HortScience 46(1):102–107. 2011.

Determination of Irrigation Water Amount and Interval for Carnation (*Dianthus caryophyllus* L.) with Pan Evaporation Method

Yusuf Ucar[1]
Suleyman Demirel University, Faculty of Agriculture, Agricultural Structures and Irrigation Department, 32260 Isparta, Turkey

Soner Kazaz
Suleyman Demirel University, Faculty of Agriculture, Horticuture Department, 32260 Isparta, Turkey

Mehmet Atilla Askin
Suleyman Demirel University, Faculty of Agriculture, Horticulture Department, 32260 Isparta, Turkey

Köksal Aydinsakir
Batı Akdeniz Agricultural Research Institute, 07100 Antalya, Turkey

Abdullah Kadayifci
Suleyman Demirel University, Technical Education Faculty, Department of Structure Education, 32260 Isparta, Turkey

Ulas Senyigit
Suleyman Demirel University, Faculty of Agriculture, Agricultural Structures and Irrigation Department, 32260 Isparta, Turkey

Additional index words. evapotranspiration, irrigation interval, water use efficiency, class A pan, yield response factor

***Abstract*. This study was carried out to determine the optimum irrigation water amount and interval for carnation plants (*Dianthus caryophyllus* L.) using the pan evaporation method. The values of class A pan, located inside the greenhouse, were used to determine the irrigation water amount. Irrigation treatments consisted of three irrigation intervals (I1: 1-, I2: 2-, and I3: 3-day) and five crop-pan coefficients (k_{cp}1: 0.25, k_{cp}2: 0.50, k_{cp}3: 0.75, k_{cp}4: 1.00, and k_{cp}5: 1.25). Irrigation water amounts applied to the experimental treatments ranged from 218 to 786 mm; seasonal evapotranspiration ranged from 219 to 601 mm and the yield acquired from the treatments ranged from 10 to 89.82 stems/m². The highest yield was obtained from I1k_{cp}4 (89.56 stems/m²) followed by I1k_{cp}5 (82.89 stems/m²) and I1k_{cp}3 (82.22 stems/m²). The seasonal yield response factor (k_y) was calculated to be 0.73, 1.00, and 1.42 in I1, I2, and I3, respectively. Significant relationships were obtained between yield and irrigation water (R^2 = 0.998) and evapotranspiration (R^2 = 0.993) in the I1 treatments, in which the highest yield was found. In carnation cultivation under greenhouse conditions, it was proposed to apply irrigation water with 1-day intervals under a crop-pan coefficient of k_{cp}4.**

The production area of ornamental plants in Turkey is 2500 ha, and cut flower production is carried out in 1199 ha (48%) of this area. Carnation is the primary cut flower crop with its production area of 514 ha (43%) among cut flower species in Turkey (T.C. Tarım ve Köy İşleri Bakanlığı, 2009). Carnation (*Dianthus caryophyllus* L.) is a native of the Mediterranean area, which includes Turkey (Besemer, 1980; Whealy, 1992). Both suitable climate structure and affordable labor in this region provide important advantages for Turkey in carnation cultivation. Suitable climate conditions provide an opportunity for carnation cultivation year-round in the Western Mediterranean Region of Turkey. Located in this region, Antalya in winter months and Isparta in summer months are important centers of carnation production.

In carnation cultivation, irrigation water amount and irrigation interval vary with soil texture, photoperiod, air temperature and humidity, air movement, the mass of the plants relative to loss of water by transpiration, and variety as well as growth stage of the plant. In general, soil must always be kept moist for good-quality carnations (Besemer, 1980; Laurie et al., 1969). Various researchers reported that when water deficiency was applied to carnation, the parameters of yield and quality were negatively affected (Baas et al., 1995; Farina and Cervelli, 1994; Konishi, 1978; Taylor et al., 2004).

Isparta has a semiarid climate characteristic with its annual rainfall of 524 mm. To obtain both efficient water use and maximum products in semiarid climate regions, research must be conducted on irrigation scheduling of the cultivated plants and water yield relationships must be determined. The data to be obtained might contribute significantly to water users in decision-making. Because it is simple and easy to apply, the pan evaporation method is a commonly used method for the irrigation scheduling of plants (Elliades, 1988; Wang et al., 2009). Studies have shown that there is a close correlation between evapotranspiration and pan evaporation. Therefore, the pan evaporation method is reported to be practicable for farmers in irrigation scheduling (Kanber, 1984).

The aim of this study was to determine the effects of different irrigation intervals and k_{cp} on the yield and evapotranspiration of carnation plants and to choose the most suitable irrigation schedule for carnation plants grown under the greenhouse conditions by using pan evaporation and related crop-pan coefficients.

Materials and Methods

The research was conducted in a polyethylene-covered greenhouse located at the Agricultural Research and Application Center of Agricultural Faculty at Suleyman Demirel University (lat. 37.83° N, long. 30.53° E, altitude 1.020 m) in Isparta, Turkey. Some characteristics of greenhouse soil (in 0- to 20-cm depth) were as follows: texture: clay-loam; bulk density: 1.31 g·cm^{-3}; field capacity: 18.10%; permanent wilting point: 7.43%; EC: 0.11 mS·cm^{-1}; pH: 7.85; $CaCO_3$: 30.12%; and organic matter: 3.45%. When the average values of the climatic parameters in the research area were considered, temperature, relative humidity, wind speed, sunshine duration, and total rainfall were 11.97 °C, 61.1%, 1.97 m·s^{-1}, 7.4 h, and 524 mm, respectively (T.C. Meteoroloji Genel Müdürlüğü, 2007).

Rooted cuttings of carnation (*Dianthus caryophyllus* cv. Turbo, which is a standard type) were planted into plots (1.25-m length, 1.00-m width) with four rows (12.5 × 20-cm spacing, 32 plants/m²) on 1 June 2007, and each plot contained 40 plants. For 20 d after planting (DAP), the depth of water evaporating from class A pan (CAP) was applied as irrigation water in all treatments to increase the survival rate of the plants. Application of irrigation treatments was started after pinching. Plants were single-pinched above the fifth leaf pair from the bottom (Kazaz et al., 2009; Whealy, 1992).

The treatments consisted of three different irrigation intervals (I1: 1-d, I2: 2-d, I3:

Received for publication 27 July 2010. Accepted for publication 13 Nov. 2010.
This study was supported by Suleyman Demirel University, Unit of Scientific Research Projects (Project No. SDU-BAP 1326-M-06).
[1]To whom reprint requests should be addressed; e-mail yucar@ziraat.sdu.edu.tr.

3-d) and five different crop-pan coefficients ($k_{cp}1$: 0.25, $k_{cp}2$: 0.50, $k_{cp}3$: 0.75, $k_{cp}4$: 1.00, and $k_{cp}5$: 1.25). They were arranged according to split-split plots experimental design with three replications. Water and nutrients were supplied using an automatically controlled fertigation computer (Spagnol Ltd., Vidor, Italy). The composition of nutrient solution (ppm) is as follows: nitrogen: 160, phosphorus: 46, potassium: 224, calcium: 140, magnesium: 18, iron: 1.95, manganese: 0.41, zinc: 0.19, boron: 0.21. The target pH and electrical conductivity (EC) values were 5.5 and 1.7 $mS \cdot cm^{-1}$ (Kazaz et al., 2009).

Irrigation treatments were based on the evaporation data (E_p, mm) obtained from a CAP located inside the greenhouse (Doorenbos and Pruitt, 1977). Irrigation water amount was calculated using Eq. [1] (Kanber, 1984).

$$I = A \times E_p \times k_{cp} \times P \qquad [1]$$

where I is the irrigation water amount (L), A the plot area (m^2), E_p the cumulative evaporation in the irrigation intervals (CAP, mm), k_{cp} the crop-pan coefficient, and P the percentage of wetted area (%).

Irrigation water was applied to the experimental plots using a drip irrigation method. Laterals with a diameter of 16 mm, a dripper spacing of 20 cm, and a discharge of 2 $L \cdot h^{-1}$ per dripper at 0.1 Mpa were used. Arrangement was made in such a way that each lateral tube irrigated one plant row. Because plant row spacing was equal to dripper spacing (20 cm), the percentage of the area wetted (P) was taken as 100% in the application of irrigation water (Keller and Bliesner, 1990). Irrigation water with EC and sodium absorption ratio being 0.73 $mS \cdot cm^{-1}$ and 0.05, respectively, was obtained from the groundwater.

To monitor soil moisture change in the root zone of plants, a tensiometer (Soilspec H&TS Electronics Pty. Ltd., Melbourne, Australia) was installed into 20-cm depth of each plot, and the tensiometer was read before each irrigation application. To express soil moisture in millimeters, a calibration curve was created according to the soil characteristics, and the calibration curve equation was calculated as

Table 1. Average monthly values of some climatic parameters in greenhouse inside and outside.

	Inside			Outside		
Month	T^z (°C)	RH^y (%)	$E_p{}^x$ (mm)	T (°C)	RH (%)	SR^w ($W \cdot m^{-2}$)
June	23	54	5	20	52	524
July	25	42	6	22	36	560
August	25	48	4	23	44	523
September	19	48	3	17	45	487
October	15	62	2	13	61	304
November	13	75	1	11	77	197

[z]Temperature.
[y]Relative humidity.
[x]Evaporation from class A pan.
[w]Solar radiation.

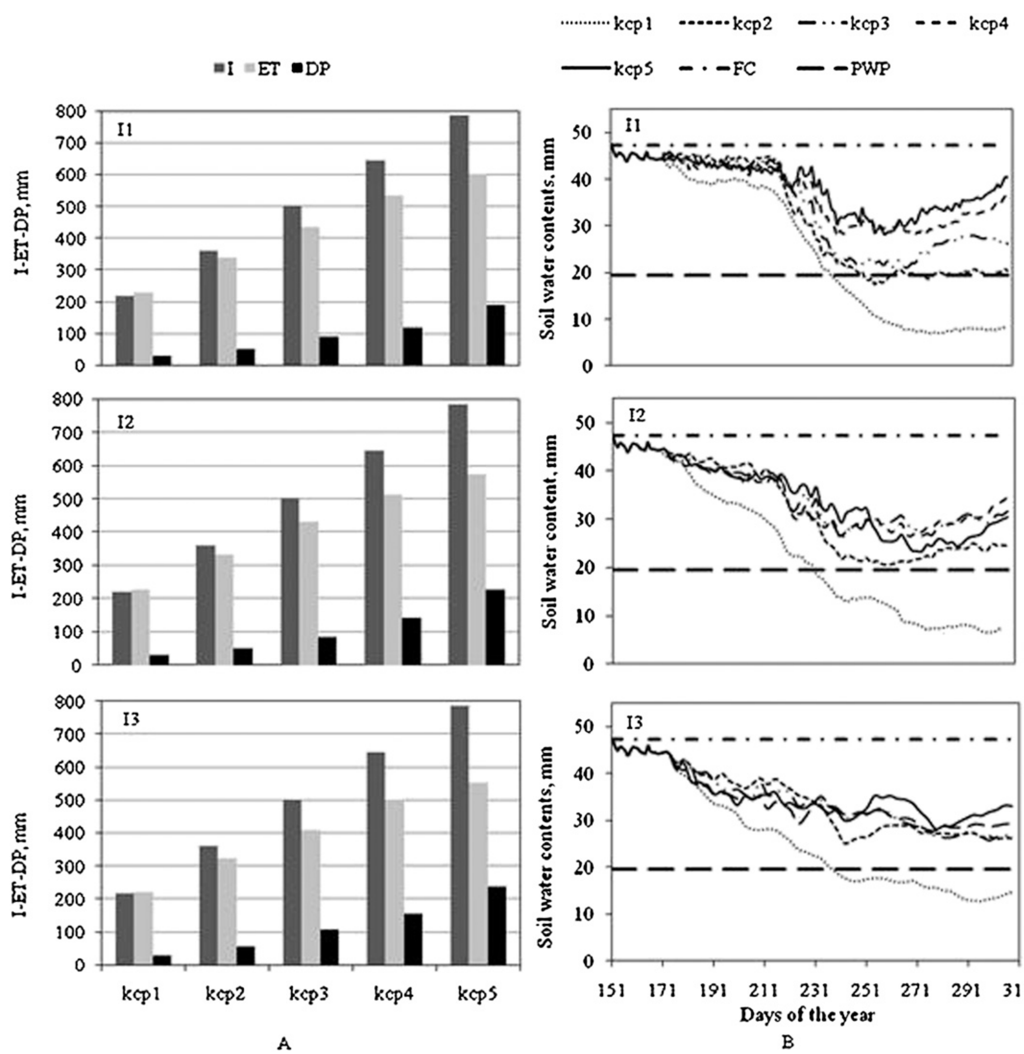

Fig. 1. (**A**) Total irrigation water amounts (I), evapotranspirations (ET), and deep percolation (DP). I1 = irrigation interval 1-d; I2 = irrigation interval 2-d; I3 = irrigation interval 3-d. $k_{cp}1$ = 0.25; $k_{cp}2$ = 0.50; $k_{cp}3$ = 0.75; $k_{cp}4$ = 1.00; and $k_{cp}5$ = 1.25; crop-pan coefficients. (**B**) Soil water contents; FC = field capacity; PWP = permanent wilting point.

$d = 31.38 \times kPa^{-0.19}$ ($R^2 = 0.953$) (d: soil moisture, mm; kPa: tensiometer readings). In those periods when no reading could be performed using a tensiometer, the soil moisture was determined with the gravimetric method.

Evapotranspiration (ET) was determined using Eq. [2] according to the principle of water balance (Allen et al., 1998).

$$ET = I + P \pm DSW - DP - RO \qquad [2]$$

where ET is the evapotranspiration (mm), I the irrigation water (mm), P the precipitation (mm), DSW the change in the soil water storage (mm), DP the deep percolation (mm), and RO the amount of runoff (mm). Runoff and precipitation were assumed to be zero. In the event that the sum of soil moisture and irrigation water amount was above the field capacity after irrigation applications, this surplus was considered as deep percolation.

The yield response factor, k_y, was determined according to the Stewart model (Doorenbos and Kassam, 1979):

$$k_y = [1-(Y_a/Y_m)]/[1-(ET_a/ET_m)] \qquad [3]$$

where Y_a is the actual crop yield (stems/m^2), Y_m the maximum crop yield without water stress (stems/m^2), ET_a the actual evapotranspiration (mm/period), ET_m the maximum evapotranspiration without water stress (mm/period) corresponding to Y_m, $1-(Y_a/Y_m)$ the relative yield decrease, and $1-(Et_a/ET_m)$ the relative evapotranspiration deficit.

Eqs. [4] and [5], given by Howell et al. (1990), were used to determine water use efficiencies.

$$WUE = (E_y/ET) \times 100 \qquad [4]$$

$$IWUE = (E_y/I) \times 100 \qquad [5]$$

where WUE is the water use efficiency, IWUE the irrigation water use efficiency, ET the evapotranspiration (mm), I the irrigation water (mm), and E_y the economical yield (stems/m^2). Instead of economical yield, the yield obtained directly per square meter was used in the calculations.

Carnation harvest was started 96 DAP, and flowers were harvested 12 times during the study. Harvesting was performed above the second node from the base when flowers were fully open (Kazaz et al., 2009). Data were subject to analysis of variance using MINITAB software (Minitab Inc., State College, PA), and the mean values were compared using the least significant difference ($P \leq 0.05$) test.

Result and Discussion

Temperature in greenhouse. Temperature is one of the important factors that affect growth of carnation and the shapes of flower, leaf, and stem. Average monthly values of some climatic parameters in greenhouse inside and outside are presented in Table 1. Throughout the vegetation period in the greenhouse, the mean daily air temperature ranged from 10 to 29 °C, and the lowest temperature averages were in October and November. Optimum cultivation temperatures for carnation should range from 10 to 14 °C at night and from 15 to 20 °C during the day (Bunt and Cockshull, 1985; Laurie et al., 1969; Yamaguchi, 1994); thus, suitable temperatures took place in the greenhouse during the growth period.

Evapotranspiration and irrigation water amount. Rooted cuttings wilt easily immediately after planting. For successful cultivation, it is quite important to prevent the cuttings from wilting and drying out within the first 2 weeks after planting (Besemer, 1980; HilverdaKooij Plant Technology, 2010). Therefore, irrigation schedules were started 20 DAP. Within this establishment period, the whole evaporation amount (76 mm) was applied to all treatments as irrigation water.

Total irrigation water amount was 218, 360, 502, 644, and 786 mm in $k_{cp}1$, $k_{cp}2$, $k_{cp}3$, $k_{cp}4$, and $k_{cp}5$, respectively. These values were applied to the treatments with 1-, 2-, and 3-d intervals. The deep percolation values ranged from 28 to 191 mm in the I1 treatments, from 29 to 225 mm in the I2 treatments, and from 30 to 239 mm in the I3 treatments (Fig. 1A). Because the root zone soil moisture content + irrigation water amount in the frequently irrigated treatments (I1 and I2) were higher than the field capacity at the beginning of the experiment (in June and July), the deep percolation was also high. Deep percolation of water is further enhanced by the fact that plants consume less water at the beginning of the growth period and a higher

Table 2. Irrigation interval × crop-pan coefficient for yield (stems/m^2).

Crop-pan coefficients	Irrigation interval		
	I1[z]	I2[y]	I3[x]
$k_{cp}1$	42.89 f[w]	32.67 h	10.00 i
$k_{cp}2$	68.00 e	43.33 g	36.00 h
$k_{cp}3$	82.22 b	53.56 f	44.67 g
$k_{cp}4$	89.56 a	77.57 b-d	71.33 de
$k_{cp}5$	82.89 b	75.33 cd	79.33 bc

[z]Irrigation interval 1-d.
[y]Irrigation interval 2-d.
[x]Irrigation interval 3-d.
[w]Means followed by the same letter do not differ significantly at $P \leq 0.05$.
$k_{cp}1 = 0.25$; $k_{cp}2 = 0.50$; $k_{cp}3 = 0.75$; $k_{cp}4 = 1.00$; and $k_{cp}5 = 1.25$; crop-pan coefficients.

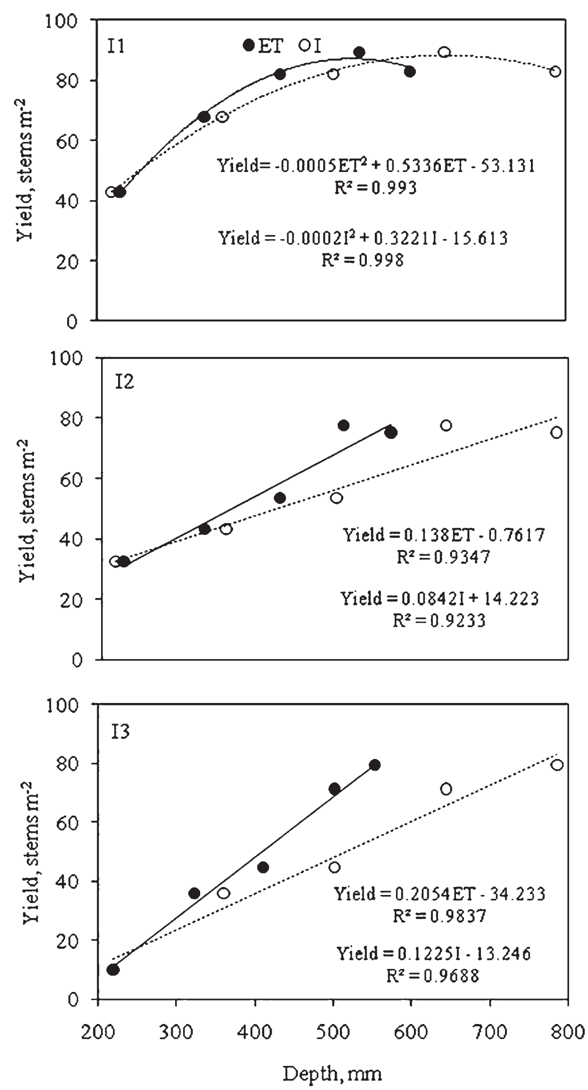

Fig. 2. Relationships between I (irrigation water amount) and yield, evapotranspiration (ET), and yield (I1 = irrigation interval 1-d; I2 = irrigation interval 2-d; I3 = irrigation interval 3-d).

irrigation water amount is applied because evaporation from CAP is high.

ET values differed in both irrigation interval and crop-pan coefficient. The highest ET was measured in I1k_{cp}5 (601 mm), whereas the lowest ET was found in I3k_{cp}1 (219 mm). Generally, the higher the values of crop-pan coefficient were, the larger the ET values became and the greater the irrigation water amount was. Likewise, in treatments with applications of the same irrigation water amount, higher ET values were obtained from those with a low irrigation interval (I1k_{cp}5: 601 mm) than those with a high irrigation interval (I3k_{cp}5: 554 mm). The wet soil surface in the I1 treatments resulting from irrigation everyday caused higher evaporation from the soil surface than those in the I2 and I3, which increased the total ET. These results are in agreement with Meiri et al. (1992), who reported that the more frequently irrigated plants absorbed more water from the soil.

Aydinsakir et al. (2009) reported that the ET value ranged from 501 to 1254 mm in the carnation supplied with irrigation water ranging from 600.1 to 1350.3 mm according to crop-pan coefficients, whereas Konishi (1978) found that the ET value ranged from 375 to 523 mm. Our results are consistent with the mentioned studies.

Soil water content before irrigation. The root zone moisture was close to the field capacity until ≈60 DAP [211 d of the year (DOY)] in all the treatments of I1, 40 DAP (190 DOY) in I2, and 30 DAP (180 DOY) in I3. Thereafter, moisture contents then showed a tendency to decrease in all treatments from the field capacity to the wilting point. Values close to, or lower than, the wilting point, especially regarding the soil moisture values in the k_{cp}1 and k_{cp}2 treatments, were recorded 90 DAP (240 DOY). A dramatic decline was observed in the soil moisture values in the k_{cp}4 and k_{cp}5 treatments of I1 and I2 from the ≈60th day to the 90th day of planting, whereas no steep decline was observed in the same treatments of I3.

The soil moisture values increased in the k_{cp}4 and k_{cp}5 treatments of I1 110 DAP (260 DOY) and in the same treatments of I2 and I3 120 DAP (270 DOY) and 130 DAP (280 DOY), respectively (Fig. 1B). During this period, the ET decreased and, in parallel with it, the root zone moisture content increased upon an increase in the harvested stem number. The gradual decrease in the number of shoots of the plant upon harvesting reduced the total transpiration and, therefore, the ET values.

Water yield relationships. The interaction between irrigation intervals (I1, I2, and I3) and crop-pan coefficients (k_{cp}) was significant in terms of yield. The highest yield was recorded in I1k_{cp}4 (89.56 stems/m^2) followed by I1k_{cp}5 (82.89 stems/m^2) and I1k_{cp}3 (82.22 stems/m^2) (Table 2). The lowest yield was in I3k_{cp}1 (10.00 stems/m^2), and I3k_{cp}1, together with I2k_{cp}1 (32.67 stems/m^2) and I3k_{cp}2 (36.00 stems/m^2), constituted the lowest yield groups. In the I1 and I2 treatments, the highest yield was obtained from k_{cp}4 treatments (I1k_{cp}4: 89.56 stems/m^2, I2k_{cp}4: 77.57 stems/m^2). Yield in k_{cp}4 treatments was higher than in k_{cp}5 (I1k_{cp}5: 82.89 stems/m^2, I2k_{cp}5: 75.33 stems/m^2) treatments, in which a higher irrigation water amount was applied and a higher ET was found. In other words, after a certain amount, water did not have any yield increasing but a yield-reducing effect in I1 and I2. Because carnation is a shallow-rooted plant, its root zone must always be kept moist (Besemer, 1980; Laurie et al., 1969). The I1 treatment irrigated everyday had higher ET values than the treatments that were irrigated at 2- (I2) and 3-d (I3) intervals and had the same k_{cp}. This was because the soil was always kept moist in I1. Likewise, the application of more water to k_{cp}4 and k_{cp}5 with high pan coefficients in I2 and I3 than the other treatments (k_{cp}3, k_{cp}2, and k_{cp}1) had an effect of increasing the ET. The high value of ET positively affected the yield and caused significant differences among the treatments.

In the research, significant quadratic relationships were obtained between ET and yield (R^2 = 0.993) and between irrigation water and yield (R^2 = 0.998) in the treatments with a 1-d irrigation interval (I1). In I2 and I3, significant linear relationships were observed between ET and yield at the levels of R^2 = 0.9347 and R^2 = 0.9837, respectively, and between irrigation water and yield at the levels of R^2 = 0.9233 and R^2 = 0.9688, respectively (Fig. 2). According to many researchers, water–yield relationship might be linear or curvilinear depending on irrigation schedules, soil, and climatic factors (Baştuğ, 1987; Kanber and Derviş, 1978). However, Tsirogiannis et al. (2010) reported that yield and the main quality characteristics (stem length and flower diameter) of gerbera flowers were unaffected by the irrigation frequency.

Our results showed that under the conditions of 1-d and 2-d irrigation intervals (especially in k_{cp}4), maximum yield could be achieved by irrigating as much as evaporation from CAP and that application of more water than this value would not have any effect of increasing the yield, but it would have a yield-decreasing effect. On the other hand, the results revealed that under the condition of a 3-d irrigation interval, it would be necessary to apply 1.25 times more water than the E_p value to obtain the maximum yield.

The yield response factor (k_y) determined between the relative deficit of ET and the relative decrease of yield in the research (Fig. 3) was 0.73 in the I1 treatment, whereas it was 1.00 and 1.42 in I2 and I3, respectively. Accordingly, yield would decrease by 0.73 units in return for a one-unit deficit in water consumption in I1, whereas yield would decrease by 1.00 and 1.42 units in I2 and I3, respectively. According to these data, water deficit should not be applied in the event that a 3-d irrigation interval is preferred, and if water deficit will be applied, it should be done so particularly under the condition of a 1-d irrigation interval.

Water use efficiency and irrigation water use efficiency. The water use efficiency (WUE) values ranged from 0.05 to 0.20 stems/m^2/mm. The highest WUE (0.20 stems/m^2/mm) was recorded in I1k_{cp}2 followed by I1k_{cp}1 and I1k_{cp}3 (0.19 stems/m^2/mm) and the I1k_{cp}4 (0.17 stems/m^2/mm), whereas the lowest WUE value (0.05 stems/m^2/mm) was determined in I3k_{cp}1. Likewise, the irrigation WUE (IWUE) values also ranged from 0.05 to 0.20 stems/m^2/mm. The highest IWUE value was found in I1k_{cp}1 (0.20 stems/m^2/mm) followed by I1k_{cp}2 (0.19 stems/m^2/mm) and I1k_{cp}3 (0.16 stems/m^2/mm), whereas the lowest IWUE value was in I3k_{cp}1 (0.05 stems/m^2/mm) (Table 3). Higher WUE and IWUE values were obtained from the treatments with a low irrigation interval than those with a high irrigation interval. These results are in agreement with Kanber et al. (1991), who reported that higher WUEs could be obtained from the

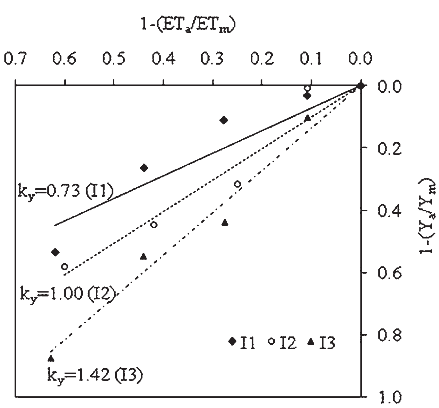

Fig. 3. Yield response factor (k_y) for irrigation interval. I1 = irrigation interval 1-d; I2 = irrigation interval 2-d; I3 = irrigation interval 3-d. Y_a = actual crop yield, stems/m^2; Y_m = maximum crop yield without water stress, stems/m^2; ET_a = actual evapotranspiration, mm/period; ET_m = maximum evapotranspiration without water stress, mm/period. 1-(Y_a/Y_m) the relative yield decrease, and 1-(ET_a/ET_m) the relative evapotranspiration deficit.

Table 3. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) (stems/m^2/mm).

Treatments	I1[z]		I2[y]		I3[x]	
	WUE	IWUE	WUE	IWUE	WUE	IWUE
k_{cp}1	0.19	0.20	0.14	0.15	0.05	0.05
k_{cp}2	0.20	0.19	0.13	0.12	0.11	0.10
k_{cp}3	0.19	0.16	0.12	0.11	0.11	0.09
k_{cp}4	0.17	0.14	0.15	0.12	0.14	0.11
k_{cp}5	0.14	0.11	0.13	0.10	0.14	0.10

[z]Irrigation interval 1-d.
[y]Irrigation interval 2-d.
[x]Irrigation interval 3-d.
k_{cp}1 = 0.25; k_{cp}2 = 0.50; k_{cp}3 = 0.75; k_{cp}4 = 1.00; and k_{cp}5 = 1.25; crop-pan coefficients.

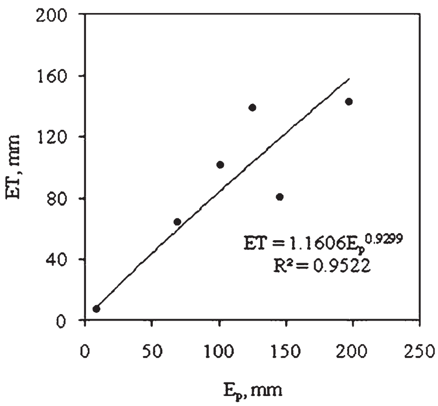

Fig. 4. Relationship between evapotranspiration (ET) and E_p (evaporation from class A pan) according to months in I1k_{cp}4 obtained the highest yield (I1 = irrigation interval 1 d; k_{cp}4 = 1.00, crop-pan coefficient).

treatments with low ET values and irrigation water amounts and with high yield.

Changes in evapotranspiration/evaporation. In irrigation scheduling with class A pan, particular rates of evaporation from CAP are applied as irrigation water. To determine which of these applied rates is/are the closest to ET, it is necessary to determine the relationships between E_p and ET as well as the ET/E_p ratios. In conjunction with the development of ET equations, it is also valuable to compare crop ET with evaporation from a class A pan (Ertek et al., 2006). With this purpose, the relationship between ET and E_p in I1k_{cp}4 produced the highest yield (Fig. 4) and the results concerning the changes in ET/E_p ratios are presented in Figure 5.

The relationship between ET and E_p in I1k_{cp}4, where the highest yield was obtained, has an exponential function (ET = 1.1606$E_p^{0.9299}$, R^2 = 0.9522). Not to have any decrease in yield, I1k_{cp}4, in which the highest yield was obtained, should be used as the irrigation schedule.

With respect to ET/E_p ratios, similar curves were observed in similar treatments. ET/E_p value seasonally ranged from 0.25 to 1.26 in treatments with a 1-d irrigation interval, whereas this value ranged from 0.08 to 1.34 and from 0.12 to 1.24 in treatments with 2- and 3-d irrigation intervals, respectively. The less the irrigation water was applied, the lower the ET/E_p values were determined in treatments. The ET/E_p ratios for all treatments were lower at the beginning, tended to increase rapidly midseason (in August), and then decreased after the first harvest (in September). A significant positive linear correlation was reported between accumulated ET and E_p by many researchers (Dogan et al., 2008; Ertek et al., 2006; Wang et al., 2009; Yuan et al., 2001). Irrigation water amount can be accomplished by inserting the accumulated evaporation of the intervals into the equations. The ratio of ET and E_p changed seasonally during the growing season. ET/E_p ratios were higher in the midseason than in the other growing periods as a result of stem elongation, leaf enlargement, and flowering (Fig. 5). Similar findings were reported by Ertek et al. (2006).

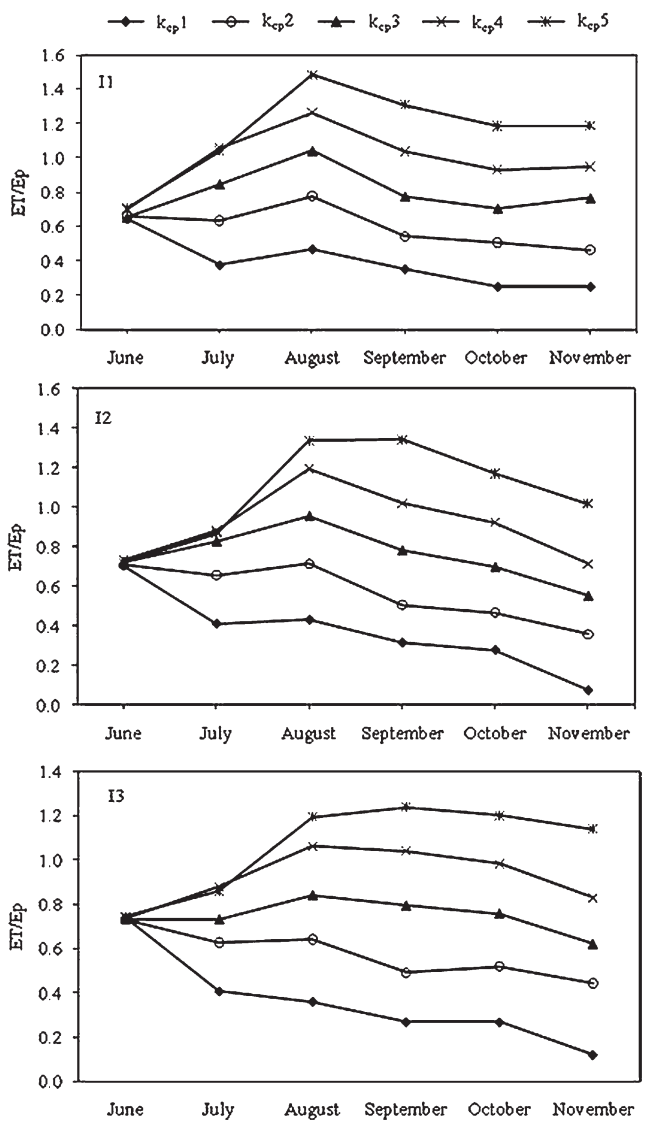

Fig. 5. Changes in ET/E_p during the growth period (k_{cp}1 = 0.25; k_{cp}2 = 0.50; k_{cp}3 = 0.75; k_{cp}4 = 1.00; and k_{cp}5 = 1.25; crop-pan coefficients. ET = evapotranspiration; E_p = evaporation from class A pan).

Conclusion

In our study, maximum yield was obtained from I1k_{cp}4. Therefore, the I1k_{cp}4 treatment (I1: 1-d irrigation interval, k_{cp}:1.00) should be taken as the basis during irrigation scheduling by means of CAP in protected carnation cultivation.

Under this condition, however, deep percolation will be much (119 mm), whereas the IWUE (0.14 stems/m²/mm) value will be less. If deep percolation is intended to be reduced and increased the IWUE value and with respect to efficient water use, it might be more suitable to apply k_{cp}2 until pinching, k_{cp}3 between pinching, and 60 DAP and k_{cp}4 treatments from 60 DAP to the end of the growing season under the condition of a 1-d irrigation interval. In this way, quality flowers can be obtained without any decrease in yield. Furthermore, it may be more convenient not to apply any water deficit based on the crop-pan coefficient or, if water deficit will be applied, it may be more suitable to do so in I1 (k_y = 0.73) with a low k_y value because of the higher k_y values in I2 (k_y = 1.00) and I3 (k_y = 1.42) than that of I1 (k_y = 0.73) and also considering the fact that the carnation plant is quite sensitive to water at these irrigation intervals.

Literature Cited

Allen, R.G., L.S. Pereria, D. Raes, and M. Smith. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrig. and Drain., Paper No. 56. Rome, Italy.

Aydinsakir, K., A. Özçelik, D. Büyüktaş, and I.H. Tüzel. 2009. Quality characteristics of drip irrigated carnation (*Dianthus caryophyllus* L.

cv. 'Eilat') under protected conditions. Acta Hort. 807:307–312.

Baas, R., H.M.C. Nijssen, T.J.M. Van Den Berg, and M.G. Warmenhoven. 1995. Yield and quality of carnation (*Dianthus caryophyllus* L.) and gerbera (*Gerbera jamesonii* L.) in a closed nutrient system as affected by sodium chloride. Sci. Hort. 61:273–284.

Baştuğ, R. 1987. Çukurova koşullarında pamuk bitkisinin su-üretim fonksiyonunun belirlenmesi üzerinde bir çalışma [in Turkish]. PhD diss., Çukuova Univ., Adana, Turkey.

Besemer, S.T. 1980. Carnations. In: Larson, R.A. (ed.). Introduction to floriculture. Academic Press Inc., New York, NY.

Bunt, A.C. and K.E. Cockshull. 1985. *Dianthus caryophyllus*, p. 433–440. In: Halevy, A.H. (ed.). Handbook of flowering. Vol. II. CRC Pres, Boca Raton, FL.

Dogan, E., H. Kirnak, K. Berekatoğlu, L. Bilgel, and A. Surucu. 2008. Water stress imposed on muskmelon (*Cucumis melo* L.) with subsurface and surface drip irrigation systems under semiarid climatic conditions. Irrig. Sci. 26:131–138.

Doorenbos, J. and H. Kassam. 1979. Yield response to water. Irrig. and Drain. Paper No. 33. FAO, Rome, Italy.

Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for predicting crop water requirements. FAO Irrig. and Drain. Paper 24, Rome, Italy.

Elliades, G. 1988. Irrigation of greenhouse-grown cucumbers. J. Hort. Sci. 63:235–239.

Ertek, A., S. Şensoy, İ. Gedik, and C. Küçükyumuk. 2006. Irrigation scheduling based on evaporation values for cucumber (*Cucumis sativus* L.) grown under field conditions. Agr. Water Manage. 81:159–172.

Farina, E. and C. Cervelli. 1994. Growth and water requirements of carnation cultivated in raised benches. Acta Hort. 361:478–485.

HilverdaKooij Plant Technology. 2010. Cultural instructions carnations. 11 Nov. 2010. <http://hilverdakooij.nl/files/download/guides/Spray_carnations_en.pdf/>.

Howell, T.A., R.H. Cuenca, and K.H. Solomon. 1990. Crop yield response. In: Hoffman, et al. (eds.) Management of farm irrigation systems. ASAE.

Kanber, R. 1984. Çukurova koşullarında açık su yüzeyi buharlaşmasından yararlanarak birinci ve ikinci ürün yerfıstığının sulanması [in Turkish]. Bölge Topraksu Araştırma Enstitüsü. Yayınları 114 (64), Tarsus, Turkey.

Kanber, R. and Ö. Derviş. 1978. Çukurova koşullarında pamuk su tüketimi [in Turkish]. Tarsus Bölge Topraksu Araştırma Enstitüsü Müdürlüğü Yayınları. Genel Yayın No. 90, Rapor Yayın No. 40, Tarsus, Turkey.

Kanber, R., O. Tekinel, and N. Baytorun. 1991. Harran ovası koşullarında pamuk sulamasında sulama aralığı ve su tüketiminin belirlenmesinde açık su yüzeyi buharlaşmasından yararlanma olanakları [in Turkish]. T.C. Başbakanlık GAP Kalkınma İdaresi Başkanlığı GAP Yayın No. 44, Adana, Turkey.

Kazaz, S., S. Yılmaz, and B. Sayın. 2009. Comparison of soil and soilless cultivation of carnation in Isparta Province. Acta Hort. 807: 547–552.

Keller, J. and R.D. Bliesner. 1990. Sprink and tricle irrigation. Von Nostrand, New York, NY.

Konishi, K. 1978. Study on the water consumption of greenhouse carnations. J. Jpn. Soc. Hort. Sci. 47:78–86.

Laurie, A., D.C. Kiplinger, and K.S. Nelson. 1969. Carnation, p. 262–282. In: Commercial flower forcing. McGraw-Hill, New York, NY.

Meiri, A., H. Frenkel, and A. Mantell. 1992. Cotton response to water and salinity under sprinkler and drip irrigation. Agron. J. Madision, Wis.: ASA 84:44–50.

Taylor, R.D., B.W.W. Grout, and J. Hill. 2004. Use of a tensiometer-based control system to reduce irrigation of cut flower *Dianthus caryophyllus* santorini whilst maintaining flower yield and quality. Acta Hort. 664:647–652.

T.C. Meteoroloji Genel Müdürlüğü 2007. Isparta Meteoroloji Bölge Müdürlüğü Kayıtları, Isparta, Turkey [in Turkish].

T.C. Tarım ve Köy İşleri Bakanlığı. 2009. Antalya İl Müdürlüğü Kayıtları, Antalya, Turkey [in Turkish].

Tsirogiannis, I., N. Katsoulas, and C. Kittas. 2010. Effect of irrigation scheduling on gerbera flower yield and quality. HortScience 45:265–270.

Wang, Z., Z. Liu, Z. Zhang, and X. Liu. 2009. Subsurface drip irrigation scheduling for cucumber (*Cucumis sativus* L.) grown in solar greenhouse based on 20 cm standard pan evaporation in Northeast China. Sci. Hort. 123: 51–57.

Whealy, A. 1992. Carnations. In: Larson, R.A. (ed.). Introduction to floriculture. 2nd Ed. Academic Press Inc., New York, NY.

Yamaguchi, T. 1994. Carnation. Horticulture in Japan. 1st Ed. Asakura Publishing Co. Ltd., Tokyo, Japan.

Yuan, B., Y. Kang, and S. Nishiyama. 2001. Drip irrigation scheduling for tomatoes in unheated greenhouse. Irrig. Sci. 20:149–154.