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Effect of irrigation frequency and amount on water use efficiency and yield of sesame (*Sesamum indicum* L.) under field conditions

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Abstract

The water-use characteristics of sesame (*Sesamum indicum* L.) were studied in the field under furrow irrigation. Irrigation water quantities were based on pan evaporation (E_{pan}) from a screened class-A pan. Treatments consisted of three irrigation intervals (I_1: 7 days; I_2: 14 days, I_3: 21 days), and four pan coefficients ($K_{cp\ 1}$: 0.60; $K_{cp\ 2}$: 0.80, $K_{cp\ 3}$: 1.00 and $K_{cp\ 4}$: 1.20). Average irrigation values for each treatment varied from 467 to 857 mm in 2003 and 398 to 654 mm in 2004. The highest seasonal evapotranspiration was obtained from the $I_3K_{cp\ 4}$ treatment in 2004 (1019 mm); the lowest value was observed in the $I_1K_{cp\ 1}$ treatment in the same year (598.0 mm). Data collected in 2003 and 2004 showed that the amount of irrigation water applied significantly the affected seed yield. However, the effects of irrigation interval on yield were not significant. On average, the $K_{cp\ 3}$ treatment gave the highest seed yield (1.915 t ha^{-1}), whereas $K_{cp\ 1}$ treatment gave the lowest (1.538 t ha^{-1}). Seasonal yield response factors (k_y) were 1.01 and 0.54 in 2003 and 2004, respectively. ET/E_{pan} ratios for each treatment varied from 0.3 to 1.3 in 2003 and from 0.1 to 1.1 in 2004. In conclusion, the $K_{cp\ 3}$ plant-pan coefficient is recommended for sesame grown under field conditions in order to maximise yield.

Keywords: Irrigation; Sesame; Pan evaporation; Irrigation scheduling

1. Introduction

Restricted water resources are a limiting factor for irrigation applications throughout the world. In some locations, naturally available water supplies do not allow the production of maximum yield from irrigable lands. In other regions, water for irrigation is regulated leading to insufficient irrigation. For many surface water projects, the annual supply of irrigation water is limited by reservoir capacity and annual reservoir inflow. These examples highlight the need for deficit irrigation management for different crops (Martin et al., 1989).

It is necessary to produce the maximum yield and profit from per unit area by using available water efficiently because the existing agricultural land and irrigation water are rapidly diminishing due to swift industrialization and urban development. Therefore, it is important to determine the right amounts of water supplies needed for plants during the vegetation period. Furthermore, it is essential to develop the most suitable irrigation schedule to produce the optimum plant yield. Such schedule should be developed for different ecological regions, as plant water consumption during the vegetation period depends mostly on plant growth, soil and climatic conditions.

Yield increase in intensive farming practices mostly depends on timely and adequate application of irrigation water needed for plant growth. Therefore, in addition to a correct determination of plant water consumption and irrigation interval, it is vital to determine the growth period when plants are most susceptible to water deficit in order to generate the highest yield per unit area.

In scheduling irrigation programs, methods based on pan evaporation have widespread usage due to their simple and easy application and low cost (Stanhill, 2002). The pan evaporation method (class-A pan) can be utilized in irrigation programming, if pan coefficients are available. Because evapotranspiration of grown plants can be deduced by pan evaporation using predetermined pan coefficients (Doorenbos and Pruitt, 1977). Studies have shown that there is a close relationship between plant water consumption and pan evaporation that can be used in irrigation scheduling for farmers (Kanber, 1984). Moreover, class-A pan is commonly used in agriculture due to the fact that

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it is the most suitable system for determining relationships among plant, water, and climate.

There are three steps in calculating the plant water consumption and evaporation ratio: (a) deciding on the most suitable irrigation method; (b) choosing the most suitable ET/ET_0 ratio; (c) checking this ratio in the field trials (Goldberg et al., 1976).

Sesame is usually planted in arid and semi-arid regions of the world and should be considered while planning crop irrigation projects in those regions. The plant is very responsive to environmental conditions and abiotic factors such as temperature, humidity, precipitation and soil moisture, all of which can affect its yield and quality. Understanding the relationship between the plant and water consumption as well as developing different management systems based on this knowledge may help maximise the yield. Since water requirements of sesame crops have not been investigated sufficiently so far, irrigation water planning and management need to be studied.

The objective of this study, therefore, was to determine the response of sesame plant to different irrigation applications. Specifically, the effects of irrigation intervals and pan coefficients (K_{cp}) on the yield and water consumption of sesame plants were studied to choose the most appropriate irrigation schedule for plants grown under field conditions using pan evaporation and related plant–pan coefficients.

2. Materials and methods

The study was carried out over the span of 2 years (2003 and 2004) at the Agricultural Research Institute of the Ministry of Agriculture and Rural Affairs in Kahramanmaras, Turkey (37°32′08″N and 36°54′59″E; altitude 568 m a.s.l.). The experimental site lies within an area of 20,000 ha with intensive cropping supported by irrigation. The area has a typical Mediterranean climate—cool and rainy in winter, hot and dry in summer. Table 1 summarizes the monthly maximum, minimum, and average temperatures, relative humidity and precipitation data for the city of Kahramanmaras, in 2003–2004. The average annual temperature, total rainfall, and the relative humidity were about 16 °C, 857 mm, 63% in 2003, and 17 °C, 721 mm, and 60% in 2004, respectively (Table 1). Only 10% of the rainfall fell in the growing season each year. Plants, therefore, required irrigation during the summer season to avoid drought stress.

The soil was classified as an Entisol type with a clay loam texture. The landscape of the site was flat. Soil properties were determined in the laboratory before the experiment (Table 2) Note that the field capacity and wilting point measurements refer to the water contents of soil at 0.33 and 15 atm of moisture tension, respectively.

Experimental plots consisted of 4 rows each 4.0 m long with a 0.7 m row spacing in between (Caliskan et al., 2004). The plots were planted using a 4-row planting machine at a 3-cm depth on 7 May 2003 and 14 May 2004. The plots contained 80 plants in an areas of 11.2 m^2. The distance between each of the plots was 2 m. The cultivar Muganli-57 was selected as the plant material. The reason for choosing this variety relates to the high seed and oil yield of the cultivar and its commonplace use as a registered sesame breed in the region. It is branched and has one capsule per leaf axil (Çağırgan, 1996). Plants were thinned to 20 cm in rows on 18 June 2003 and 24 June 2004. Water was applied equally to all irrigation treatments through sprinklers to increase the soil moisture up to the field capacity (FC) before thinning. Then the process of the irrigation treatment was started (Table 3). A total of 148 mm of water was applied in both years. The numbers of irrigations applied to each of the three irrigation intervals of I_1, I_2 and I_3 were 8, 7 and 4 in 2003, and 7, 4 and 3 in 2004, respectively. Water (2 l s^{-1}) was applied to each furrow in each plot uniformly using a flow meter. The treatment program was stopped at the end of August during both years.

The water used for irrigation was obtained from a deep well in the experimental area. Water quality was classified as C_2S_1, with a pH value of 7.0 and an average electrical conductivity score of 0.33 dS m^{-1}.

All plots were fertilized with the same amount of fertilizer based on soil analysis. The fertilizer contained 75 kg of N ha^{-1}, 75 kg of P_2O_5 ha^{-1}, and 75 kg of K_2O ha^{-1} before planting an additional 75 kg of N ha^{-1} nitrogen at the beginning of flowering. Weeds were controlled manually and hoed as necessary.

The experiment was conducted in three irrigation intervals (I_1: 7, I_2: 14 and I_3: 21 days) and the results yielded four different plant-pan coefficients ($K_{cp\,1}$: 0.60; $K_{cp\,2}$: 0.80, $K_{cp\,3}$:

Table 1
Monthly maximum, minimum, and average temperature, relative humidity and precipitation at Kahramanmaras, Turkey in 2003 and 2004

Month	2003					2004				
	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Precipitation (mm)	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Precipitation (mm)
May	14.1	29.5	15.4	51.9	30.4	20.0	26.4	14.6	62.0	28.7
June	25.6	33.1	18.9	54.0	1.6	25.8	32.5	19.6	56.8	0.0
July	28.3	36.1	22.3	58.2	0.0	29.3	37.2	22.3	53.1	0.4
August	29.4	38.0	22.4	56.6	0.0	28.0	35.6	22.3	58.3	0.2
September	24.3	31.5	17.9	54.7	22.4	26.3	34.8	18.4	45.4	0.0
Annual	16.2			63.0	857.5[a]	17.2			59.7	721.5[a]

[a] Total precipitation.

Table 2
Some physical and chemical properties of soil in the experimental area

Depth (cm)	Bulk density (g cm^{-3})	Field capacity (Pw)	Wilting point (Pw)	pH	Electrical conductivity (dS m^{-1})	Salt (%)	Phosphorus (kg ha^{-1})	Total nutrients (%)	Organic matter (%)	Texture
0–30	1.43	26.34	14.62	7.9	0.37	0.08	48.5	0.24	1.12	Clay loam
30–60	1.46	26.62	14.49	8.1	0.34	0.08	52.4	0.27	1.18	Clay loam
60–90	1.46	24.00	13.80	8.1	0.34	0.09	55.9	0.25	1.16	Silty loam

1.00 and $K_{cp\,4}$: 1.20), where K_{cp} is a coefficient used to determine the amount of water applied to plants based on the evaporation from a class-A pan. The experiments were arranged in a randomized complete block design with three replications. Blocks were irrigated using the closed-end furrow method. Irrigation started when the first flowers appeared. The number of days to initial flowering from the date of planting was 54 in 2003 and 56 in 2004.

Table 3
Monthly and total irrigation water amount (I, mm), plant water consumption (ET, mm), evaporation (mm) and precipitation (mm)[a] in different years and treatments

Treatments	Months											
	May		June		July		August		September		Total	
	I	ET	I	ET	I	ET	I	ET	I	ET	I	ET
2003												
$I_1K_{cp\,1}$	63.5	47.3	85.0	101.6	276.0	346.0	78.0	108.0	–	–	502.5	602.9
$I_1K_{cp\,2}$	63.5	47.3	85.0	101.6	368.0	455.5	104.2	147.2	–	–	620.7	751.6
$I_1K_{cp\,3}$	63.5	47.3	85.0	101.6	460.3	532.8	130.0	205.0	–	–	738.8	886.7
$I_1K_{cp\,4}$	63.5	47.3	85.0	101.6	552.0	599.5	156.5	216.5	–	–	857.0	964.9
$I_2K_{cp\,1}$	63.5	47.3	85.0	101.6	234.2	299.2	84.0	249.0	–	–	466.7	697.1
$I_2K_{cp\,2}$	63.5	47.3	85.0	101.6	312.8	387.8	112.8	247.8	–	–	574.1	784.5
$I_2K_{cp\,3}$	63.5	47.3	85.0	101.6	390.0	450.0	140.0	270.0	–	–	678.5	868.9
$I_2K_{cp\,4}$	63.5	47.3	85.0	101.6	468.0	533.0	168.8	288.8	–	–	785.3	970.7
$I_3K_{cp\,1}$	63.5	47.3	85.0	101.6	192.4	257.4	126.5	256.5	–	–	467.4	662.8
$I_3K_{cp\,2}$	63.5	47.3	85.0	101.6	256.4	326.4	168.0	378.0	–	–	572.9	853.3
$I_3K_{cp\,3}$	63.5	47.3	85.0	101.6	311.6	396.6	210.0	400.0	–	–	670.1	945.5
$I_3K_{cp\,4}$	63.5	47.3	85.0	101.6	384.0	449.0	252.0	402.0	–	–	784.5	999.9
Pan evaporation[b]	74.0		165.7		285.2		272.4		–		797.3	
Precipitation	30.4		1.6		–		–		22.4		54.4	
2004												
$I_1K_{cp\,1}$	56.8	45.5	92.0	112.0	139.0	279.4	120.7	150.9	–	10.2	408.5	598.0
$I_1K_{cp\,2}$	56.8	45.5	92.0	112.0	181.0	291.4	160.0	200.2	–	34.5	489.8	683.6
$I_1K_{cp\,3}$	56.8	45.5	92.0	112.0	223.0	323.4	200.7	225.9	–	50.3	572.5	757.1
$I_1K_{cp\,4}$	56.8	45.5	92.0	112.0	263.0	383.4	240.0	300.2	–	89.0	651.8	930.1
$I_2K_{cp\,1}$	56.8	45.5	92.0	112.0	97.0	227.4	162.7	202.9	–	24.6	408.5	612.4
$I_2K_{cp\,2}$	56.8	45.5	92.0	112.0	125.0	275.4	216.8	232.0	–	45.0	490.6	709.9
$I_2K_{cp\,3}$	56.8	45.5	92.0	112.0	153.0	273.4	270.0	280.2	–	64.3	571.8	775.4
$I_2K_{cp\,4}$	56.8	45.5	92.0	112.0	181.0	311.4	324.3	354.5	–	80.0	654.1	903.4
$I_3K_{cp\,1}$	56.8	45.5	92.0	112.0	126.0	256.4	123.1	233.3	–	32.4	397.9	679.6
$I_3K_{cp\,2}$	56.8	45.5	92.0	112.0	168.0	308.4	164.5	234.7	–	38.0	481.3	738.6
$I_3K_{cp\,3}$	56.8	45.5	92.0	112.0	210.0	380.4	205.0	325.2	–	62.0	563.8	925.1
$I_3K_{cp\,4}$	56.8	45.5	92.0	112.0	252.0	382.4	266.6	386.8	–	92.5	647.4	1019.2
Pan evaporation[c]	85		210		320		260		65		940	
Precipitation	28.7		–		0.4		0.2		–		29.3	

	2003		2004	
	Averages total I	Averages total ET	Averages total I	Averages total ET
$K_{cp\,1}$	478.9	654.3	405.0	630.0
$K_{cp\,2}$	589.2	796.5	487.2	710.7
$K_{cp\,3}$	695.8	900.4	569.4	819.2
$K_{cp\,4}$	808.9	978.5	651.1	950.9
Average	643.2	832.4	528.2	777.7

[a] Irrigation during the seedling stage was added to I.
[b] Monthly pan evaporations values from 7 May to 1 September in 2003.
[c] Monthly pan evaporations values from 15 May to 18 September in 2004.

We followed Allen's et al. (1998) method to calculate the amount of irrigation water using the equations below:

$$\mathrm{ET}_0 = K_\mathrm{p} E_\mathrm{pan} \quad (1)$$

$$\mathrm{ET}_\mathrm{c} = K_\mathrm{c} \mathrm{ET}_0 \quad (2)$$

where ET_0 is a measure of evapotranspiration (mm), K_p refers to the pan coefficient, E_pan represents pan evaporation (mm) score, ET_c indicates crop evapotranspiration (mm), and K_c denotes a crop coefficient. In order to calculate ET_c from E_pan, we took a product of K_p and K_c as demonstrated in Eq. (3). This technique has been suggested by Kanber (1984) and used by Yıldırım (1996) and Ertek et al. (2004)

$$K_\mathrm{cp} = K_\mathrm{c} K_\mathrm{p} \quad (3)$$

In this Eq. (3) K_cp represents a crop-pan coefficient. Crop evapotranspiration is calculated directly as a product of pan evaporation and crop pan coefficient:

$$\mathrm{ET}_\mathrm{c} = K_\mathrm{cp} E_\mathrm{pan} \quad (4)$$

A screened class-A pan located at the meteorological station next to the experimental area was used for accurately determining and recording the current weather conditions. Changes in water levels were measured each day at 8 a.m. using a micrometer.

E_pan, measured in millimetres (mm), is the amount of cumulative evaporation during each 7, 14, and 21-day irrigation interval. Four crop-pan coefficients ($K_\mathrm{cp\ 1} = 0.60$, $K_\mathrm{cp\ 2} = 0.8$, $K_\mathrm{cp\ 3} = 1.0$ and $K_\mathrm{cp\ 4} = 1.2$) were employed to determine the appropriate irrigation amounts utilizing the following equation (Doorenbos and Pruitt, 1977; Kanber, 1984)

$$I = A \times \mathrm{ET}_\mathrm{c} \quad (5)$$

where I is the amount of applied irrigation water (mm), and A the plot area (m^2).

Evapotranspiration was calculated for each treatment using a water balance equation (James, 1988)

$$\mathrm{ET} = I + P + C_\mathrm{r} - D_\mathrm{p} - R_\mathrm{f} \pm \Delta s \quad (6)$$

where ET represents evapotranspiration (mm), I refers to irrigation water (mm), R is the score of precipitation (mm), C_r denotes the capillary rise (mm), D_p indicates the loss by deep percolation (mm), R_f is the measure of surface run-off (mm), and Δs symbolizes the change in soil profile water content (mm).

The irrigation water quantity used when applying Eq. (6) was calculated separately for each treatment. C_r was considered negligible and taken as zero as there was no high underground water problem in the area. Whenever available water in the root zone (0–90 cm) and the total amount of water applied by irrigation were above the field capacity, it was assumed that excess water leaked into the deeper soil zones and was called deep percolation (D_p = amount of available total water at 0–90 cm soil depth before irrigation (mm) + irrigation water applied (mm) − soil moisture hold in field capacity (mm)) (Kanber et al., 1993).

Three soil samples were collected from each furrow on the plots. The samples were distanced 30 cm from each other and were gathered from a depth reaching 90 cm. Soil moisture of each sample was determined gravimetrically (oven dry basis) at thinning, before each irrigation, and at harvesting time.

Irrigation water use efficiency (IWUE, kg mm^{-1} ha^{-1}) and water use efficiency (WUE, kg mm^{-1} ha^{-1}) were calculated using Eqs. (7) and (8) (Howell et al., 1990)

$$\mathrm{IWUE} = \frac{Y}{I} \quad (7)$$

$$\mathrm{WUE} = \frac{Y}{\mathrm{ET}} \quad (8)$$

where Y represents the sesame yield (kg ha^{-1}) harvested from irrigation treatments.

Eq. (9) was used to determine the contribution of different irrigation levels on plant water consumption (Howell et al., 1990)

$$I_\mathrm{rc} = \frac{I}{\mathrm{ET}} \times 100 \quad (9)$$

where I_rc is the irrigation water compensation for plant water consumption (%).

The relationship between relative evapotranspiration deficit ($1 - \mathrm{ET}/\mathrm{ET}_\mathrm{m}$) and relative sesame yield reduction ($1 - Y_\mathrm{a}/Y_\mathrm{m}$) was determined using Eq. (10) (Doorenbos and Kassam, 1979)

$$1 - \frac{Y}{Y_\mathrm{m}} = k_\mathrm{y}\left(1 - \frac{\mathrm{ET}}{\mathrm{ET}_\mathrm{m}}\right) \quad (10)$$

where Y_m is the maximum sesame yield (t ha^{-1}), which was with the $I_1K_\mathrm{cp\ 4}$ treatment, k_y is the crop response factor, and ET_m is the maximum ET among the treatments, which was also with the $I_1K_\mathrm{cp\ 4}$ treatment.

Three-meter middle sections of two central rows of each plot were harvested when 95% of the capsules on plants turned yellowish and the leaves collapsed. Plants were removed by hand and heaped to dry for 2 weeks. They were threshed by hand and seed was cleaned and weighed. Sesame seed yield was obtained from an area of 4.2 m^2 for each irrigation treatment.

The collected data were analysed using Statistical Analysis System (SAS Institute, 1989). As the statistical methodology, the Duncan test for ranking means was employed.

3. Results

3.1. Irrigation

The overall results are shown in Table 3. Treatments $K_\mathrm{cp\ 1}$ and $K_\mathrm{cp\ 4}$ received the lowest and highest amount of water, respectively, throughout the entire experiment. Similarly, ET increased as the amount of water applied enhanced. There was a significant positive linear correlation between I and ET, $R^2 = 0.81$ in 2003 and $R^2 = 0.78$ in 2004 (Fig. 1).

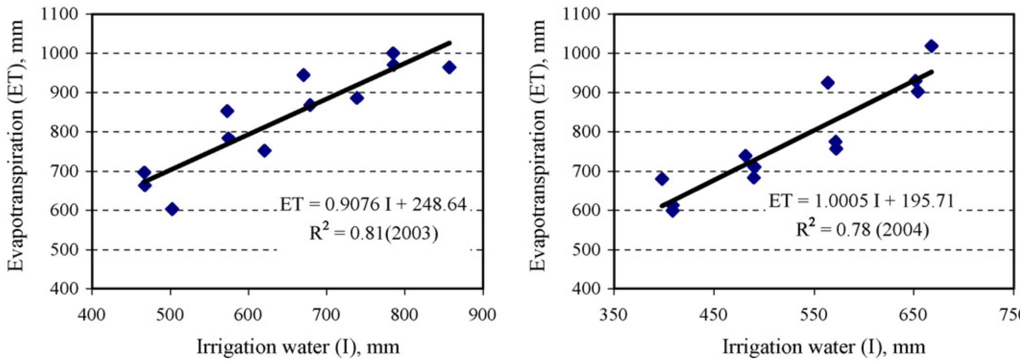

Fig. 1. Relationship between irrigation (I) and evapotranspiration (ET) for 2003 and 2004.

3.2. Sesame yield

The average yield of sesame based on 2 years, irrigation frequencies and amounts are given in Table 4. There was a statistically significant difference in average yield between the years ($P < 0.01$) and the maximum seed yield of sesame was found in 2004 (1.836 t ha^{-1}). The effect of irrigation intervals was not statistically significant, but amounts of irrigation, have showed significant effects ($P < 0.01$) on sesame yield. The $I \times K_{cp}$ interaction was not statistically significant.

3.3. Irrigation water use efficiency

Table 5 shows the quantity of applied water, seed yield, IWUE, WUE and I_{rc} values. Applied irrigation water varied from 467 to 857 mm in 2003, and 398 to 654 mm in 2004. IWUE values varied from 1.64 to 3.12 kg mm^{-1} ha^{-1} in 2003 and from 2.35 to 4.23 kg mm^{-1} ha^{-1} in 2004. WUE values varied from 1.40 to 2.60 kg mm^{-1} ha^{-1} in 2003 and from 1.54 to 3.03 kg mm^{-1} ha^{-1} in 2004. On the other hand, IWUE and WUE values in the treatments with the high total water application were generally low. In addition, irrigation water compensation values (I_{rc}) varied from 67 to 89% in 2003, and 59 to 76% in 2004. The irrigation water use efficiency data show that sesame plants use water efficiently during the vegetation period.

Table 4
Average sesame yields and Duncan test groups for different years, irrigation intervals and pan coefficients

Years	Average sesame yield (t ha^{-1})
2003	1.593 b
2004	1.836 a
LSD (0.01)	0.16
Irrigation intervals	
I_1	1.841
I_2	1.670
I_3	1.632
LSD (0.05)	ns
Pan coefficients	
$K_{cp\,1}$	1.538 b
$K_{cp\,2}$	1.734 ab
$K_{cp\,3}$	1.914 a
$K_{cp\,4}$	1.673 ab
LSD (0.01)	0.33

ns: non-significant.

3.4. Yield response factor (k_y)

The slopes representing relationship between relative sesame yield reduction and relative evapotranspiration deficit and termed ‘‘yield response factor (k_y)’’ by Doorenbos and Kassam (1979) are shown in Fig. 2. The yield response factor (k_y) is plotted for the whole growing season as well as individual growth periods. The k_y was 1.01 for 2003 and 0.54 for 2004 with an average of 0.65. These findings show that the sesame plant was very insensitive to a lack of available soil water throughout the entire growing season.

3.5. Soil water content changes

Soil water content in the treatments was measured at the 0–90 cm depth in 2004. It is shown in Fig. 3. Whenever soil water content was close to the wilting point (187 mm) before irrigation, it was brought up to the field capacity (334 mm) after irrigation. The I_1 treatments were closer to wilting point than the I_2 and I_3 treatments before irrigation. On the other hand, the I_2 and I_3 treatments were closer to field capacity after irrigation than the I_1 treatments because of the greater water amount of water applied per irrigation in with I_2 and I_3.

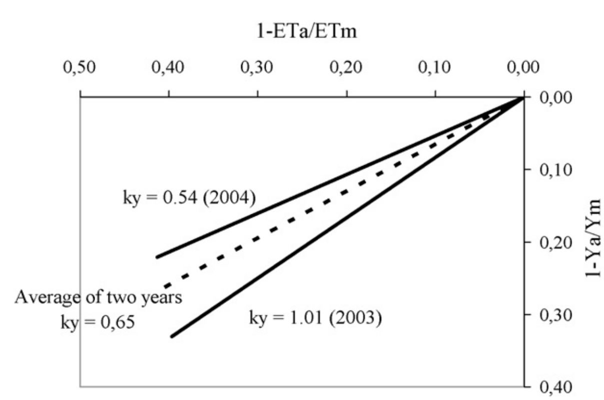

Fig. 2. Yield response factor (k_y) for individual growth years and average of both years.

Table 5
Yield, irrigation (I), evapotranspiration (ET), irrigation water use efficiency (IWUE), water use efficiency (WUE), irrigation water compensation (Irc), relative yield and relative ET values in different years and treatments

Years	Treatments	Yield ($t\ ha^{-1}$)	I (mm)	ET (mm)	IWUE ($kg\ mm^{-1}\ ha^{-1}$)	WUE ($kg\ mm^{-1}\ ha^{-1}$)	(%)[a]	Irc (%)	Relative yield (%)	Relative ET (%)
2003	$I_1K_{cp\ 1}$	1.568	502.5	602.9	3.12	2.60	16.7	83	78.2	60.3
	$I_1K_{cp\ 2}$	1.822	620.7	751.6	2.94	2.42	17.4	83	90.9	75.2
	$I_1K_{cp\ 3}$	2.005	738.8	886.7	2.71	2.26	16.7	83	100.0	88.7
	$I_1K_{cp\ 4}$	1.407	857.0	964.9	1.64	1.46	11.2	89	70.2	96.5
	$I_2K_{cp\ 1}$	1.294	466.7	697.1	2.77	1.86	33.1	67	64.5	69.7
	$I_2K_{cp\ 2}$	1.555	574.1	784.5	2.71	1.98	26.8	73	77.6	78.5
	$I_2K_{cp\ 3}$	1.939	678.5	868.9	2.86	2.23	21.9	78	96.7	86.9
	$I_2K_{cp\ 4}$	1.447	785.3	970.7	1.84	1.49	19.1	81	72.2	97.1
	$I_3K_{cp\ 1}$	1.353	467.4	662.8	2.89	2.04	29.5	71	67.5	66.3
	$I_3K_{cp\ 2}$	1.506	572.9	853.3	2.63	1.76	32.9	67	75.1	85.3
	$I_3K_{cp\ 3}$	1.813	670.1	945.5	2.71	1.92	29.1	71	90.4	94.6
	$I_3K_{cp\ 4}$	1.404	784.5	999.9	1.79	1.40	21.5	78	70.0	100.0
2004	$I_1K_{cp\ 1}$	1.650	408.5	598.0	4.04	2.76	31.7	68	78.2	58.7
	$I_1K_{cp\ 2}$	2.070	489.8	683.6	4.23	3.03	28.3	72	98.1	67.1
	$I_1K_{cp\ 3}$	2.110	572.5	757.1	3.69	2.79	24.4	76	100.0	74.3
	$I_1K_{cp\ 4}$	2.100	651.8	930.1	3.22	2.26	29.9	70	99.5	91.3
	$I_2K_{cp\ 1}$	1.690	408.5	612.4	4.14	2.76	33.3	67	80.1	60.1
	$I_2K_{cp\ 2}$	1.620	490.6	709.9	3.30	2.28	30.9	69	76.8	69.6
	$I_2K_{cp\ 3}$	1.710	571.8	775.4	2.99	2.21	26.3	74	81.0	76.1
	$I_2K_{cp\ 4}$	2.107	654.1	903.4	3.22	2.33	27.6	72	99.9	88.6
	$I_3K_{cp\ 1}$	1.670	397.9	679.6	4.20	2.46	41.5	59	79,1	66.7
	$I_3K_{cp\ 2}$	1.830	481.3	738.6	3.80	2.48	34.8	65	86.7	72.5
	$I_3K_{cp\ 3}$	1.910	563.8	925.1	3.39	2.06	39.1	61	90.5	90.8
	$I_3K_{cp\ 4}$	1.570	647.4	1019.2	2.35	1.54	34.5	65	74.4	100.0

[a] Difference between IWUE and WUE [100 − ((WUE × 100)/IWUE)].

3.6. ET/E_{pan} change

Fig. 4 shows the changes in ET/E_{pan} ratio. Variation in ET/E_{pan} was similar ranging from 0.3 to 1.3 in 2003 and from 0.1 to 1.1 in 2004. The ET/E_{pan} ratio was high in the period when sesame plants developed well because their water consumption increased then. Generally, E_{pan} was higher than ET at the beginning and end of the growing season due to low ET in those periods. The ET/E_{pan} ratio increased as plant growth and development increased but it decreased after the physiological maturity stage.

4. Discussion

The amount of water applied increased from the $K_{cp\ 1}$ treatments to the $K_{cp\ 4}$ treatments. Because the highest evaporation levels occurred in July, the highest amount of water was also applied then. As shown in Fig. 1, there was a positive significant relationship between I and ET in 2003 ($r = 0.899$, $P < 0.01$) and 2004 ($r = 0.904$, $P < 0.01$). The cumulative ET over time for the irrigation treatments during the growing periods can be seen in Fig. 5.

There was a statistically significant difference in average yield between the 2 years ($P < 0.01$), possibly due to climate differences. It is well-known that the amount and distribution of rainfall and differences in temperature and soil conditions are the major factors affecting seed yield and some yield components of sesame in arid and semi-arid regions (Nath et al., 2001). The low seed yield in 2003 might have been caused by the low temperature in May. Irrigation amount had significant effects ($P < 0.01$) on sesame yield, but irrigation intervals. In addition, the $I \times K_{cp}$ interaction was not statistically significant. The average seed yield varied from 1.632 to 1.841 t ha^{-1} in all irrigation frequencies (Table 6). The highest and lowest seed yields (1.914 and 1.538 t ha^{-1}) were obtained from the $K_{cp\ 3}$ and $K_{cp\ 1}$ treatments, respectively. The $K_{cp\ 3}$ treatment produced 25% more seed yield than that the $K_{cp\ 1}$ treatment (Table 6). The $K_{cp\ 4}$ treatment gave a lower seed yield than the $K_{cp\ 3}$ treatment. The $K_{cp\ 4}$ treatment would have had extra water in the profile; there was a water-logging in this treatment (Fig. 3).

The ET value increased markedly when I raised (Table 5). The highest seasonal evapotranspiration was obtained from the $I_3K_{cp\ 4}$ treatment in 2004 (1019.2 mm), whereas the lowest value was observed in the $I_1K_{cp\ 1}$ treatment in the same year (598 mm). The other treatments had ET values between these extremes. Derviş (1981) reported that the highest seed yield of sesame (1.640 t ha^{-1}) was obtained from the irrigations applied at 50% soil moisture content in soil. He found that seasonal ET of sesame was 396.40 mm. On the other hand, it was reported that the highest yield of sesame after the wheat production and ET were 1.668 t ha^{-1} and 464.61 mm, respectively (Derviş, 1986). In the study of Sepaskhah and Andam (2001), the ET value for sesame was found to be 915.6 mm under semi arid conditions. Ashri (1995) reported that the total amount of water required to grow a sesame crop ranges from 600 to 1000 mm,

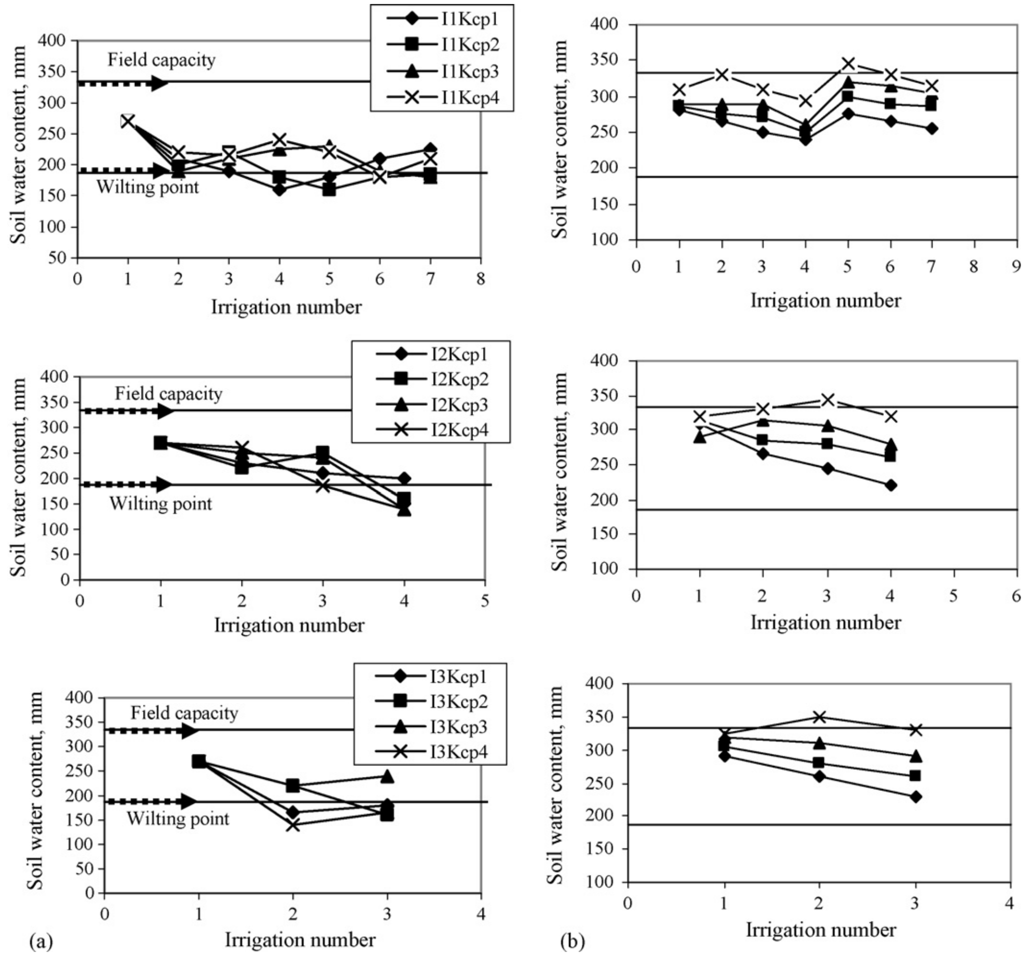

Fig. 3. Soil water content of I_1, I_2 and I_3 treatments.measured before (a) and after (b) irrigations.

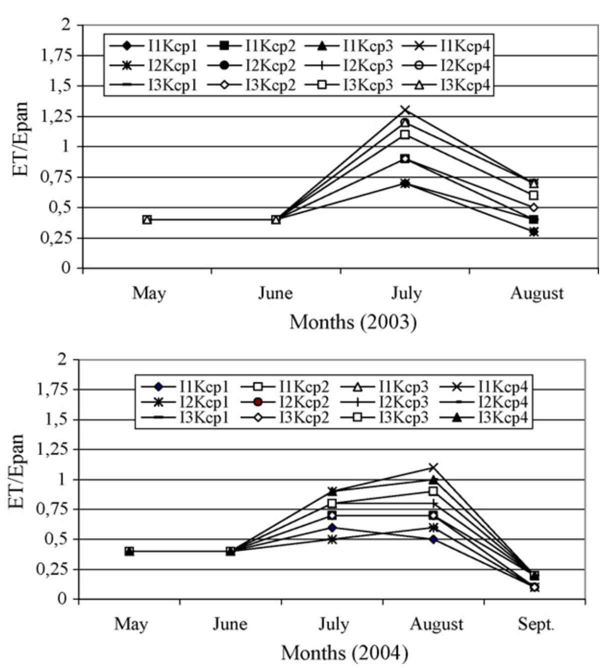

Fig. 4. Variation in ET/E_{pan} ratio in the growing period for 2003 and 2004.

depending on the cultivar and the climatic conditions. ET is influenced by environmental factors as well as plant characteristics (Göksoy et al., 2004).

Kanber et al. (1991) reported that the amount of irrigation water decreased when IWUE and WUE values increased. Studies have shown that frequently applied low irrigation water increases the yield because ET was higher when irrigation started at low soil water tensions (Stansell and Smittle, 1989). Goldberg et al. (1976) stated that irrigation period was more effective than the total amount of water applied, when plants were irrigated with a limited amount of water in early growth stage because of higher photosynthetic efficiency and vegetative growth. In this study, IWUE and WUE values from $K_{cp\ 4}$ to $K_{cp\ 1}$ have been generally increasing. This indicates that sesame uses water economically. These findings agree with those of Dallyn (1983).

Irrigation water consumption, I_{rc}, was in general higher in the treatments irrigated with high amount of water than those irrigated with low amount of water. I_{rc} values of the I_1 treatment were higher than those of the I_2 and I_3 treatments (Table 5). This might be due to the fact that plants were not suffered from water deficit in short irrigation intervals. According to Radin et al. (1989), frequent irrigations prevent the large fluctuation in plant water stress caused by infrequent irrigations.

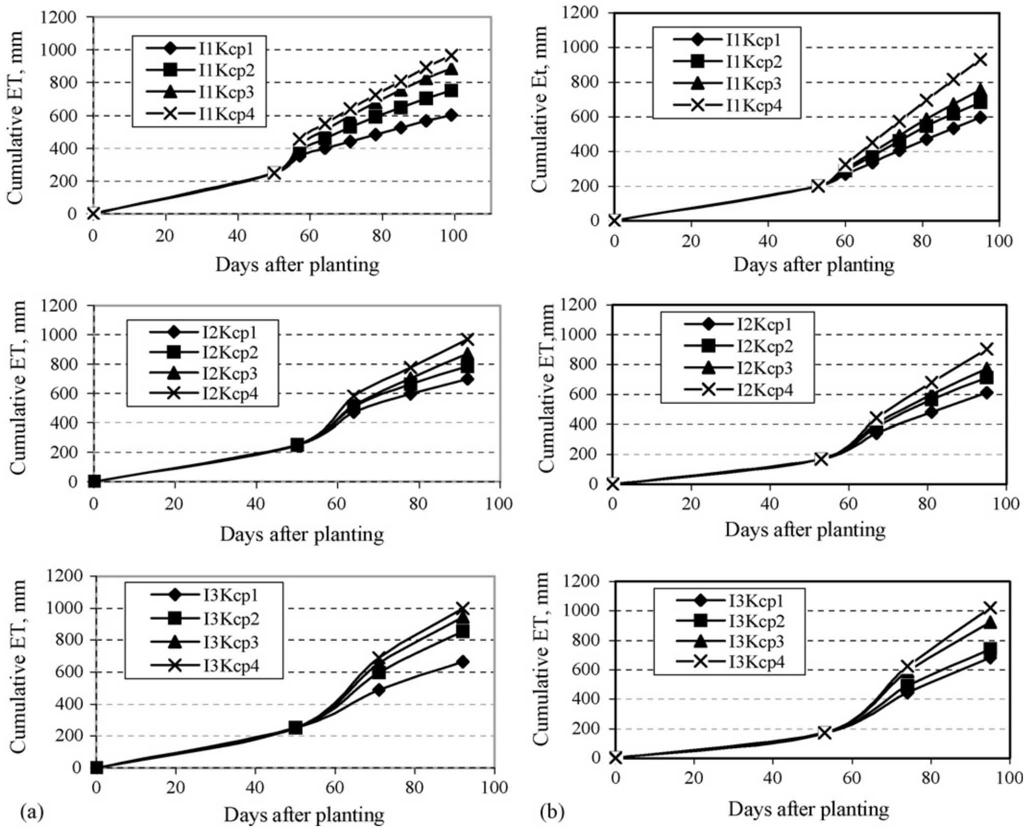

Fig. 5. The time-series of cumulative evapotranspiration (ET) for the irrigation treatments during the growing periods (a: 2003, b: 2004).

Application of the k_y for the planning, design and operation of irrigation projects allows quantification of water supply and water use in terms of crop yield and total production for the experimental area. In different areas irrigated with furrows, seasonal k_y values were between 0.7 and 1.1 (Kodal, 1994). The k_y was determined by Gençoğlan (1996), Doorenbos and Kassam (1979), and Yıldırım et al. (1995) as 1.23 (1.08 and 1.61), 1.25, and 0.94, respectively. Some differences in the yield response factor (k_y) might be due to climatic changes, cultural practices, irrigation methods and programs.

As stated in Meiri et al. (1992), plants took up more water from soil in infrequently irrigated treatments. In general, soil water content before and after irrigation gradually decreased towards the end of the season when temperatures were lower. This might be due to the fact that irrigation could not fully compensate for evapotranspiration (ET) loss. Some of the previously stored water in the soil profile was used up towards the end of the season. However, because much more water was applied with increasing K_{cp} coefficients, the soil water content of treatments with high K_{cp} values were higher than others before and after irrigations. That is why there was more water in the soil profile in the $K_{cp\ 4}$ than in all the other treatments. When the $K_{cp\ 1}$ and $K_{cp\ 2}$ treatments declined below the wilting point before irrigation, they negatively affected vegetative and generative development. After the irrigation the $K_{cp\ 4}$ treatment received more close to field capacity and therefore yielding less than the $K_{cp\ 3}$ treatment due to water logging (Fig. 3). Maintaining soil water content between 65 and 80% of field capacity is required to increase yield (Dunwell et al., 2001). Other studies, Richard et al. (2002) have also advised against inadequate or excessive irrigations.

Variation in ET/E_{pan} of treatments was similar to others. It ranged from 0.3 to 1.3 in 2003 and from 0.1 to 1.1 in 2004 (Fig. 4). The ET/E_{pan} ratio was high in the period when sesame plants

Table 6
Average seed yield with varying irrigation frequency (I) and pan coefficient (K_{cp})

Irrigation frequency	Average seed yield (kg ha^{-1})			Pan coefficient	Average seed yield (kg ha^{-1})		
	2003	2004	Average of years		2003	2004	Average of years
I_1	1700	1982	1841	$K_{cp\ 1}$	1405	1670	1538
I_2	1559	1782	1670	$K_{cp\ 2}$	1628	1840	1734
I_3	1519	1745	1632	$K_{cp\ 3}$	1919	1910	1914
				$K_{cp\ 4}$	1419	1926	1672
Average	1593	1836	1714	Average	1593	1836	1714

developed well with higher water consumption. Sepaskhah and Andam (2001) found that the minimum and maximum values of the ET/E_{pan} ratios were determined as 0.4 and 1.0 at the beginning and middle of the growing season, respectively. ET/E_{pan} ratios (0.6, 0.9 and 1.2 values) were used to determine the amount of irrigation water by Praveen and Raikhelkar (1994). They reported that the highest ET and yield values were obtained from the 1.2 ET/E_{pan} ratios. Treatments received the low water under the small ET/E_{pan} ratio. Doorenbos and Kassam (1979) observed for annual plants an increase in the ET/E_{pan} ratio in the middle of the growing period. This ratio then stabilizes but ultimately decreases at the end of the season. Moreover, Goldberg et al. (1976) find a positive linear correlation between ET/E_{pan} ratio and plant cover percentage until plant canopy covers 80% of the soil in plant rows. Our results concur with those findings. The relationship between ET and E_{pan} for the highest yield was ET = 0.7569, E_{pan} − 36.629 (R^2 = 0.98) in 2003 and ET = 0.5863, E_{pan} − 33.216 (R^2 = 0.99) in 2004 in the treatment $I_1K_{cp\ 3}$. That means that the $I_1K_{cp\ 3}$ treatment can be used in scheduling irrigation programs in sesame production.

5. Conclusion

Sesame is commonly grown as a dry land crop, but it responds significantly to irrigation. In this study, our results demonstrated that the effects of irrigation water amount and plant water consumption are important in order to produce high yields of sesame. As our results indicate, pan coefficient significantly affected the yield of sesame at $P < 0.01$. Yet, the differences between the irrigation intervals were not significant. Hence, irrigation interval could be extended 21 days (I_3) without decreasing yield. The amount of irrigation water applied had a significant effect on sesame yield. The highest seed yield (1.914 t ha^{-1}) was obtained from the $K_{cp\ 3}$ treatment, followed by the $K_{cp\ 2}$ treatment. The lowest average seed yield (1.538 t ha^{-1}) was obtained from the $K_{cp\ 1}$ treatment. The IWUE and WUE values decreased when irrigation water increased. This shows that the sesame plant can use water efficiently due to its morpho-physiologic characteristics. In conclusion, we recommend use of the $K_{cp\ 3}$ (1.00) pan coefficient in order to produce high yields of sesame.

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