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Water and Nitrogen Application Levels for the Optimum Tomato Yield and Water Use Efficiency

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ABSTRACT

This study was conducted to determine the effects of different water and nitrogen application levels on drip-irrigated tomato plants. The amount of water usage was based upon the pan evaporation from a screened (class "A") evaporation pan. The treatments consisted of two irrigation intervals (I1= 5 days and I2= 10 days), three plant-pan coefficients (K_{cp}1= 0.50; K_{cp}2= 0.75 and K_{cp}3= 1.00) and three nitrogen (N) levels (N0 = 0, N1= 80 and N2= 160 kg ha^{-1}). The I, K_{cp} and N levels affected the tomato yields and water usage efficiencies, however the effects of nitrogen applications were found to be greater than those of the other applications. Consequently, to reach the maximum tomato yields under similar climate and soil conditions, plant-pan coefficients (K_{cp}) and nitrogen values should be equivalent to 1.00 and 160 kg ha^{-1}, respectively.

Keywords: Irrigation, N fertilization, Pan evaporation, Plant-pan coefficient, Tomato.

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INTRODUCTION

Both fertilizer and water are important factors, or inputs, to commercial vegetable production. Nitrogen is the most widely used element of plant mineral nutrition. It is essential for the optimal growth of plants and for the maximum yield and quality of fruit. Some previous studies showed that biomass production, yield, and tissue *N*-concentrations increased with irrigation and *N*-fertilization (Wiedenfeld, 1995; Pandey *et al.,* 2001). In a study conducted by Eck and Fanning (1961), it was observed that N and P uptakes of sorghum plants increased with increasing soil water and fertilizer applications.

The water usage efficiency (WUE) shows an important correlation between plant water usage and plant dry matter accumulation. The soil fertilization makes *WUE* increase thereby saving on water (Bauer, 1966). It is estimated that the overall efficiency of water in irrigated and dry land farming is 50%. In general, any growth factor that increases plant growth and yield such as fertilization, improves the water use efficiency (Aydeniz, 1985). Viets (1962) expressed that water use efficiency and water use increased due to the increased root growth and vegetation through fertilization.

Pan evaporation-based methods have been widely used due to their simplicity and easy application (Elliades, 1988). Many studies have shown that pan evaporation can be used for irrigation scheduling. The E_t (plant water consumption) of the grown plants can be estimated by using pan evaporation and a pre-determined crop coefficient (Doorenbos and Pruitt, 1975).

The present production of tomatoes worldwide is reaching nearly 100 million metric tons of fresh fruit with a total acreage of 3.7 million ha (FAO, 2001). The production of tomatoes for consumption as a fresh fruit and for the tomato paste industry in Turkey approaches 7.3 million metric tons

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per year amounting to 38% of all vegetables produced (Anonymous, 2004). Processing tomatoes are long-season and relatively shallow-rooted plants with high water requirement. Excess water may hamper crop production as much as dry weather. A maximum utilization of irrigation will be achieved by adding proper amounts of water at the right intervals to reduce moisture stress of the plants (Tan, 1990).

Over-fertilization increases the risk of nitrate pollution in soil and water. To minimize theb potential risk of nitrate contamination, N and water supplies should be well-balanced with the crop's requirement without yield loss. Using carefully regulated irrigation increases N use efficiency by tomato (Doss et al. 1975; Nassar, 1986). Thus, the objective of this study was to determine the most appropriate plant-pan coefficient (K_{cp}) and nitrogen level for drip irrigation of tomato plants under field conditions.

MATERIALS AND METHODS

Soil and Climatic Characteristics and Design of the Experiment

The field experiment was conducted at Suleyman Demirel University's experimental station which is located in southwestern Turkey, near the city of Isparta (37° 52' N, 30° 40' E, and 930 m altitude) during the year 2003. Some physical and chemical characteristics of soil in the trial plots are presented in Table 1. This area has a predominantly Mediterranean climate with the average relative humidity equivalent to 61% on an annual basis as well as an average wind speed of 1.9 m s^{-1}. The precipitation during summertime, when the plant water usage is at its highest, does not meet the needs of the plants (Table 2).

The treatments were two irrigation intervals (*I*1: 5 days and *I*2: 10 days); with three plant-pan coefficients ($K_{cp}1$= 0.50; $K_{cp}2$= 0.75, and $K_{cp}3$= 1.00); and three N levels (N0= 0, N1= 80, and N2= 160 kg ha^{-1}). Irrigations for tomato plants in the region have been generally conducted in 5 and 10 day intervals. Actually, drip irrigation systems are by far more proper for frequent irrigation than others. However, in this study it was endeavoured to evaluate the effects of slightly longer irrigation intervals under the deficit consditions. Furthermore, frequent irrigation intervals entail more labor force and they are not appealing to growers in the region. The experiment was set up as a randomized complete block design in split-split plot arrangement with three replications. The tomato plants of "cv. Rio Grande-0624" were planted on June 8, 2003 at 1.4 m×0.3 m spacing (i.e., 4 rows with 10 plants in each row). The distance between the plots was 1.5 m. Each plot consisted of 40 plants in 16.8 m^2 (3 m×5.6 m). There were 54 plots used in this experiment.

Table 1. Physical and chemical properties of the experimental area.

Depth cm	ρ_b[a] g cm^{-3}	*FC*[b] θ_{fc}	*PWP*[c] θ_{pwp}	pH	*EC* dS m^{-1}	$CaCO_3$ %	Total N %
0-30	1.16	27.9	15.1	7.8	2.9	3	0.20
30-60	1.18	30.7	16.6	7.8	3.1	3	0.13
60-90	1.09	31.2	16.9	7.9	2.3	2.8	0.13

Depth cm	Available P mg kg^{-1}	Extractable K me 100 g^{-1}	*CEC* me 100 g^{-1}	Texture
0-30	6.14	0.53	12.4	CL[d]
30-60	0.88	0.46	13.2	CL
60-90	0.7	0.45	12.7	CL

[a] Soil bulk density; [b] Field capacity; [c] Permenant wilting point; [d] Clay loam.

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Table 2. Monthly climate data in the growing season[a].

Parameter	June	July	August	September	October
Temperature, °C	21.4	24.0	23.9	18.1	14.2
Precipitation, mm	17.6	-	-	6.8	24.4
Pan evaporation, mm	185.7	272.6	245.7	135.0	66.3

[a] Evaporation and precipitation values from 8 June to 17 October were given monthly.

Irrigation

Irrigation water was provided from a well using a pump and supplied through a drip irrigation system. The water was in the C_1S_1 category which means a sodium risk and a low electrical conductance (USSL, 1954). The 16- mm diameter lateral pipes carrying 4 L h^{-1} of water at a pressure of 1.8 kPa had inline drippers located at 60 cm intervals. The dripper intervals were calculated based on both discharge and infiltration rates of the soil. Irrigation rates requirements were computed using Equation (1) (Doorenbos and Pruitt, 1975):

$$I_r = E_{pan} \times K_{cp}, \quad (1)$$

Where, I_r= The irrigation water (mm); E_{pan}= The cumulative evaporation at class "A" pan in the irrigation intervals; and K_{cp}= The plant-pan coefficient.

After the seedlings were planted, tomato seedlings were irrigated a few times until they were established. Then, when the available water in the 0-90 cm of the soil profile dropped to about 40%, all treatments were irrigated to field capacity. Subsequent irrigations were done with intervals of five and 10 days. Soil water contents were measured by the gravimetric method in 30 cm increments to a depth of 90 cm in each plot at planting, before irrigations, and at the final harvesting date. The E_t was estimated using Equation (2) (James, 1988):

$$E_t = I_r + P + C_r - D_p - R_f \pm \Delta s, \quad (2)$$

Where, E_t= Plant water consumption (mm), I_r= Irrigation water (mm), P= The precipitation (mm), C_r = The capillary rise (mm), D_p= The deep percolation losses (mm), R_f = The runoff losses (mm), and Δs= The moisture storage in soil profile (mm).

The irrigation water usage efficiency (IWUE) and simple water usage efficiency or plant water consumption efficiency (WUE) were calculated *via.* Equtions (3 and 4) (Howell *et al.,* 1990; Kanber *et al.,* 1992):

$$IWUE = (E_y/I_r) \times 100, \quad (3)$$

$$WUE = (E_y/E_t) \times 100, \quad (4)$$

Where, *IWUE*= The irrigation water use efficiency (t ha^{-1} mm^{-1}), E_y= The marketable yield (t ha^{-1}), *WUE*= The water use efficiency (t ha^{-1} mm^{-1}).

Moreover, Eqution (5) was used to determine the contribution of different irrigation water levels on plant water consumption (Howell *et al.,* 1990; Kanber *et al.,* 1992).

$$I_{rc} = (I/E_t) \times 100, \quad (5)$$

Where, I_{rc} is the compensation rate of E_t by irrigation water applied (%).

Equation (6) was used to determine the yield-response factor (K_y) (Doorenbos and Kassam, 1979):

$$[1 - (Y/Y_m)] = K_{yEt}\,[1 - (E_t/E_{tm})], \quad (6)$$

Where, Y= The real yield (t ha^{-1}), Y_m= The maximum yield (t ha^{-1}), E_{tm}= The maximum plant water consumption (mm), K_{yEt}= The yield-response factor for *Et*.

Fertilization and Plant Analysis

The pre-plant fertilizer was spread at a rate of 30 kg ha^{-1} of phosphorous as triple superphosphate (45% of P_2O_5) and 50 kg ha^{-1} of potassium as potassium sulfate (48% of K_2O) as basal fertilization. The nitrogen from ammonium sulfate (21% of N) was applied at three different periods (after planting, at flowering and at fruit ripening).

Hence, 1/3 of total N applied was delivered at each period using fertilizer tanks.

Leaf samples were collected at the flowering stage to determine plant N content. To determine N uptake, fruit and plant *N* concentrations were also analyzed. For this, six plants including above-ground organs and root (vegetative biomass) from each plot were taken randomly and the mature fruits from these plants were collected. The samples were washed in tap water to remove surface residues and soaked in diluted hydrochloric acid (0.2 N HCl) for 20 seconds. This procedure was followed for four or five rinses with distilled water, after which the samples were dried at 65°C for 48 hours, to bring them to a constant weight. Dried samples were ground to a powder using mortar and pestle, and subsequently stored in polyethylene bottles. Nitrogen concentrations in samples were determined using the Kjeldahl method (Bremner, 1965). According to this method, 0.5 g of each ground sample was placed into digesting tubes, after which 6 ml of concentrated H_2SO_4 and 5 grams of (K_2SO_4+$CuSO_4$) catalyst were added. The sample was digested using a block digesting system (KB 8 S Kjeldatherm, Gerhardt). After the sodium hydroxide (40% w/w) was added, the sample was distilled using an automatic unit (VAP20, Gerhardt). The ammonium-N was fixed with 2% H_3BO_3 and titrated with 0.1 N of H_2SO_4 in the presence of the indicator (bromocresol-green and methyl-red in 95% ethanol). The N concentration was calculated using Eqution(7):

N (%)= (H_2SO_4 (ml) used for sample titration–H_2SO_4 (ml) used for blank titration) × N_{H2SO4}×(1.4/Sample dry mass), (7)

Where, N_{H2SO4}= The normality of H_2SO_4 solution used for titration.

N Uptake and Utilization from Fertiliser

To calculate *N* uptake by plants, both fruit and vegetative biomass (VB) were dried at 65 °C to a constant weight. Following that, the *N* uptake was calculated by multiplying the *N* concentration by the weight of oven-dried matter (Scholberg *et al.,* 2000). The utilization rate from applied *N* was estimated by comparing the total *N* removed with the *N* applied as described by Equations (8, 9 and 10):

$N_{up}= DM \times N_{C},$ (8)

$N_{UF}= N_{U1}-N_{U0},$ (9)

$BFF= (N_{UF} \times 100)/N_{F},$ (10)

Where, N_{up}= The *N* uptake (kg ha^{-1}) by plants (plant nitrogen consumption), *DM* = The oven-dry matter (kg ha^{-1}), N_C= The N concentration (%), N_{UF}= The *N* uptake from fertilizer (kg ha^{-1}), N_{U1}= The N uptake from fertilized plots (kg ha^{-1}), N_{U0} = The N uptake from control plots (kg ha^{-1}), *BFF* – the utilization rate from fertilizer (%), N_F= The N application with fertilizer (kg ha^{-1}).

Similar procedures for the *N* consumption in the Equation (11) by using Equation (4) were followed. To determine *NUE*, only N-applied treatments were considered:

$NUE= (E_y / N_{up}) \times 100$ (11)

Where, *NUE*= The nitrogen use efficiency (t kg^{-1}), E_y= The marketable yield (t ha^{-1}),

The *NUE* is marketable yield obtained per unit weight of N consumed by plants.

Equation (12) can be written based on the procedure followed in accordance with Equation (6) for E_t if the plant water consumption (E_t) and the *N* consumption (N_{up}) are both considered as factors in plant production increase. Therefore, the decrease in yield per one unit of decrease in *N* consumption could be estimated by using Equation (12):

$(1-Y/Y_m)= K_{yNup} [1-(N_{up} / N_{upm})],$ (12)

Where, N_{upm}= The amount of maximum *N* consumption (kg ha^{-1}), K_{yNup}= The yield-response factor for N_{up}.

Harvesting and Other Operations and Variance Analysis

The fruits were harvested five times from September 16 through October 17 with the total growth period comprising 131 days, and weighted. During the harvest, 16 plants in the middle rows from each plot were chosen to escape edge effects. The marketable fruits were removed by hand at two week intervals from the beginning of maturity and the numbers, diameters and lengths of fruits were recorded. Height, ground cover and stem diameters of plants were measured, along with the number of lateral branches. The first harvest was considered to be equal to the early yield.

The level of significance (LSD at ** P< 0.01) was used in the ANOVA to test the effect of irrigation treatments on different variables of response (Steel and Torrie, 1980). Means were separated by Duncan's multiple range test (P< 0.01).

RESULTS AND DISCUSSION

Irrigation Water, Plant Water and Nitrogen Consumption and Yields

The first and the last irrigations were made on July 8, and September 11. The plants had been watered 14 and 7 times with 5 and 10 day intervals, respectively. The lowest and the highest irrigation water amounts in both irrigation intervals were in $K_{cp}1$ and $K_{cp}3$ treatments, respectively (Table 3). The E_t values ascended with increased irrigation water. There was a significant linear correlation between I_r and E_t (R^2= 0.89**). The months of July and August, in which the highest E_t occurred, included both flowering and fruit maturing periods. Tan (1990) and FAO (2004) reported that water use by irrigated tomato varied with the crop development stages and the peak water use periods occurred during fruit set and fruit development. Irregular and inadequate water supply during these periods can result in poor fruit set and blossom-end rot. Both optimum yield and fruit quality are obtained by matching water application to peak crop water use rate (Tan, 1990).

In this study, the same amount of water was applied in both irrigation intervals; however, E_t was higher (18-35 mm) under the *N* application at 10 day intervals. As Meiri et al. (1992) reported, plants extracted more water from soil treatment plots that were irrigated infrequently. This can be explained by the increase in E_t resulting

Table 3. Some yield and irrigation parameters.

Treatments		I_r (mm)	E_t (mm)	MarketableYield (t ha^{-1})	Early Yield (t ha^{-1})	*IWUE* (kg m^{-3})	*WUE* (kg m^{-3})	*NUE* (t kg^{-1})	I_{rc} (%)	N uptake from fertiliser (kg ha^{-1})	Benefit rate from fertiliser (%)
I1 (5 days irrigation interval)											
$K_{cp}1$	N0	503.7	516.1	23.32	2.52	4.6	4.5	0	97,60	0	0
	N1		532.1	55.53	4.85	11.0	10.4	1.00	94.66	55.3	69
	N2		551.2	78.90	5.76	15.7	14.3	0.56	91.38	141.2	88
$K_{cp}2$	N0	657.7	676.7	25.27	3.66	3.8	3.7	0	97.19	0	0
	N1		689.1	60.53	7.41	9.2	8.8	0.84	95.44	71.7	90
	N2		699.8	88.83	3.73	13.5	12.7	0.56	93.98	159.8	100
$K_{cp}3$	N0	811.7	839.2	31.49	6.27	3.9	3.8	0	96.72	0	0
	N1		847.2	63.70	7.10	7.9	7.5	1.00	95.81	63.6	80
	N2		859.2	95.61	5.10	11.8	11.1	0.66	94.47	145.7	91
I2 (10 days irrigation interval)											
$K_{cp}1$	N0	503.7	536.3	12.83	2.94	2.6	2.4	0	93.92	0	0
	N1		547.8	46.01	4.58	9.1	8.4	0.75	91.95	61.0	76
	N2		554.1	61.00	4.20	12.1	11.0	0.48	90.90	127.0	79
$K_{cp}2$	N0	657.7	690.8	14.64	3.62	2.2	2.1	0	95.21	0	0
	N1		702.1	57.78	4.26	8.8	8.2	0.74	93.68	78.0	99
	N2		709.7	73.44	3.97	11.2	10.4	0.45	92.67	162.2	102
$K_{cp}3$	N0	811.7	831.2	17.62	4.15	2.2	2.1	0	97.65	0	0
	N1		856.4	61.06	4.80	7.5	7.1	0.69	94.78	89.0	111
	N2		863.8	78.23	3.73	9.6	9.1	0.52	93.97	185.2	116

from increased plant growth in treatments with higher levels of applied N. The increase in applied *N* increased vegetative and productive growth of the plants. Increased growth as found in plant height and cover expansion positively affected *LAI* (leaf area index). Therefore, *LAI* becomes one of the most impotant factors leading to an increase in E_t.

The amount of *N* consumption by plants (N_{up}) increased depending on the irrigation water amounts and on irrigation intervals. The highest N_{up} values were from I2*Kcp2*N2, I2*Kcp3*N1, and I2*Kcp3*N2 treatments and those treatments benefited from the *N* already present in soil in addition to the applied amounts of N (Table 3). While the soil water content in 0-90 cm depth before irrigation was close to the wilting point (166 mm), after irrigations it approached field capacity (307 mm) (Figure 1). Because the extension of irrigation intervals contributed to the increase in the total amount of water applied at each time, I2 treatments supported more N uptake from the soil than did I1 treatments. Also, water is a good solvent and conveyor for plant nutrients. Furthermore, the soil water contents after irrigation were closer to field capacity in I2 compared with I1 treatments. However, the yields decreased in I2 treatments compared with I1 treatments. The

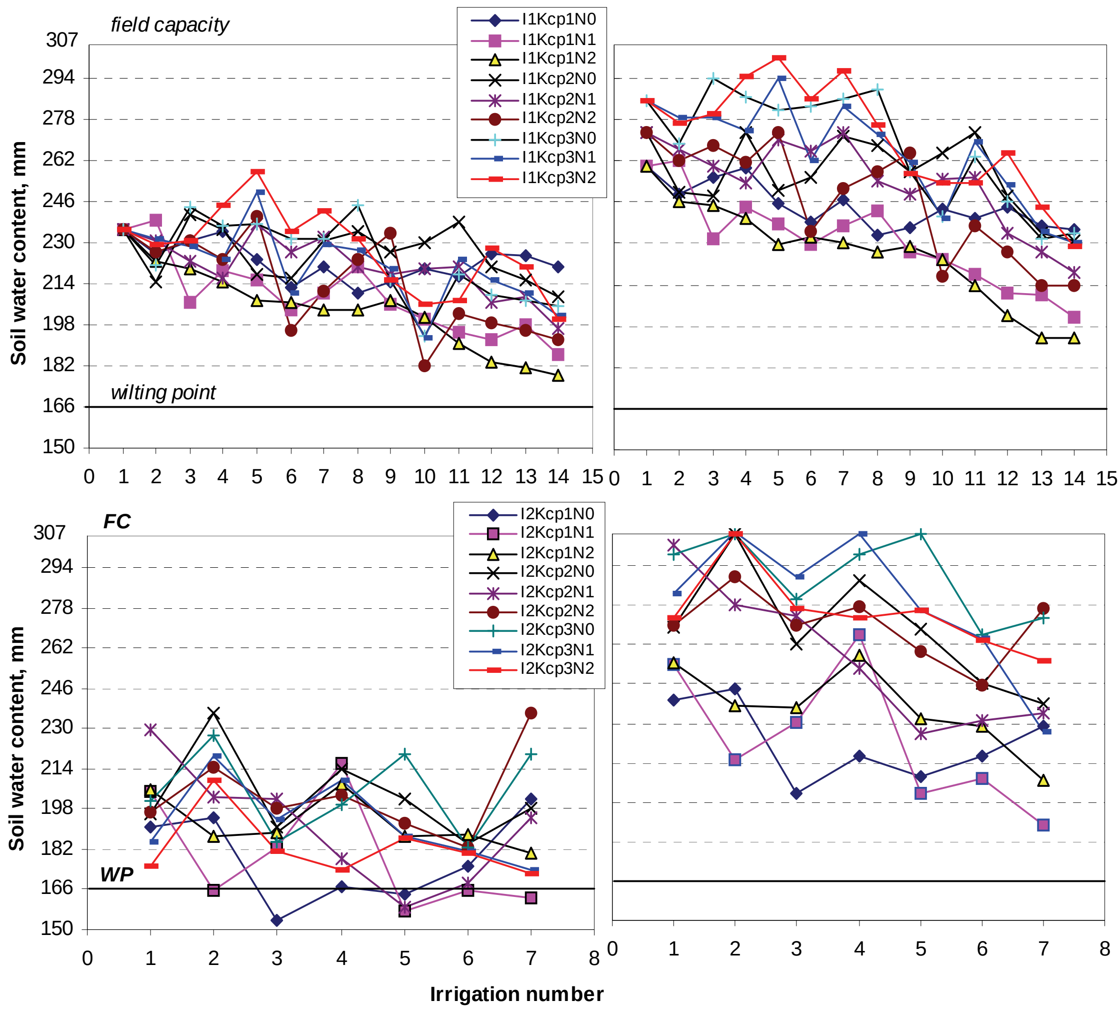

Figure 1. Soil water content measured before irrigations (a) and after irrigations (b) of I1 and I2 treatments.

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extra N consumption led to an increase in vegetative growth rather than increasing yield. The reduction of the irrigation interval resulted in water stress leading to a decrease in early and total marketable yields (Table 3). In *I*1 treatments, the soil water contents approached wilting point before irrigation than in *I*2 treatments. Thus, flower shedding could have occurred leading to the yield decrease. Radin et al. (1989) note that short irrigation cycles prevent wide fluctuations in crop water stress level which can occur within longer irrigation intervals. Another study indicated that the irrigation period was more significant than the total amount of irrigation water; when plants were irrigated with a limited amount of water during early growing stages, they grew out better and their photosynthetic efficiency improved (Goldberg *et al.,* 1976).

Generally, soil water contents before and after the irrigations gradually decreased toward the end of the season (Figure 1). Probably, irrigation could not compensate fully for plant water consumption needs, and some of the water previously being stored in the soil profile was used at the end of the season (Ertek *et al.,* 2004). Besides, a dramatic decrease in water contents in the soil profile before and after the irrigations significantly affected yields as well as plant water consumption. Increase in K_{cp} throughout both irrigation intervals increased the soil water contents before and after the irrigation procedures due to the increased irrigation water amounts. The soil water depletion from similar irrigation treatments was higher with 160 kg ha^{-1} of N than with other N application levels. Novoa and Loomis (1981) stated that soil water availability is the main factor influencing nitrogen uptake by a root and its transport to a leaf. The allowable soil water depletion is the percentage of available water that can be depleted from the soil before an adverse effect occurs on the yield and on fruit quality. The allowable soil water depletion value for tomato is stated to be about 50% (Tan, 1990). In our study, higher yields were obtained in the treatments where the available water contents were higher than 50% before irrigation.

The highest early yields within both irrigation intervals were obtained in direct connection with $K_{cp}3$ treatments where both E_t and I_r amounts were the highest. The average early yields in I1 and I2 treatments were equal to 5.16 and 4.03 t ha^{-1}, respectively. In terms of N applications affecting yields, the lowest and the highest average early yields were obtained from N0 (3.86 t ha^{-1}) and N1 (5.5 t ha^{-1}), respectively. The average early yield under N2 fell in between these values (4.42 t ha^{-1}). The decrease of early yield resulting from N2 treatments may occur due to the shortening of vegetative and generative periods. The above findings were confirmed when less early yield and higher total yield were obtained from the same *N*2 treatments. The greatest total marketable yields were obtained from *I*1 treatments (58.13 t ha^{-1}) rather than from *I*2 treatments (46.96 t ha^{-1}). Depending on the amounts of irrigation water applied, the yields increased as follows: $K_{cp}1$= 46.3; $K_{cp}2$= 53.4; and $K_{cp}3$= 58.0 (t ha^{-1}). The average yields for N0, N1 and N2 treatments were equivalent to 20.9; 57.4 and 79.3 (t ha^{-1}), respectively.

Despite the fact that the yield amounts tended to increase depending on the applied irrigation water levels without N fertilization, it was not increased as much as in fertilizer (N) treatments (Table 3). it did not increase topics. The tomato yield responses to irrigation were greater with the higher N application rates; an increase in *N* fertilizer in treatments with the same amount of water applied led to a nearly 2-4 times increase in yields. Optimum N supply under non-water limiting conditions can result in full yield potential, but under water-limiting conditions, N may increase the severity of drought stress (Fredrick and Camberato, 1995). In studies done on the same variety, optimum N rates to attain the highest yields were determined by various researchers to be 120 kg ha^{-1} (Alan, 1990), 140 kg ha^{-1} (Başar *et al.,* 1996), and 240 kg ha^{-1} (Hakerlerler *et al.,* 1990). In our study, the application of 146 kg ha^{-1} of N was sufficient to achieve maximum tomato yield. As a result, utilization of specific combinations of water and nitrogen under different climate and soil conditions is very important in order to reach high tomato yields.

Water deficiency in the initial growth periods resulted in more yield losses than deficiencies in other periods of this experiment. Also, in the total growing period, the 0.46 unit of yield decrease per one unit of water deficiency and the 1.29 unit of yield decrease per one unit of nitrogen deficiency should be expected. It was discovered in a previous study that K_y values were higher during the flowering period (FAO, 2004), which could be due to N applications. FAO (2004) and Sagardoy *et al.* (1986) report that the K_y for total growing period on tomatoes was equivalent to 1.05.

I_{rc} values icreased when the N applications were less at both irrigation intervals. This can be explained as a result of decreasing N levels which led to the lower plant growth and consequently to the decrease in E_t. Such a condition increased the compensation rate of E_t by water applied. In I1 treatments, the I_{rc} values were found to be higher than in I2 treatments. I_{rc} values of treatments were higher than 90%, and irrigation programs had little effect on I_{rc}. In our study, the irrigation water compensation for E_t was over 90%, therefore, the irrigation programs used had almost no effect on the mentioned compensation rate.

Water-nitrogen-yield Analysis

While K_{cp}, N and I significantly affected yields, their interactions were not significant relative to yields (Table 4). According to Duncan's test, treatments were separated into three groups for K_{cp} ($K_{cp}1^c$, $K_{cp}2^b$ and $K_{cp}3^a$) and *N* ($N0^c$, $N1^b$ and $N2^a$). The highest group for I was I1 treatment. The highest yield group was represented by the $K_{cp}3$ and by the N2 treatments. Furthermore,

Table 4. Analysis of variance for examined growth parameters.

Variation sources	*df*	yield	Fruit number	Fruit diameter	Fruit length	Average fruit weight	Plant height	Lateral branch number	Stem diameter	Cover growth
		F-Values								
I	1	0.04*	35.5 *	0.79 ns	0.10 ns	3.43 ns	0.49 ns	1.05 ns	3.39 ns	0.63 ns
K_{cp}	2	0.002***	23.1***	28.0***	20.3 ***	17.7 ***	1.48 ns	0.45 ns	0.41 ns	0.11 ns
K_{cp}xI	2	0.596 ns	4.52*	0.31 ns	0.23 ns	1.07 ns	0.97 ns	0.39 ns	0.94 ns	0.23 ns
N	2	0.002***	254.7***	5.6 *	4.96 *	4.47 *	31.6***	20.9 ***	12.7***	0.00 ***
NxI	2	0.056 ns	3.2 ns	0.4 ns	1.75 ns	1.27 ns	0.57 ns	0.44 ns	0.08 ns	0.85 ns
NxK_{cp}	4	0.041 ns	0.44 ns	0.13 ns	0.58 ns	1.89 ns	1.13 ns	0.42 ns	0.68 ns	0.15 ns
NxK_{cp}xI	4	0.93 ns	0.83 ns	0.11 ns	1.04 ns	1.69 ns	0.41 ns	1.19 ns	0.68 ns	0.74 ns

* $P< 0.05$; * ** $P< 0.001$; ns: Non significant, df : Degree of freedom.

yields increased with increase in irrigation water levels despite that the same amount of N was applied, however $N \times K_{cp}$ interaction was non-significant. On the other hand, in spite of the similarity among N applications, the I1 treatments led to the increase in yields compared with the I2 treatments.

The yield response factors (K_{yEt} and K_{yN}) for water and nitrogen consumptions during the total growing period were determined to be 0.46 and 1.29, respectively (Figures 2-a and 2-c). The K_{yEt} values for initial period, crop development (flowering) period, mid-period (yield formation), and late-period (ripening) were 1.32, 0.40, 0.35, and 0.48, respectively (Figure 2-b). Figure 1-c indicates that the yield loss per one unit of *N* deficiency might be 2.8 times higher than yield loss per one unit of water deficiency.

Vegetative and Generative Growth Properties

Table 5 illustrates the treatment values for the following parameters; the fruit number (FN), the fruit diameter (FD), the fruit length (FL), the fruit weight (FW), the plant height (PH), the lateral branch number (LBN), the stem diameter (SD), and the cover growth (CG). The *FD*, *FL* and *FN* parameters were significantly affected by N and K_{cp}. While *I* produced no significant effect on *FD*, *FL* and on average *FW*, the effect of *I* on *FN* was significant. Thus, the increased frequency and the increased amount of irrigation water positively correlated with the increases in fruit numbers and of fruit yield. On the other hand, N fertilization

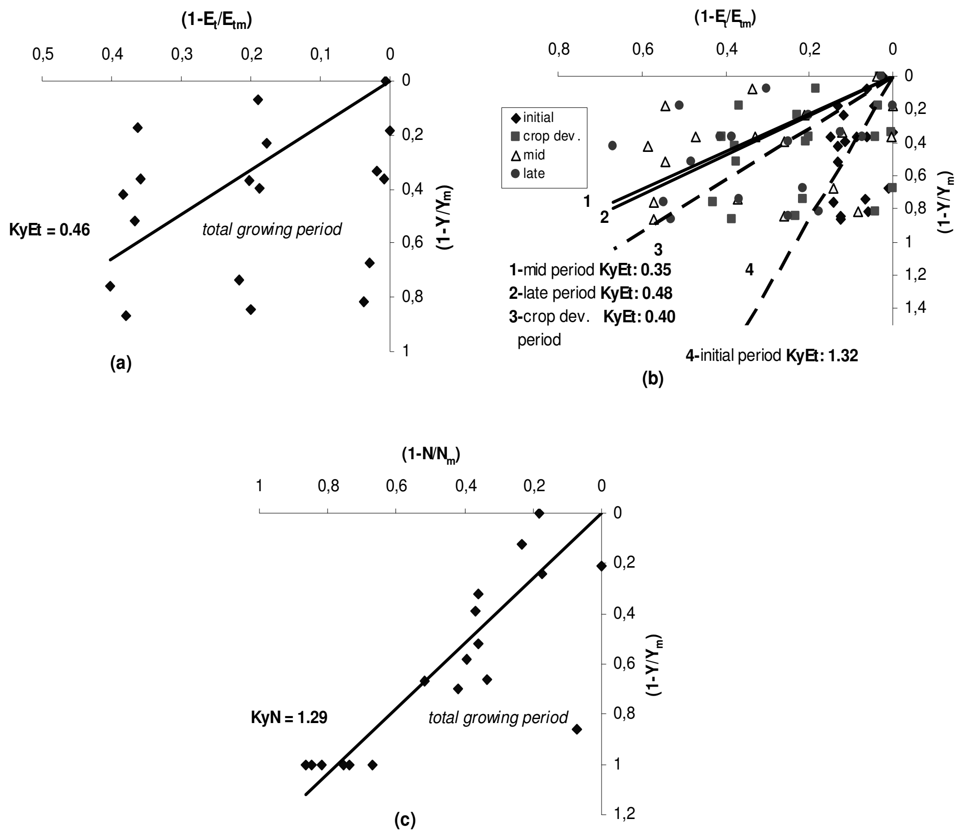

Figure 2. Relationships between relative yield decrease and relative E_t deficit (**a**); relative evapotranspiration deficit for different growth period (**b**), Relative N deficit (**c**) for the total growing period.

Table 5. The vegetative and generative growth properties*.

Treatments	*AFN* [a]	*FD* [b] mm	*FL* [c] mm	*AFW* [d] g	*PH* [e] cm	*LBN* [f]	*SD* [g] mm	*CG* [h] cm
I1K_{cp}1N0	193	52.26	72.32	80.13	55.5	6.2	12.0	61.2
I1K_{cp}1N1	215	52.60	73.41	90.07	47.8	6.0	10.3	66.2
I1K_{cp}1N2	255	53.54	74.21	82.6	51.5	6.8	10.3	70.2
I1K_{cp}2N0	405	56.01	78.51	92.2	58.3	7.3	12.8	89.2
I1K_{cp}2N1	434	55.96	77.43	93.83	61.7	7.3	11.3	93.8
I1K_{cp}2N2	431	57.35	78.41	99.53	57.5	7.0	12.1	98.3
I1K_{cp}3N0	570	55.87	77.46	93.33	67.8	9.0	13.0	113.2
I1K_{cp}3N1	562	56.65	78.19	106.3	67.0	8.5	13.1	123.5
I1K_{cp}3N2	663	56.61	78.26	96.9	65.5	7.5	12.3	123.2
I2K_{cp}1N0	104	50.67	71.45	83.45	46.8	6.7	10.2	63.5
I2K_{cp}1N1	121	52.30	71.82	80.87	48.7	5.5	10.0	57.8
I2K_{cp}1N2	148	53.48	73.82	82.07	43.5	6.2	10.3	65.8
I2K_{cp}2N0	349	55.42	77.28	88.73	55.3	7.7	11.8	86.9
I2K_{cp}2N1	439	55.90	78.77	88.91	64.5	7.7	11.3	82.5
I2K_{cp}2N2	430	57.53	79.00	95.60	52.7	7.5	12.1	92.2
I2K_{cp}3N0	477	54.71	76.26	85.98	70.0	8.7	11.8	107.0
I2K_{cp}3N1	538	55.06	77.26	91.57	66.3	7.8	12.5	105.5
I2K_{cp}3N2	518	56.47	78.66	101.9	65.7	9.3	12.6	118.0

[a] Average fruit number; [b] Fruit diameter; [c] Fruit length; [d] Average fruit weight; [e] Plant height; [f] Lateral branch number; [g] Stem diameter, [h] Cover growth.

significantly increased *PH*, *LBN*, *SD*, and *CG*. However, those parameters were not affected by either I or K_{cp} treatments.

Uexkull (1978) stated that the effect of nitrogen on vegetative and fruit yields was greater than that of any other nutrient. Nitrogen deficiency can cause stunted growth and high rates of flower shedding, whereas its excess supply delays maturity and decreases fruit sizes. Al-Mohammadi and Al-Zu'bi (2011) found average fruit weight enhanced by increased N level.

Water and Nitrogen Usage Efficiency and E_t/E_{pan} Changes

The *IWUE* was negatively correlated with irrigation water levels, but positively correlated with *N* application levels. The lowest and the highest *IWUE* values were 2.2 and 15.7 kg m^{-3}, respectively (Table 3). The effects of irrigation on *IWUE* under fertilized conditions were higher than those under unfertilized conditions. Nevertheless, the same amount of N applied with the increased irrigation water levels led to the decrease of the *IWUE*. The highest yields per one unit of water applied from both I1 and I2 treatments were obtained with the lowest water levels and the highest N levels (K_{cp}1N2). The *IWUE* was greater in I1 than in I2. Such a condition indicated that notwithstanding the same (cumulative) amount of water applied during both irrigation intervals, the extension of irrigation intervals led to the decrease in yields due to plant-water stress. Moreover, the nitrogen usage efficiencies (NUE) in the frequent irrigation treatments turned out to be higher than in the similar water application treatments in I2. The highest yield per one unit of N used by the plants was obtained in N1 treatments.

The tendency of all E_t/E_{pan} ratios to increase in treatments within the same irrigation program was quite similar to each other. Their seasonal mean values varied from 0.21 to 1.41 (Figure 3). The lowest E_t/E_{pan} ratios were obtained from K_{cp}1 treatments. However, the E_t/E_{pan} ratios from beginning through the end of the growing season increased in all treatments, except for K_{cp}1. They began to decrease again in September. The plant cover was not fully developed from the beginning to

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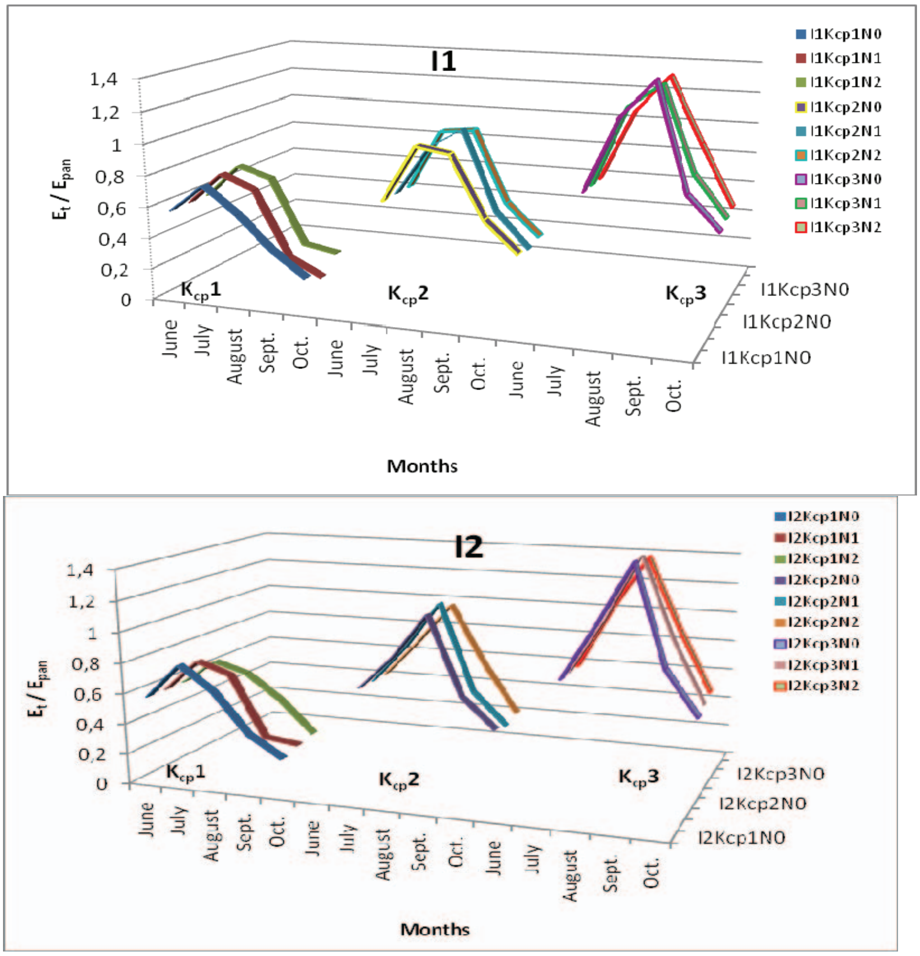

Figure 3. E_t/E_{pan} ratios in growing period in the I1 and I2 treatments.

the first irrigation, and E_t, therefore, as well as E_t /E_{pan} ratios were lower for that period. During the flowering and the fruit-setting stages (in the months of July and August), when the systemic irrigation began, the E_t / E_{pan} ratios, were highest due to the increase in E_t resulting from plant growth and canopy expansion. Notwithstanding the similar amount of water applied, E_t /E_{pan} ratio increased depending on N levels.

In conclusion, the effect of N on vegetative and generative properties was higher than the effects of I and K_{cp}. Viets (1962) found that both *WUE* and water usage increased with fertilization, as evidenced by increased transpiration as a result of promulgation of root growth and of vegetation. In the current study, plant cover was found to be greater under the higher N treatments applied with the same amount of irrigation water, while the evaporation from soil decreased and thus, irrigation efficiency improved. Ritchie (1983) suggested that an expansion of canopy may reduce soil evaporation thereby offseting the increased water losses directly from the plants. The *WUE* therefore can be improved, but it depends on the relative significance of those two processes. In the current study, the *IWUE* was found to be greater in I1 than in I2. Also, the soil-water contents before irrigations were closer to wilting point in I2 interval than those in *I1* treatments. Such situations indicate that despite the similar amounts of water (cumulatively) being applied between both irrigation intervals, the extension of irrigation intervals led to yield decrease due to plant-water stress.

Because the increased irrigation water and plant water consumption both heavily depended on each other, the *WUE* of the treatments similarly varied with the *IWUE*; *WUE* increased with N rates throughout all irrigation regimes. In all agricultural systems, a low *WUE* can occur when the evaporation from soil is high in relation to crop evapotranspiration, and the early growth rate is slow, as well as when the water applications do not meet crop demands while the shallow roots cannot utilize deep water in the soil (Stark et al., 1983; Doerge et al., 1991). The *WUE* of harvested yield for fresh tomatoes is from 10 to 12 kg m^{-3} (FAO, 2004). In our study, *WUE* values ranged from 2.1 to 14.3 kg m^{-3}, and they were strongly affected by water and *N* levels. The most economical yields under similar climate and soil conditions can be obtained by including I1K_{cp}1N2 treatments in irrigation scheduling because the high *WUE* increases productivity and decreases crop production costs (Bravo *et al.,* 1987).

As a result of E_t decline due to yields and canopy covers both diminishing towards the end of the season, E_t /E_{pan} ratio also tended to decline during that period. Previous studies had shown a significant linear correlation between E_t and canopy cover growth (Ertek *et al.,* 2004). A crop uses water at a fairly low rate during the initial period. As the crop develops, this rate increases, reaching its maximum in most instances while entering the flowering stage and thereafter declining as it reaches the plant maturity stage. The K_{cp} parameter for tomatoes at mid-season and at the final stage of growth under both humid and arid conditions was equal to 1.10, 0.65 and 1.20, 0.65, respectively (Doorenbos and Pruitt 1977). Doorenbos and Kassam (1979) stated that annual plants show an increasing trend in E_t /E_{pan} ratio throughout the middle of the growing period, then this trend leads to the lag phase, and eventually, in the end of the season, the E_t /E_{pan} ratio declines. Goldberg et al. (1976) discovered the positive linear correlation between E_t /E_{pan} ratio and plant cover to the point when the plant canopy covers 80% of the soil surface in plant rows.

In this study, the highest K_{cp} value was taken as 1, whereas the applied irrigation water in July and especially in August did not compensate for the E_t . Thus, it is clear that some part of plant water consumption during those months was made possible due to the water that had been previously stored in the soil profile. The K_{cp} values increased from 1.0 to 1.41 during those months (which are the periods of flowering and fruit maturity). Therefore, the most suitable irrigation programs can be built up taking into account the possible variations of E_t /E_{pan} ratios during the growing season. A lack of water at any growing stage reduces both yields and fruit qualities alike.

CONCLUSIONS

In the current study, the I1K_{cp}1N2 treatment provided higher irrigation efficiency and saved significant amounts of irrigation water. For example, while the highest yield was obtained from the I1K_{cp}3N2 treatment, 3080 t ha^{-1} of water was saved through the I1*K*cp1N2 treatment when tomato yield was reduced down by only 16.7 t ha^{-1}. With that amount of water saved, 48.46 t ha^{-1} of tomato can be produced. As a result, the total yield would reach up to 127 t ha^{-1} (78.90+48.46). This is evidently much more than the tomato yield obtained from the I1K_{cp}3N2 (95.61 t ha^{-1}). Therefore, to reach the most economical yield under similar climate and soil conditions, it is advised that irrigation be scheduled with 5-day intervals and K_{cp}= 1, and 160 kg ha^{-1} of N. Hovewer, the I1K_{cp}3N2 treatment should be preferred if the highest yield is supposed to be achieved while the water is abundant, but the cultivated area is scarce.

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سطوح کاربرد آب و نیتروژن به منظور بهینه سازی بازده گوجه فرنگی و کارایی مصرف آب

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چکیده

این مطالعه به منظور تعیین اثر سطوح مختلف کاربرد آب و نیتروژن بر گیاهان گوجه فرنگی آبیاری شده به روش قطره ای به انجام رسید. مقدار مصرف آب بر مبنای تبخیر از یک تشت تبخیر (کلاس A) بود. تیمارها شامل دو فاصله زمانی آبیاری (I1=۵ روز و I2=۱۰ روز)، سه ضریب گیاه-تشت ($K_{cp}1$ =۰/۵ ، $K_{cp}2$ =۰/۷۵ و $K_{cp}3$ =۱/۰۰) و سه سطح نیتروژن ($N0$ =۰، $N1$ =۸۰ و $N2$ =۱۶۰ $kg\ ha^{-1}$) بودند. سطوح مختلف I، K_{cp} و N بر بازده گوجه فرنگی و کارایی مصرف آب موثر بودند اما مشخص شد که اثر نیتروژن از عوامل دیگر بیشتر است. در نتیجه به منظور دستیابی به حداکثر بازده گوجه فرنگی در شرایط اقلیمی و خاک مشابه ، ضریب گیاه-تشت و مقدار نیتروژن باید به ترتیب ۱/۰۰ و ۱۶۰ $kg\ ha^{-1}$ تنظیم شوند.