Fruit weight is closely associated with a lack of soil water in the root zone; when soil water deficit in the root zone increases, there is a loss in turgidity, and a reduction in growth and fruit weight. Similar results were obtained by Smittle *et al.* (1994) in bell pepper grown at water stress.

Fruit width

Effects of treatments on fruit width were similar to those for the fruit weight. In the first year, Kcp_3 coefficient in each irrigation interval resulted in highest mean fruit width; and in the second year, highest mean fruit width was obtained from the I_1Kcp_3 treatment (*Table 4*). The results revealed that water stress reduced the fruit width in this study.

Fruit length

Highest mean fruit length was obtained from the I_1Kcp_3 treatment in 2002 growing season; and Kcp_3 coefficient in each irrigation interval resulted in highest mean fruit length in 2003 growing season (*Table 4*). The results indicated that higher the Kcp coefficient (Kcp_3), higher is the fruit length.

Stem Diameter

Largest mean stem diameters were measured in the I_1Kcp_3 treatment in both experimental years. The rest of the treatments resulted in lower stem diameter in the first year, and treatments with largest irrigation interval (I_3) yielded the minimum stem diameters in the second year (*Table 4*).

Plant Height

Plant height values in different treatments at harvest varied from 43 to 51 cm in the first year; and from 51 to 65 cm in the second year. Kcp_3 coefficient resulted in the highest plant height in each irrigation interval in both experimental years. As the amount of irrigation water applied decreased (lower Kcp) plant height decreased significantly.

Growth stages of bell pepper

Time to transplanting, occurrence of the different growth stages and harvesting time were recorded as number of days after transplanting (DAT). For the suggested treatment (I_1Kcp_3), dates of occurrence of growth stages were given in *Table 6*. The total length of growing season of bell pepper was 131 days in 2002, and 125 days in 2003 growing season. Çelik (1991) has determined the length of the pepper growing season as 125 days in North central Anatolia.

Table 6. Growth stages of bell pepper in the I_1Kcp_3 treatment in the experimental years

Growth stages of bell pepper	2002		2003	
	Date	DAT*	Date	DAT
Planting	02.08.2002	0	01.08.2003	0
First flowering	12.08.2002	10	14.08.2003	13
Fruit setting	19.08.2003	17	21.08.2003	20
%50 flowering	02.09.2002	31	02.09.2003	32
First harvesting	16.09.2003	45	23.09.2003	53
Last harvesting	11.12.2002	131	04.12.2003	125

*DAT: days after transplanting

There was no difference among the plants in each treatment until vegetative stage. After the vegetative stage, occurrence of flowering, first fruit set, and 50% flowering stages of bell pepper were observed at an earlier date in the lower irrigation frequencies (I_2 and I_3) than the higher irrigation frequency (I_1), and in deficit irrigation treatments (Kcp_1 and Kcp_2) as compared to and unstressed treatment (Kcp_3) in both experimental years. The reason for this was treatments received different irrigation amounts at different intervals. The first harvest was made on DAT 45 and final picking was made on DAT 131 in 2002; and the corresponding figures for the second year were DAT 53 and DAT 118, respectively.

Soil water content variations

Water management of bell pepper is extremely important at all stages of plant development due to its influence on stand establishment, fungal problems, and fruit set and quality. Profile soil water storage variations during the 2002 and 2003 growing seasons for each irrigation frequency are shown in Fig. 5a-c and 6a-c, respectively. As shown in these figures, soil water contents in the 0.60 m soil depth were kept fairly constant until 18-19 days after transplanting (DAT) on which 0.60 m depth was replenished to field capacity in all treatments, then treatment irrigations commenced on 16.08.2002, and 19.08.2003.

Soil water contents in the 0.60 m profile decreased gradually from DAT 20 until 65 DAT then started to increase slightly until harvest period in all treatments in both growing seasons. Available soil water in Kcp_2 and Kcp_3 treatment plots remained above 50% throughout the growing season except I_3 treatment. On the other hand, almost all Kcp plots in I_3 treatment, available water fell below 50% after 25 DAT during the growing season and resulted in both lower yield and quality due to water stress occurring prior to flowering. The period at the beginning of the flowering period is most sensitive to water shortage and soil water depletion in the root zone during this period should not exceed 25 % percent. Water shortage just prior and during early flowering reduces the number of fruits (Doorenbos and Kassam, 1986). Jones et al (2000) stated that water deficit during this period will have the greatest negative impact on yield and quality. Optimum soil water content during flowering was at 65-80 % of the available water and that either higher or lower water content resulted in sub - optimal fruit yields.

In the high frequency treatment plots (I_1), soil water contents remained fairly high as compared to lower frequency irrigation treatments. For high yields, an adequate water supply and relatively moist soils are required during the total growing period. Reduction in water supply during the growing period in general has adverse effect on yield and the greatest reduction in yield occurs when there is a continuous water shortage until the time of first picking. Water stress in peppers also causes fruit drop, sun scalding and blossom end rot. Soil water should be maintained between 65 and 80 percent of field capacity (Jones *et al.*, 2000).

Thus, water stress gradually increased in the lower frequency irrigation treatments, and reduced fruit yield significantly. Higher frequency irrigation with high Kcp values created favourable soil water environment for bell pepper growth and resulted in higher yields.

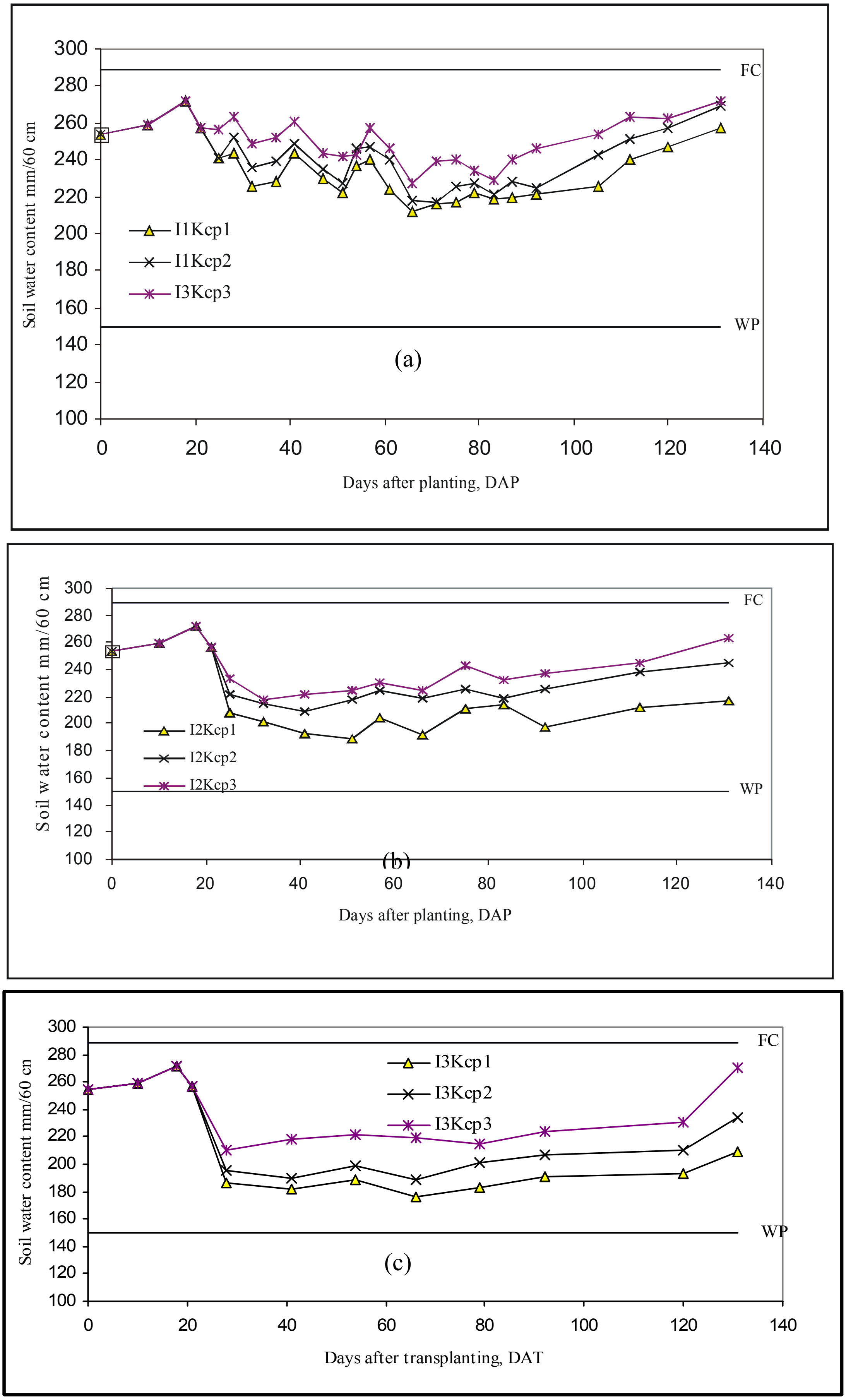

Fig. 5a-c. Soil water storage variation during 2002 the growing season in all treatments

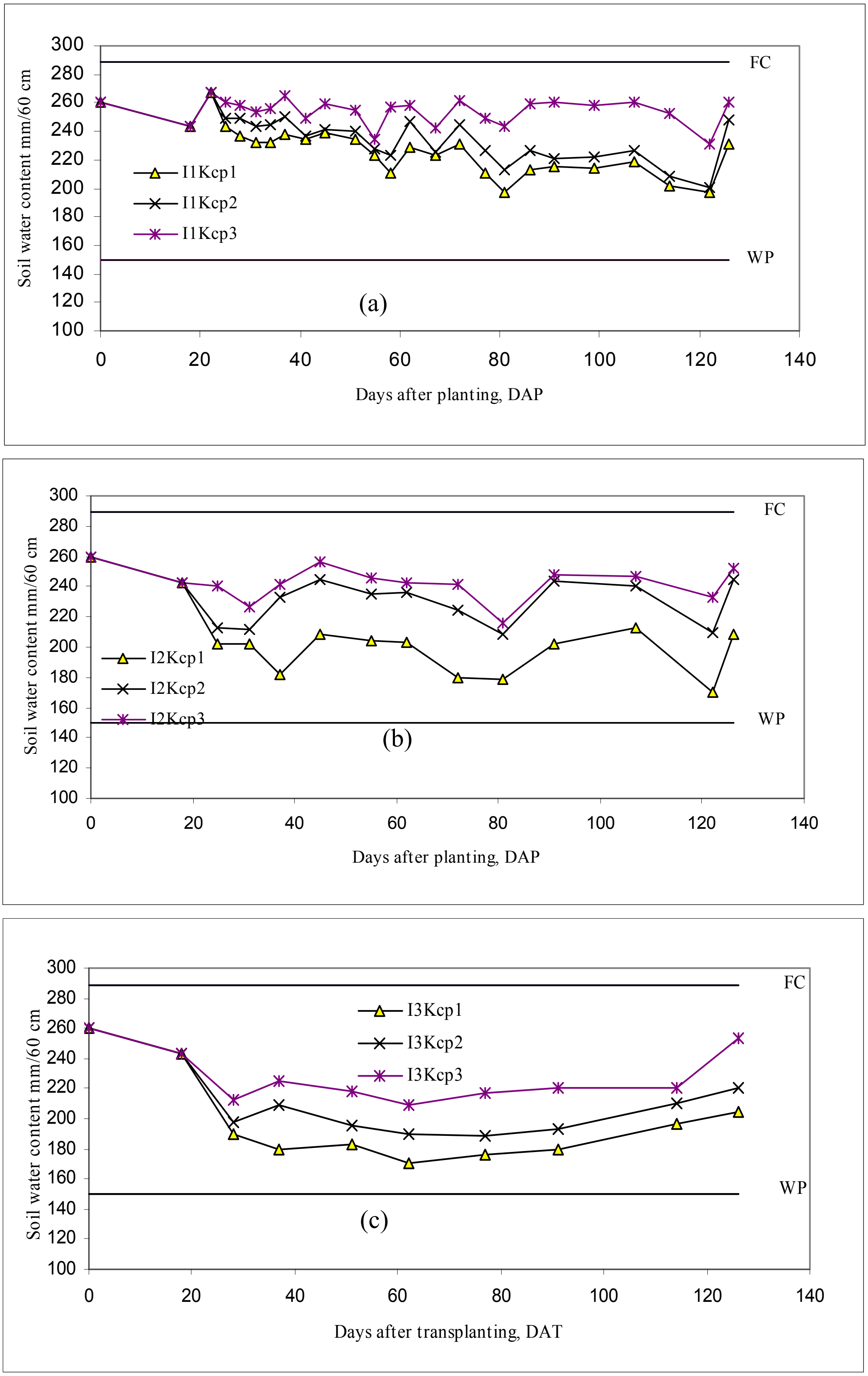

Fig. 6a-c. Soil water storage variation during 2003 the growing season in all treatments

CONCLUSIONS

In this study, our results demonstrate that the effects of irrigation water amount, and irrigation frequency and water use are significantly important in order to obtain higher yields of field grown bell pepper under the Mediterranean climatic conditions in Turkey. Irrigation intervals and plant-pan coefficients had significant effect on yield and quality of bell pepper at P<0.01 levels The maximum yield of 33140 kg ha^{-1} in 2002 and 35298 kg ha^{-1} in 2003 growing season was obtained from I_1Kcp_3 treatment, which had the highest water use. Moreover, I_1Kcp_3 treatment resulted in better quality than as compared to other treatments, because higher frequency (3-6 days) and higher Kcp (Kcp=1.0) positively affected quality parameters. Therefore, higher and better quality bell pepper yield was obtained from the I_1Kcp_3 treatment plots.

The results indicated that WUE and IWUE values decreased with increasing irrigation interval. Higher WUE and IWUE were obtained with lowest Kcp coefficient in each irrigation interval. However, lowest Kcp coefficients resulted in lower total yield and lower quality. Thus, it is not recommended to use less frequent irrigation with low Kcp coefficients for trickle irrigated bell pepper production in the region.

In our study, significant second degree polynomial relationships between bell pepper yield and seasonal water consumption were found for each irrigation frequency in both experimental years. Irrigation intervals resulted in similar seasonal water use in the treatments with the same Kcp value.

CONCLUSION

I_1Kcp_3 treatment (3-6 days irrigation interval and Kcp=1.0) is recommended for drip irrigated bell pepper grown under field conditions in order to obtain higher and better quality yield in the Mediterranean region of Turkey. Moreover, generative growth parameters beside vegetative ones were best in the I_1Kcp_3 treatment because higher irrigation water amount and plant water consumption positively affected pepper quality parameters such as the fruit width, length, number of fruits and fruit weight; therefore more abundant and better quality pepper were obtained in this treatment. However, evapotranspiration of the bell pepper is smaller than evaporation from Class A Pan in the early growing stage and late growing stage, thus lower Kcp values should be used instead of Kcp_3 in order for saving water. Considering the IWUE and WUE, I_1Kcp_2 irrigation regime can be recommended in case of water shortage.

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