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DETERMINATION OF IRRIGATION WATER REQUIREMENTS OF FIELD GROWN TOMATO USING CLASS A PAN EVAPORATION

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ABSTRACT: *The effect of different irrigation water amounts on tomato vegetative growth, yield and yield components, water use efficiency and plant minerals composition was studied in 2005 and 2006 in field conditions. Treatments consisted of four irrigation water amounts i.e., 50, 75, 100 and 125% times of class A pan evaporation value. The results indicated that increasing irrigation water amounts from 50 to 125% of class A pan value gradually increased plant vegetative growth i.e., plant height, number of branches / plant, number of leaves / plant, leaf area / plant and dry weights of different plant organs. However, irrigating tomato plants with the lowest ratio of class A pan (50%) gave the highest value of specific leaf weight and the deepest roots only, when measured at later growth stage (85 days after transplanting). Although, irrigation of tomato with 125% of class A pan gave the highest total and marketable yields, this particular treatment showed the lowest ratio of marketable yield / total yield. Such results also indicated that the marketable yield obtained by irrigation tomato with 100% in both seasons and that obtained by irrigation with 75% of class A pan value in one season did not significantly differ than marketable yield obtained when the highest ratio (125%) of A pan value was used. This may suggests that using amounts of water in irrigation equal or even lesser than that of 100% of class A pan value could be used successfully in irrigation tomato without severe reduction in yield. Fruits produced from plants received the lowest and moderate amounts of water i.e., 50 and 75% of class A pan showed the highest TSS, vitamin C and dry matter contents.*

Key words: *class A pan evaporation, tomato yield, water use efficiency, amount of irrigation water, fruit quality*

INTRODUCTION

Tomato, *Lycopersicon esculentum* Mill., is one of the most leading vegetable in economic importance throughout the world including Egypt. Tomato is a widely distributed annual vegetable crops which is consumed fresh, cooked or after processing: by canning, making into juice, pulp, paste, or as a variety of sauces. More than 30% of world production comes from countries around the Mediterranean sea and about 20% from California (FAO, 1995).

Egypt has a history of irrigated agriculture going back at least 6000 years. Almost all crops production depends entirely on irrigation, derived from the water of the river Nile, which is limited particularly in some years of drought at the sources, of river in Middle Africa. However, the Egyptian farmers and growers used to over irrigate their crops, especially under conditions of furrow irrigation, which is the most common method of irrigation in Egypt. This usually lead to raise the level of groundwater associated with salinity, alkalinity and spread of soil borne diseases. So, in order to rationalize water use in irrigation, it would be important to determine the actual water requirements for crops, which could be maintain only when farmers know the answers of the following questions; when field might be irrigate? and how much water might be applied? The metrological data obtained such as weather conditions and evaporation measurements of class A pan evaporation, could used successfully in determining the irrigation schedule for a crop.

Irrigation must be applied to minimize water stress and obtain maximum production with high fruit quality. Scheduling water application is also critical, as excessive irrigation reduce yield (Locasico *et al.*, 1989), while inadequate irrigation cause water stress and reduce production. Irrigation scheduling can be achieved using a continuously updated water balance; the estimate of the crop evapotranspiration (ET) by means of climatic data and crop characteristics is therefore required (Doorenbos and Pruitt, 1975).

Almost all plant biological process are affected directly or indirectly by the water supply. Metabolic activity of cells and plants is closely related to their water content (Mcllrath *et al.*, 1963

The objective of this study was to provide information about the proper irrigation water regime for tomato using class A pan evaporation, to realize the national goal which aims to rationalize the use of Nile water.

MATERIALS AND METHODS

The experiment was carried out in the open field at Kaha Horticultural Research Station, Agriculture Research Center, Ministry of Agriculture to study the growth and productivity of tomato with relation to different irrigation regimes

Seeds of tomato, cv. Floradade were sown in seed bed on the 15th of January of years 2005 and 2006. The seedlings were transplanted, 60 days afterwards.

Transplants were set on one side of the rows; 120 cm apart and 4 m. long with 40 cm between transplants. Each experimental unit consisted of 3 rows. The plot area was 14.40 m^2. The plots were separated by not less than 1.5 m from its counterpart neighbour plot to reduce treatment overlapping as possible.

The soil at the experimental site was clayey in texture. The physical and chemical properties of the soil are shown in Table (1).

Table (1): Physical and chemical properties of the soil under study*.

a. Physical properties:

Water field capacity (%)	Organic matter (%)	Total $CaCO_3$ (%)	Texture class
32.8	1.2	1.70	Clayey

b. Chemical properties:

pH 1:2.5 soil : water ratio	E.C dSm^{-1}	Available (ppm)			Soluble ions (meq / 100 gm soil)							
					Cations				Anions			
		N	P	K	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	$CO_3^{=}$	$SO_4^{=}$
8.22	0.346	42.5	7.66	337.5	0.82	0.32	0.43	0.17	0.91	0.68	–	0.15

* The soil was analyzed at soil Science Department, Faculty of Agric., Minufiya University.

To obtain good plant establishment all plots were irrigated as usually followed with tomato, in commercial farms, up to 25 days after transplanting. The next irrigation considered the beginning point of irrigation treatments. Field capacity and welting point were estimated according to the method described by Michael (1978). The available soil moisture was then determined.

Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm / day or mm / period. The level of ET has been shown to be related to the evaporative demand of the air. The evaporative demand can be expressed as the reference evapotranspiration (ET_o) which, predicts the effect of climate on the level of crop evapotranspiration. There are several methods used to calculate ET_o, one of those is pan evaporation methods.

The US Class A Pan Evaporation used in this study was similar to that standard descriptions mentioned by Allen *et al.* (1998).

Pan readings were taken daily in the early morning at the same time that precipitation is measured (if found).

Empirically-determined crop coefficients (Kc) can be used to relate ET_o to maximum crop evapotranspiration (ET_m) when water supply fully meets the water requirements of the crop. Kc values of tomato at different stages were taken from a Table shown in Doorenbose *et al.* (1979).

Water requirements determination were obtained and calculated according to the following equations of Doorenbos and Pruitt, 1977:

$$ET_o = Kp \times E\ pan = mm\ /\ day \quad \text{.............................} \quad (1)$$

where:

ET_o = potential evapotranspiration

Kp = pan coefficient = 0.85

E pan = pan evaporation in mm / day

$$ET\ crop = ET_o \times Kc = mm\ /\ day \quad \text{.............................} \quad (2)$$

where:

ET crop = crop water requirement.

ET_o = the rate of evapotranspiration from an excessive surface of green cover of uniform length (8 to 15 cm) actively growing, completely shading the ground and did not face shortage in water.

Kc = crop coefficient

WR = ET × L % = mm / day .... (3)

where:

WR = water requirements

ET = evapotranspiration in mm / day

L % = Leaching requirements = (1.25)*

Then water required / plot = WR × plot area

The calculated amount of water as previously mentioned considers as 100% of pan evaporation value.

In this experiment, four irrigation regimes were used; 50%, 75%, 100% and 125% times pan evaporation. Irrigation was applied when the available soil moisture in the treatment of 100% pan evaporation depleted to 60%.

Tap water was the source of the irrigation water, which was delivered to each experimental unit through rubber tube (3 cm in diameter). The amount of water was measured by using a normal water counter.

Soil moisture content was determined periodically between irrigations by taking soil samples from each / plot (by an auger), at 15 and 30 cm depth (root zone). Soil samples were immediately kept in moisture tins and were dried in an oven at 105°C till constant weight. Soil moisture percentage was calculated according to the following equation.

$$S.M.\ \% = \frac{\text{Loss of weight by drying}}{\text{Weight of oven dry soil}} \times 100$$

Where: S.M. % = Soil moisture percentage.

The date of irrigation was determined on the light of the soil moisture determinations, while irrigation water amount were applied according to the treatments of pan readings. All plots were fertilized, as commonly practiced (as recommended by Ministry of Agriculture) in tomato farms; i.e.; 400 kg/fed super phosphate (15.5% P_2O_2), 650 kg/fed $(NH_4)_2\ (SO_4)_3$ + 500 kg/fed calcium nitrate and 300 kg/fed potassium sulphate. Other cultural practices such as harrowing, pests and diseases control were applied when needed.

Three plant samples were taken from each plot (from outer rows only leaving the inner row for yield determination) at 21, 36 and 51 days after treatments initiation. Each plant sample consisted of 3 plants, the plants were dissected into different organs (roots, stems, leaves and fruits) and the following data were recorded:

Root length: (a great attention was paid in order to obtain the whole root as possible), plant height, number of branches / plant., leaf number/ plant, leaf area /plant, specific leaf weight (SLW), dry weight of roots, stems, leaf blades and petioles, fruit dry weight (the fruits which were found on the plant at sampling time) and relative growth rate (RGR).

Yield and its components were also determined as follows: early yield (is the fruit yield of the first three harvests), total yield (ripe fruits were harvested every 2 – 3 days/week) throughout the entire harvesting season, marketable yield (that was the weight of fruits which were free from disorders, malformations, rots and etc) and average fruit weight.

In addition fruit quality was also determined as follow: random samples of 5 ripe marketable fruits were taken from every plot, and the following data were recorded:

a) Total soluble solids (TSS): was determined using an Abbè hand Refractometer.

b) Ascorbic acid content was determined using the 2, 6, dichlorophenol indophenol dye and oxalic acid as extractor (A.O.A.C., 1965).

c) Dry matter content (%).

Plant water relations in tomato plants were also determined as follow:

a) Water use efficiency (WUE): It was measured according to the following formula.

$$WUE = \frac{\text{Yield (kg)}}{\text{Water applied (m}^3\text{)}}$$

b) Osmotic pressure: this character was calculated after determining the total soluble solids of the cell sap by using an Abbe Refrectometer and the values obtained were transformed to osmotic pressure by using special tables. The determination was carried out in vegetative growth stage (27 days after treatment initiation) and at fruiting stage (63 days after treatment initiation) in both seasons.

Chemical composition in leaves:

The following chemical constituents were determined in dried ground leaves taken at time of plant sampling.

1)Total nitrogen in young leaves was determined by micro kjeldahl method, as described by Pergel (1945).

2)Total phosphorus in young leaves was determined using the method described by Chapman and Pratt (1961).

3) Potassium and sodium in plant stem, and in young active (the 4^{th} and 5^{th} leaves from plant top) and old leaves (the 6 older leaves) was determined photometrically using the Elmar-flame Photometer Model 149.

Randomize Complete Block design with 4 replications were used.

The experimental design in this experiment was carried out according to the method described by (Snedecor, 1956). The data were subjected to the proper analysis of variance and the significance of differences between treatments was determined by least significant difference (Steel and Torrie, 1981).

RESULTS AND DISCUSSION

1. Vegetative growth characters:

1.1. Root length:

Root length was not significantly influence by irrigation regimes used, except in 2006 season, at 70 days after transplanting (DAT) i.e., 36 days after treatment initiation (Tables 2 & 3). Generally, root length at 70 DAT increased with increasing irrigation water amount from 50 to 125% class A pan evapotranspiration so the highest percentage of A pan evaporation (125%) gave the longest roots. While a reverse trend was observed at 85 DAT (51 days after treatment initiation) i.e., increasing irrigation water applied (From 50% to 125% of A pan evaporation) gradually decreased root length, but the differences between treatments were not significant in both seasons at this growth stage. These results are in accordance with those obtained by Sanders *et al.* (1989) who found that, greater tomato root length and density was obtained with 35% ET than when 70 or 105% ET were applied through trikle irrigation. In the recent study, high irrigation amount of water could enhance vegetative growth (including roots) at early stages, but plants continuously received low irrigation water amount may enhance root length, as roots looking for moisture in deeper soil layers, such root response may appear in later stages.

1.2. Plant height:

Water regimes showed a remarkable effect on tomato plant height especially at the later stages (85 DAT) where the differences between different treatments were significant (Tables 2 & 3). At 70 DAT, height of tomato plants were 35.4, 48.9, 56.3 and 57.0 cm in the first season and 33.5, 39.9, 42.9 and 50.0 cm in the second one for plants irrigated with 50, 75, 100 and 125% of the class A pan evapotranspiration, respectively. The corresponding plant height at 85 days after transplanting were 40.5, 50.3, 53.8 and 56.8 cm in the first season and 32.6, 45.5, 48.5 and 51.0 cm in the second one, respectively. The adequate water applied at the ratio of 100 and 125% of the class A pan encouraged growth and hence, the height of plant. These are in agreement with these obtained by Kirnak *et al.* (2002 and Carvalho *et al.* (2004) on eggplant. They found that, plant height increased with increasing irrigation water.

1.3. Number of branches / plant:

The results presented in Tables 2 & 3 clearly show that tomato plants irrigated at 125% A pan evapotranspiration gave more branches than those irrigated at 50, 75 and 100% A pan evapotranspiration. In other words, water deficit significantly reduced number of branches of tomato plants. This observation was more pronounced at 85 days after transplanting. However, there are no significant differences between obtained by irrigation at 75 and 100% of the class A pan. These results are true in both sampling dates and in both seasons. Byari and Al-Rabighi (1996) on eggplant came to similar results concerning the favorable effect of high soil moisture on number of branches per plant.

Table (2): Effect of different irrigation regimes on root length, plant height, number of branches / plant, number of leaves / plant, leaf area / plant and specific leaf weight (SLW) of tomato plants at 70 days after transplanting (at 36 days after treatments initiation) in 2005 and 2006 seasons.

Irrigation (%) from class A pan	2005 season						2006 season					
	Root length (cm)	Plant height (cm)	Number of branches / plant	Number of leaves / plant	Leaf area / plant (m^2)	SLW (%)	Root length (cm)	Plant height (cm)	Number of branches / plant	Number of leaves / plant	Leaf area / plant (m^2)	SLW (%)
50	35.4	43.4	11.3	85.3	0.581	56.203	30.3	33.5	5.6	46.8	0.273	67.000
75	38.6	48.9	12.0	106.5	0.864	54.921	31.0	39.9	6.1	50.6	0.395	66.608
100	40.9	56.3	13.0	108.0	1.280	50.556	38.3	42.9	6.6	56.6	0.578	59.580
125	43.9	57.0	17.8	155.5	1.546	49.384	48.6	50.0	9.6	70.8	0.969	54.506
LSD at 0.05	NS	9.244	2.619	14.763	0.263	4.896	9.205	7.741	1.904	NS	0.162	5.863

1.4. Number of leaves / plant:

Data presented in Tables 2 & 3 show the effect of irrigation regimes on leaf number. The results show that, there was a tendency that leaves number / plant increased with high irrigation water regimes compared with low irrigation water regime (50% class A pan) in both sampling dates, the differences were more pronounced at 85 days after transplanting in both seasons.

The detrimental effect of water deficit on plant leaf number was also detected by Byari and Al-Rabighi (1996) and Carvalho *et al.* (2004) on eggplant, who suggested that, water deficit decreased number of leaves per plant.

Table (3): Effect of different irrigation regimes on root length, plant height, number of branches / plant, number of leaves / plant, leaf area / plant and specific leaf weight (SLW) of tomato plants at 85 days after transplanting (at 51 days after treatments initiation) in 2005 and 2006 seasons.

Irrigation (%) from class A pan	2005 season						2006 season					
	Root length (cm)	Plant height (cm)	Number of branches / plant	Number of leaves / plant	Leaf area / plant (m^2)	SLW (%)	Root length (cm)	Plant height (cm)	Number of branches / plant	Number of leaves / plant	Leaf area / plant (m^2)	SLW (%)
50	38.6	40.5	8.8	68.5	0.471	61.827	33.4	32.6	5.8	55.6	0.213	73.252
75	35.6	50.3	15.0	108.3	1.047	55.781	31.9	45.5	10.0	98.8	0.566	61.049
100	34.7	53.8	16.0	113.0	1.295	51.644	30.0	48.5	11.0	99.7	0.750	55.971
125	32.5	56.8	17.0	144.5	1.532	49.747	28.5	51.0	12.0	100.3	0.986	54.892
LSD at 0.05	NS	8.909	3.945	25.334	0.295	6.995	NS	4.649	1.579	17.751	0.080	5.069

1.5. Leaf are / plant:

Data in Tables 2 & 3 reveal that the amount of irrigation water used, affected significantly average leaf area. Increasing irrigation water amount as a ratio of A pan values gradually increased leaf area / plant in both sampling dates and seasons. The increase percent of leaf area on plants received the higher amount of irrigation water (125% of A pan) was tremendously higher i.e., more than 200% (average of the two seasons) over those received 50% of class A pan, the counterpart value was more than 300% (average of the two seasons) at 70 and 80 DAT, respectively. This may suggests that, enough water applied, proves suitable soil moisture conditions for growth and expansion of leaves. The increase in number of leaves / plant with increasing water amount applied at high class A pan ratios was also responsible for further increase in plant leaf area, as a result of using such treatments. The obtained results on leaf area are in harmony with those reported elsewhere (Fattahallah, 1992 a, on tomato and Hegazi and Awad, 2002, on potato).

Reduction in leaf area of plants received the lowest class A pan ratio (50%) may be due to the relatively severe reductions in cell turgidity which reduce cell size and intercellular spaces. Similarly, Byari and Al-Rabighi (1996) on eggplant and Moreno *et al.* (2003) on pepper recorded that water deficit reduced leaf area. Also, Oppenheimer (1960) mentioned that, water stress decrease formation of new leaves and hence decrease total leaf area (assimilating surface).

The favourable effect of appling reasonable amount of irrigation water on plant growth may be due to increasing minerals uptake. As a result, adequate water application increased N uptake in pepper (Malash and Ahmed, 1990).

In addition the reduction in plant growth as the results of irrigation of tomato plants at the low level regime was explained by Pondey and Sinha (1972) who indicated that photosynthetic and enzyme activity were decreased under drought conditions. Also, the relatively high water saturation deficit in plant tissue caused various metabolic changes subsequently reflected in lower growth of plants (Chmela, 1994).

1.6. Specific leaf weight (SLW):

It is obvious from the data in Tables 2 & 3 that, there were significant variations in specific leaf weight (SLW) according to irrigation regimes. Irrigated tomato plants at the lowest ratio of class A pan (50%) gave the highest value of SLW compared with the other irrigation treatments (75, 100 or 125% class A pan). This result could be noticed in both sampling dates and in both seasons. Obtained results are in conformity with those of Manning *et al.* (1977) on pea plants, Hassan (2000) on pepper and Hegazi and Awad (2002) on potato. They reported that, specific leaf weight (SLW) decreased with increasing amount of irrigation water. Leaf thickness was regulated by the size of the palisted and spongy mesophyll cells. Plants grown at high moisture levels do not need to develop a full leaf mesophyll complement because of optimum water supply.

1.7. Dry weight of plant organs:

Effects of irrigation water regimes on dry weight of tomato plants are shown in Tables 4 & 5, it is quite clear that all irrigation regimes exerted a marked effect on dry weight of different organs of tomato plant. Generally, irrigation tomato plants at 125% class A pan produced the highest values of dry weight of roots, stems, leaves, fruits and entire plant, while irrigation at 50% class A pan produced the lowest values of dry weight of different plant organs. These results are true in both sampling dates and in both seasons.

These results are confirmed with the results of El-Beltagy *et al.* (1984) who found that, fresh and dry weights of tomato plants were greater under the wet regime, while drought treatment decreased plant growth. Also, Malash (1990) reported that, higher irrigation rate (5200 m^3 / feddan) enhanced vegetative growth of pepper. In addition, Fattahallah (1992 a) reported that, fresh and dry weights of tomato plant were increased with increasing the amount of irrigation water applied. Similarly, Si-Smail *et al.* (2003) indicated that, under 3 levels of water supply (maximum, one-half and one-fourth and evpotranspiration), shoot dry weight of tomato plant was positively affected by increasing water supply without restriction. Also, Byari and Al-Sayed (1999) found that, water deficit decreased dry weight of stems, leaves and roots of tomato plants. Such result may be due to less dry matter accumulation in plants under water deficit conditions (Moreno *et al.*, 2003). In addition to the restriction of plant vegetative growth as a result of insufficient water applied.

Table (4): Effect of different irrigation regimes on dry weight of roots, stems, leaves, fruits and entire plant of tomato plants at 70 days after transplanting (at 36 days after treatments initiation) and relative growth rate (RGR) taken between the period from 55 to 70 days after transplanting (from 21 to 36 days after treatments initiation) in 2005 and 2006 seasons.

Irrigation (%) from class A pan	2005 season						2006 season					
	Dry weight of roots	Dry weight of stems	Dry weight of leaves	Dry weight of fruits	Dry weight of entire plant	RGR (g / week)	Dry weight of roots	Dry weight of stems	Dry weight of leaves	Dry weight of fruits	Dry weight of entire plant	RGR (g / week)
50	6.52	40.63	32.66	9.53	89.35	0.5292	3.09	19.23	18.19	13.35	54.10	0.3163
75	8.38	53.88	45.29	9.86	117.39	0.5861	4.87	27.77	26.31	17.71	76.66	0.3558
100	9.75	59.46	68.09	15.48	152.73	0.6694	6.28	36.23	34.16	32.10	108.76	0.4496
125	14.16	106.29	79.05	11.69	211.20	0.6339	11.06	59.11	52.42	36.87	158.96	0.5064
LSD at 0.05	3.183	21.333	14.859	5.832	27.972	0.0889	1.926	9.283	7.251	12.499	24.220	0.1100

1.8. Relative growth rate (RGR):

Data presented in Tables 4 & 5 reveal that, RGR was significantly affected by irrigation regimes. Irrigation tomato plants with high amount of water increased RGR at the early stage (between 55 to 70 days after transplanting). However, irrigation tomato plants at 75% class A pan gave the highest values of RGR in the late period (70 – 85 days after transplanting) in the two growing seasons. Irrigation tomato plants at 100% class A pan gave the second highest value of RGR. While using 50 or 125% class A pan in irrigation decreased RGR. This result suggested that, both highest and lowest amounts of irrigation water decreased RGR, whereas moderate amounts produced higher value of this character.

Irrigation tomato plants at adequate water supply was favourable to give good solubility of soil nutrients and its uptake. Also, suitable soil moisture enhanced photosynthesis and the translocation of the assimilates to different plant organs. On the other, hand, the reduction in plant water potential (under water stress conditions) tends to close the stomata which interferes with carbon dioxide and hence with growth (Winter, 1981). Also, the unfavourable effect of water deficit on relative growth rate may be due to, the reduction in the uptake of nutritional elements (Slatyar, 1969), that causes a disturbance in the physiological process needed for plant growth. Another explanation could be built upon the fact that, water deficit causes a reduction in leaf area, formation of new leaves and photosynthesis rate (Brix, 1962, and Fisher and Hagan, 1965) and increased chlorophyll destruction, (Zelepuhin, 1969) and such factors may negatively affected plant growth.

Table (5): Effect of different irrigation regimes on dry weight of roots, stems, leaves, fruits and entire plant of tomato plants at 85 days after transplanting (at 51 days after treatments initiation) and relative growth rate (RGR) taken between the period from 70 to 85 days after transplanting (from 36 to 51 days after treatments initiation) in 2005 and 2006 seasons.

Irrigation (%) from class A pan	2005 season						2006 season					
	Dry weight of roots	Dry weight of stems	Dry weight of leaves	Dry weight of fruits	Dry weight of entire plant	RGR (g / week)	Dry weight of roots	Dry weight of stems	Dry weight of leaves	Dry weight of fruits	Dry weight of entire plant	RGR (g / week)
50	3.93	36.60	28.59	58.39	125.97	0.1363	3.26	26.16	15.52	31.33	76.14	0.1702
75	7.64	78.55	57.97	81.15	225.29	0.3117	7.16	48.11	34.65	55.01	144.92	0.3369
100	9.57	95.08	67.11	96.08	267.82	0.2470	10.38	67.63	40.38	66.03	184.42	0.2559
125	10.83	113.27	76.75	126.44	326.10	0.2451	14.12	88.06	54.03	78.43	234.64	0.2509
LSD at 0.05	2.237	16.570	15.248	32.026	46.629	0.0671	2.416	19.437	6.377	25.930	42.675	0.0594

The reduction of relative growth rate observed when 125% of class A pan was used mainly may due to the reduction in dry matter accumulation in plant organs as a result of irrigation with high amount of water.

Our obtained results are in harmony with those found by El-Beltagy *et al.* (1984) who found that, relative growth rate (RGR) was affected by watering treatments.

2. Yield and its components:

2.1. Early yield (kg / plot):

Data presented in Table 6 showed that increasing amounts of irrigation water (50, 75, 100 and 125% class A pan) gradually increased early yield of tomato plants. Thus, the highest record of early yield was obtained by plants irrigated with the highest amount of water, i.e., 125% class A pan, whereas, the lowest amount of water regime, i.e., 50% class A pan showed the lowest value of early yield. The second and third highest early yield were obtained when tomato irrigated, respectively with 100 and 75% of class A pan ratios meanwhile, the differences between early yield obtained in these two irrigation regimes were not significantly differ than early yield when 125% ratio used only in 2005 season.

These results are in accordance with those obtained by Pimpini *et al.* (1985) on tomato who indicated that, seasonal watering volumes equal to "class A pan" evaporation (E) increased early yield more than application of 0.5 E. Well watered plants initially demonstrated higher canopy photosynthesis which resulted in early fruit growth compared with other treatments (Alvino *et al.,* 1990 a). In addition, Tuzel *et al.* (1994 a) on tomato and El-Nemr (1997) on pepper indicated that, the highest soil moisture treatment gave the highest early yield. However, Malash (1990) reported that, the second highest amount of irrigation water treatment (3900 m^3 / fed) gave the highest early yield (fruit weight and numbers) of pepper than those obtained when higher or lower amounts were used. He added that, the second highest early yield was obtained with the highest amount of irrigation water (5200 m^3 / fed).

2.2. Total yield (kg / plot):

Total yield of tomato fruits was strongly influenced by different irrigation regimes. The results given in Table 6 elicit that, total fruit yield of tomato was significantly increased by increasing amount of irrigation water. On other words, irrigation tomato plants, at 125% class A pan gave the highest total yield / plot. These results were true in both seasons. The second highest total yield was obtained by irrigation tomato at 100% class A pan, which was not significantly differ than that produced by 125% ratio of A pan only in 2005 season.

Table (6): Effect of different irrigation regimes on early, total, marketable yields / plot (14.40 m^2), marketable yield/total yield (%) and average fruit weight of tomato in 2005 and 2006 seasons.

Irrigation (%) from class A pan	2005 season					2006 season				
	Early yield (kg/plot)	Total yield (kg/plot)	Marketable yield (kg/plot)	Marketable yield / total yield (%)	Average fruit weight (g)	Early yield (kg/plot)	Total yield (kg/plot)	Marketable yield (kg/plot)	Marketable yield / total yield (%)	Average fruit weight (g)
50	13.30	45.43	43.51	95.77	50.23	17.75	26.36	25.78	97.80	42.58
75	19.23	52.15	50.30	96.45	53.57	23.91	34.01	33.35	98.06	51.11
100	23.10	56.17	54.17	96.44	57.09	24.92	35.67	34.99	98.09	54.06
125	24.70	58.78	54.36	92.48	59.25	30.35	41.86	39.57	94.53	57.43
LSD at 0.05	5.855	5.468	5.402	--	6.896	3.225	3.921	4.023	–	3.254

Canopy temperature decreased as the amount of water restored increased and was significantly and negatively correlated with leaf water potential.

Moreover, it was significantly and negatively correlated with fruit yield and plant dry weight (Mauromicale *et al.*, 2002).

Somewhat similar results were obtained by Mostaghimi and Mitchell (1982), Pimpini *et al.* (1985), Hermus (1986), Rubino and Tarantino (1988), Alvino *et al.* (1990 b) and Barua *et al.* (1997) who reported that the highest tomato yield was obtained from irrigation with amount of water similar to ET value i.e., that equal to "class A" pan evaporation (1.0 × ^{E}pan). On the other hand, low amount of water applied (25% ET) generally reduced tomato fruit set but the reduction varied according to varieties (Wudiri and Henderson, 1985). While, relatively higher water application i.e., 1.3 times pan evaporation reduced tomato yield by reduced N, P and K absorption (Ferreyra *et al.*, 1987). They added that, yields were highest with 0.7 times pan evaporation.

2.3. Marketable yield and its ratio to total yield:

Amount of irrigation water calculated according to class A pan evapotranspiration method exerted considerable effect on marketable yield of tomato plants as shown in Table 6. Although, irrigation tomato plants by 125% of class A pan evapotranspiration treatment increased marketable fruit yield, this particular treatment showed the lowest ratio of marketable yield / total yield. Such ratio, however, was higher when tomato irrigated with moderate amounts of water i.e., 75 and 100% of class A pan. The slight reduction in this ratio observed when tomato irrigated with 50% of class A pan was mainly due to the susceptibility of fruits to the physiological disorder blossom end rot which is commonly occurs under water deficit. On the other high reduction in ratio of marketable yield / total observed when 125% of class A pan was mainly due to the infection of fruits with rots as the results of increasing amount of water.

These results are confirmed with Ferreyra *et al.* (1985) who reported that marketable fruit yields of pepper were highest with 0.7 times pan evaporation compared to 0.3, 1.0 or 1.3 times Class A pan evaporation. In addition, Costa and Gianquinto (2002) reported that, the highest and lowest marketable yield of bell pepper were obtained from plants irrigated with 120 and 40% ET, respectively. They added that marketable yield did not differ among treatments of 60, 80 and 100% ET.

2.4. Average fruit weight (gm / fruit):

Average fruit weight (Table 6) was also increased as the amounts of irrigation regimes increased from 50 to 125% class A pan. Full turgid of cells in fruits that produced from plants received high amounts of irrigation water indeed increases fruit size and weight. These findings are in agreement with those obtained by Tedeschi and Zerbi (1985) who showed that, average fruit weight of eggplant was linearly related to evapotranspiration.

In addition, Kirnak *et al.* (2002) found that, well watered treatment receiving 100% replenishment of a pan evaporation on a daily basis produced the largest and the heaviest fruits than other watering treatments. Si-Smail *et al.* (2003) found that, mean fruit weight of tomato was positively affected by amount of water applied (maximum, one-half and one-fourth evapotranspiration) without restriction. Similarly, Ortega-Farias *et al.* (2003) found that, tomato fruit weight reduced as the water application decreased.

3. Fruit quality:

Data in Table 7 indicate that fruit TSS and vitamin C contents tended to decrease by increasing irrigation amount i.e., 100 and 125% class A pan evapotranspiration. So, fruits produced from plants irrigated at the lowest irrigation regimes i.e., 50 and 75% class A pan showed the highest TSS and vitamin C contents. Using the lowest amount of irrigation water i.e., 50% of class A pan reduced water uptake in fruits which led to increases in solute concentrations, particularly sugars, and hence increased TSS. Also, vitamin C increased as sugars are necessary of its formation.

The increase in soluble solids in tomato fruits as water application decreased was also found elsewhere (Alvino *et al.,* 1980; Yadav *et al.,* 1992; Tüzel *et al.,* 1994 b; Candido *et al.,* 2000 a and Ortega-Farias *et al.,* 2003). In addition, vitamin C content in fruits likewise TSS decreased with increasing amount of irrigation water or with increasing soil moisture content (El-Beltagy *et al.,* 1984 on tomato; Malash, 1990 on pepper; Mary and Balakrishnan, 1990 on pepper).

Concerning the effect of different irrigation regimes on dry matter % in tomato fruits, it is clear from data in Table 7, that there significant differences between all irrigation regimes in this respect in the two seasons. Dry matter % in tomato fruits were decreased by using 1.25% class A pan compared with other irrigation regimes i.e., 50, 75 and 100% class A pan.

Table (7): Effect of different irrigation regimes on total soluble solids (TSS), dry matter % and ascorbic acid in tomato fruits in 2005 and 2006 seasons.

Irrigation (%) from class A pan	2005 season			2006 season		
	TSS (%)	Dry matter (%)	V.C (mg/100 g fresh weight)	TSS (%)	Dry matter (%)	V.C (mg/100 g fresh weight)
50	5.30	6.71	31.78	8.10	2.77	33.65
75	4.80	6.39	29.56	5.80	2.72	32.73
100	4.60	6.36	28.04	5.60	2.62	29.74
125	4.40	5.82	24.30	5.20	1.92	26.87
LSD at 0.05	0.647	0.529	3.712	0.584	0.374	5.120

These results are in accordance with those obtained by Tüzel *et al.,* 1994 b who found that dry matter content of tomato fruits however decreased by using 1.2 pan coefficient compared with the other treatments i.e., 0.6, 0.8 and 1.0 pan coefficients. Similarly, Candido *et al.* (2000 b) found that, dry matter content of tomato fruits was at highest value in non-irrigated control compared with the other irrigated treatments. Also, Ortega-Farias *et al.* (2003)

found that, dry matter increased as water application decreased (60, 100, 140% of the actual evapotranspiration).

4. Mineral contents in leaves:

4.1. Nitrogen, phosphorus and potassium contents:

Concerning the effect of different irrigation regimes on N content of tomato leaves, data in Tables 8 & 9 i.e., at 70 and 85 DAT and in both seasons show that leaf N contents (%), with few exceptions, were higher in leaves of plants received the moderate amounts of water i.e., 75 and 100% of class A pan value than other two treatments. N uptake however, showed different response to the irrigation regimes used; N uptake gradually and consistently increased with increasing amounts of irrigation water i.e., increasing ratios from 50 to 125% of the ET value.

Table (8): Effect of different irrigation regimes on nitrogen, phosphorus, potassium contents and uptake in tomato leaves at 70 days after transplanting (at 36 days after treatments initiation) in 2005 and 2006.

Irrigation (%) from class A pan	2005 season						2006 season					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)
50	3.08	1.001	0.362	0.118	3.13	0.899	3.00	0.541	0.267	0.049	2.93	0.490
75	3.47	1.573	0.432	0.194	2.78	1.415	3.10	0.856	0.284	0.075	2.70	0.770
100	3.43	2.340	0.534	0.390	3.43	2.335	3.15	1.078	0.338	0.116	3.32	1.133
125	3.19	2.511	0.389	0.307	3.64	2.874	3.08	1.611	0.316	0.168	3.22	1.692
LSD at 0.05	NS	0.587	NS	0.188	0.473	0.560	0.175	0.209	0.023	0.027	0.102	0.241

P contents (%) and uptake followed similar trend to that observed with nitrogen content and uptake. In other words, P content (%) was higher in leaves of plants received moderate irrigation water amounts particularly when 100% of ET was used, in both sampling dates and seasons (Tables 8 & 9).

In the case of applying moderate amounts of irrigation water, such adequate water in soil provides good conditions for N and P uptake by plants and produce a balanced growth, meanwhile reasonable amount of water uptake to leaves under such conditions did not reduce concentrations of N and P contents (%). Also, with increasing leaf area as a result of increasing irrigation water amount (observed early in this study) may responsible for increasing uptake of such minerals. This may explain the response of N and P contents and uptake to irrigation regimes used in this study.

Table (9): Effect of different irrigation regimes on nitrogen, phosphorus, potassium contents and uptake in tomato leaves at 85 days after transplanting (at 51 days after treatments initiation) in 2005 and 2006.

Irrigation (%) from class A pan	2005 season						2006 season					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)	%	Uptake (g/plant leaves)
50	2.73	0.781	0.189	0.054	2.70	0.772	2.14	0.329	0.282	0.044	2.13	0.330
75	2.80	1.618	0.284	0.167	2.78	1.710	3.08	1.070	0.326	0.113	2.57	0.891
100	2.87	1.928	0.390	0.257	2.95	1.861	2.70	1.094	0.392	0.159	2.51	1.011
125	2.63	2.019	0.302	0.232	3.18	2.448	2.49	1.342	0.316	0.171	2.65	1.432
LSD at 0.05	0.237	0.362	0.192	0.141	0.033	0.381	0.231	0.182	0.087	0.037	NS	0.270

Potassium uptake followed similar response as did N and P to the irrigation regimes used in this study (Tables 8 & 9). However, K content (%) showed (with few exceptions particularly at 85 DAT) a tendency to increase with increasing irrigation water amount. The high concentration and mobility of K in the transpiration stream in plants, may increase its concentration (%) in leaves.

Somewhat, similar results were obtained by Ferreyra *et al.* (1987) on pepper who suggested that excessive water application (1.3 times pan evaporation) significantly reduced N, P and K absorption. They added that, at 0.7 times pan evaporation, N, P and K absorption rates were higher. Also, Malash and Ahmed (1990) on pepper and Fattahalla (1992 a) on tomato showed that increasing amounts of irrigation water resulted in increasing P and K contents in leaves. However, Locascio *et al.* (1995) found that, leaf tissue N concentrations were reduced by an increase in water quantity applied (0, 0.17, 0.34 and 0.50 times pan evaporation), which is similar to the results of this study. Karaman *et al.* (1999) indicated that N uptake decreased with utilization of 1.00, 1.25 and 1.50 C referring to class A pan evaporation coefficients possibly due to the high N leaching losses with these practices.

It could concluded then that minerals concentration and uptake not only depend on irrigation water regimes and amount of irrigation water added but also for soil physical and chemical properties and for environmental conditions such as temperature and relative humidity.

5. Plant water relations:

5.1. Osmotic pressure of leaf blade and relative water content:

Results in Tables 10 & 11 show that at vegetative growth stage (at 57 days after transplanting), there were no significant differences between both OP and RWC as a result of using the recent irrigation regimes in 2005 season. However, at the same stage but in 2006 season, the differences showed significance, but no constant trend was detected (Table 10). At fruiting stage (at 66 days after transplanting), the values of OP were decreased however, RWC were increased with increasing irrigation water amount i.e., 50, 75, 100 and 125% class A pan evapotranspiration. However, differences between OP values as influenced by such water regimes were not significant in 2006 season. Previous study carried out by Kirnak *et al.* (2002) also revealed that, water-stressed treatment gave relative water content which was similar to that of well-watered treatment.

Table (10): Effect of different irrigation regimes on osmotic pressure of leaf blade and relative water content (RWC) in leaves of tomato plants in vegetative growth stage at 57 days after transplanting (27 days after treatments initiation) in 2005 and 2006.

Irrigation (%) from class A pan	2005 season		2006 season	
	Osmotic pressure (OP) of leaf blade (-MPa)	Relative water content (RWC)	Osmotic pressure (OP) of leaf blade (-MPa)	Relative water content (RWC)
50	10.85	88.50	10.05	91.59
75	12.30	84.46	11.69	88.18
100	12.76	90.36	11.14	92.28
125	11.56	90.50	10.20	91.26
LSD at 0.05	NS	NS	1.274	2.429

Table (11): Effect of different irrigation regimes on osmotic pressure of leaf blade and relative water content (RWC) in leaves of tomato plants at fruiting stage at 93 days after transplanting (63 days after treatments initiation) in 2005 and 2006.

Irrigation (%) from class A pan	2005 season		2006 season	
	Osmotic pressure (OP) of leaf blade (-MPa)	Relative water content (RWC)	Osmotic pressure (OP) of leaf blade (-MPa)	Relative water content (RWC)
50	12.65	90.66	11.42	91.20
75	12.16	94.53	11.14	94.23
100	9.82	96.93	10.72	96.20
125	9.43	98.98	10.46	98.99
LSD at 0.05	2.000	5.279	NS	2.896

5.2. Water use efficiency (WUE):

Data shown in Table 12 show that water consumptive use of tomato (m^3 / plot) was gradually and consistently increased as the amounts of irrigation water increased. This is quite expected as ETa values increased. However, WCU amounted to 4.584, 6.876, 9.169 and 11.461 m^3 / plot in the first season and 5.243, 7.865, 10.486 and 13.140 m^3 / plot in the second season, respectively for tomato plants irrigated by 50, 75, 100 and 125% of class A pan method. The variance of amount of water between the two seasons may be due to increase values of ET pan (mm) in the second season than the first season (Table 13).

Water use efficiency (calculated as kg fruits produced per a unit of water applied throughout the season i.e., kg / m^3) of tomato decreased markedly as the water consumption use increased (Table 12). WUE were 9.910, 7.585, 6.126 and 5.129 kg / m^3 in the first season and 5.027, 4.324, 3.400 and 3.185 kg / m^3 in the second season when tomato plants were irrigated by 50, 75, 100 and 125% of class A pan. These obtained results suggest that the increase in irrigation water by increase ratios relevant to class A pan value did not increase fruit yield parallel with increasing amount of water applied. So, one who interesting in rationalize irrigation water (which is a national goal in many countries, particularly those in arid and semiarid regions) might balance between amount of irrigation water applied and yield obtained.

Table (12): Effect of different irrigation regimes on water consumption use and water use efficiency of tomato plants in 2005 and 2006.

Irrigation (%) from class A pan	2005 season			2006 season		
	Water consumption use (WCU)		Water use efficiency (WUE) (kg / m^3)*	Water consumption use (WCU) (m^3 / plot)		Water use efficiency (WUE) (kg / m^3)*
	m^3 / plot	m^3 / m^2		m^3 / plot	m^3 / m^2	
50	4.584	0.318	9.910	5.243	0.364	5.027
75	6.876	0.478	7.585	7.865	0.546	4.324
100	9.169	0.637	6.126	10.486	0.728	3.400
125	11.461	0.796	5.129	13.140	0.913	3.185
LSD at 0.05	-		0.649	-		0.587

$$\text{* Water use efficiency (WUE)} = \frac{\text{kg / plot}}{\text{m}^3 \text{ / plot}}$$

The goal of rationalization of irrigation water is aggravated nowadays, so, it should be important to choose the suitable irrigation regime which prove using less amount of water without significant reduction in marketable yield. The results of this study (Table 6) showed that marketable yield obtained by irrigation with 100% of class A pan value in both seasons and that obtained by irrigation with 75% of class A pan in one season did not significantly differ than marketable yield obtained when the highest amount of water (125% of class A pan) used. This may suggests that using amount of water in irrigation equal to the value of class A pan (100%) or even lesser amount of water i.e., 75% of class A pan could used successfully in irrigation tomato without severe reduction in yield. Meanwhile, fruit quality was better when less water amount used (Table 7). So, we recommend increasing number of metrological data stations in everywhere in the country, to use their data particularly the measurements of class A pan evaporation, in determining when and with how much irrigation water might be applied.

Table (13): The values of ET pan (mm) during the months under study in 2005 and 2006 seasons.

Months	Values of ET pan (mm)	
	2005 season	2006 season
April	5.82	6.33
May	8.88	9.44
June	9.57	10.23
July	8.99	9.65

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تقدير احتياجات مياه الري للطماطم المنزرعة فى الحقل باستخدام وعاء النتح بخر

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الملخص العربى

أجريت تجربة حقلية فى عامى ٢٠٠٥ ، ٢٠٠٦ تحت ظروف الحقل لدراسة تأثير كمية ماء الرى على النمو الخضرى ، المحصول ومكوناته ، كفاءة استخدام المياه والعناصر فى نباتات الطماطم . تم استخدام ٤ كميات من ماء الرى هى ٥٠ ، ٧٥ ، ١٠٠ و ١٢٥% من قراءة وعاء النتح بخر . ولقد تم استخدام ماء الصنبور كمصدر لماء الرى حيث تم إضافته لكل وحدة تجريبية من خلال خرطوم . وتم قياس كمية المياه باستخدام عداد مياه عادى . ولقد أوضحت النتائج أن زيادة كمية مياه الرى من ٥٠ إلى ١٢٥% من قراءة وعاء النتح بخر تعمل على زيادة النمو الخضرى للنبات مثل ارتفاع النبات ، المساحة الورقية / نبات والوزن الجاف لأجزاء النبات المختلفة . بينما أدى رى نباتات الطماطم بأقل نسبة من قراءة وعاء النتح بخر (٥٠%) إلى أعلى قيمة من الوزن النوعى للورقة وكذلك أعمق جذور فقط عند قياسها عند مرحلة النمو المتأخرة وهى ٨٥ يوم بعد الشتل . وبالرغم من أن رى الطماطم بـ ١٢٥% من وعاء النتح بخر أعطى أعلى محصول كلى وتسويقى إلا أن هذه المعاملة أعطت أقل نسبة من المحصول التسويقى / المحصول الكلى . وأوضحت النتائج أيضاً أن المحصول التسويقى الناتج من الرى باستخدام ١٠٠% فى كلا الموسمين والمحصول الناتج بالرى باستخدام ٧٥% من قراءة وعاء النتح بخر فى موسم واحد فقط لا يختلف معنوياً عن المحصول التسويقى الناتج

من استخدام أعلى كمية من الماء (١٢٥% من قراءة وعاء النتح بخر) . هذا ويُمكن إقتــراح استخدام كميات من ماء الرى تُعادل أو حتى أقل من ١٠٠% من قراءة وعاء النتح بخر بنجاح فى رى الطماطم بدون نقص واضح فى المحصول . أدى إستخدام أقل كمية والكميــة المعتدلــة مثل ٥٠ ، ٧٥% من قراءة وعاء النتح بخر إلى أعلى محتوى للثمار من المواد الصلبة الذائبة الكلية ، فيتامين ج والمادة الجافة .