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The effects of regulated deficit irrigation on yield and certain fruit characteristics of tomato (*Solanum lycopersicon* mill)

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1 ABSTRACT

Studies on effective use of water resources for sustainable agricultural production are necessary to achieve the required food production to meet the growing demand in the world. This study was conducted, under the field conditions to determine the effects of regulated deficit irrigation (RDI) on yield, and to suggest irrigation management guidelines for tomato farming in the semi-arid area. Irrigation was applied in three-day intervals, at ratios of 133% (T_1), 100% (T_2) and 66% (T_3), as determined from the amount of total irrigation (IW)/total evaporation (CPE) for different three growth stages. Although the greatest water saving was 43%, the yield loss was increased up to 62%. The total fruit yield ranged from 33.34 t ha^{-1} to 83.59 t ha^{-1}. The water savings were 21% and 43% for the T_2 and T_3 treatments, respectively, compared with the T_1 treatment. In tomato, the water saved with deficit irrigation does not compensate for the yield reduction that resulted under these experimental conditions.

2 INTRODUCTION

Tomato (*Solanum lycopersicon*) is one of the most commonly cultivated and consumed vegetable with more than 161 million tons produced (on 4.8 million hectares) annually worldwide (FAO, 2014). According to recent data, 11.8 million tons of tomato is produced (on 304.000 hectares) annually in Turkey. The share of processing tomatoes in total tomato production is approximately 3.9 million tons. A large proportion of tomatoes are processed as paste, sun-dried, cubic-cut, mash and frozen products (TUIK, 2015). Studies on the effective use of natural resources, responding appropriately for sustainable production and good agriculture practices, are necessary to achieve the food production required to meet the growing demand for food around the world. One of the main reasons for low productivity in agriculture is the use of inadequate or inappropriate irrigation practices. At present, 73% of the total global arable land does not have any irrigation management system. Due to the fact that more than 60% of this land is located in emerging and relatively undeveloped countries, there is a need for improving irrigation practices which require changing policies and methods of irrigation in arid and semi-arid regions. Considering that, 70% of the fresh water around worldwide is used for agriculture (www.worldwaterforum5.org), limited irrigation practices can be an appropriate means of saving water for extensive tomato cultivation.

Irrigation is artificial application of water to the soil, properly in time, amount, and in proper technique, when plants can not met their water needs for growing and development through natural precipitation to assist; increasing crop yields, improving crop quality, effective management of crop water needs, provide the opportunity for double cropping etc. There are three main irrigation systems called surface irrigation, sprinkler irrigation and drip irrigation. Because of all methods have their advantages and disadvantages, to choose an irrigation method suits the local conditions, the advantages and disadvantages of the various methods must known. The suitability of the various irrigation methods depends mainly on water availability, natural conditions, type of crop, type of technology, required labour inputs, costs and benefits. Surface irrigation is the easiest and least costly method, but is usually highly inefficient, only less than 10% of the water is taken up by the plant. Sprinkler irrigation systems are more efficient than surface irrigation, but, more costly to install and operate. Drip irrigation is highly efficient because only the immediate root zone of each plant is wetted. This system also allows precise application of water-soluble fertilizers and other agricultural chemicals. Drip irrigation is reported to help achieve yield gains of up to 100%, water savings of up to 40-80%, and associated fertilizer, pesticide, and labor savings over conventional irrigation systems (Mirata and Emtairah, 2010). Water efficiency in agriculture has been extensively researched for many years. Increase productivity and water efficiency of irrigation can be improved by making the right crop selection, proper irrigation planning, and effective irrigation techniques. When plants cannot meet all their water needs through natural precipitation irrigation is necessary. Irrigation effort should aims to cover the deficit between a crop's optimal water needs and what it can take up through natural means. Irrigation is necessary in arid and semi-arid region. Crops need different amounts of water at different growth stages. Regulated deficit irrigation (RDI) method is important for the development of strategies for optimizing crop production and use of water resources while preserving the environment. Furthermore, RDI is considered as an efficient way to achieve a certain amount of water savings, either in a predetermined developmental stage or throughout the whole production season, without decreasing plant yield. With this practice, it is possible to obtain the optimum benefit without significantly decreasing product yield by conserving allowable water savings. The main objective of RDI is to use water efficiently by determining the irrigation treatments that marginally contribute to yield. In this way, water use efficiency (WUE) can be increased. Water shortages, before and after fruit set, reduce the number of fruit and the marketable fruit yield, depending on the number of flowers, by causing an increase in fruit quality, total soluble solids (TSS), and acidity in tomato (Colla *et al*., 1999; Stikic *et al*., 2003). The total yield and water content of the fruit increase with the amount of water applied. However, an increase for water applied significantly reduces TSS. Processing tomatoes that are exposed to excessive irrigation levels produce higher yields, lower TSS compared to tomatoes under the low irrigation level in which lower yield and higher TSS levels are obtained (Hanson and May, 2004; Baselga *et al*., 1993). Deficit irrigation reduces the water content of tomato fruit and fruit yield but increases TSS, hexose sugar and citric acid concentrations in fruit (Mitchel *et al*., 1991) while limited irrigation volumes increased citric acid concentrations in tomato (Mitchel *et al*., 1991; Colla *et al*., 1999; Stikic *et al*., 2003). The average total dry matter (DM) content of tomato is 5%. Tomato paste (pulp) yield is increased with increment of DM content. High contents of total DM, sugar, red fruit shell and flesh are desirable in processing tomatoes. Producers are testing the use of RDI and extension of the no-irrigation period prior to harvesting to improve fruit quality, especially the amount of total DM and TSS, without significantly reducing yield (Mitchell, 1991). Lowengart *et al*. (1999) reported that postponing the start of irrigation of processing tomatoes in semi-arid conditions results in significant reductions in fruit yield depending on the fruit number. On the other hand, postponing the cessation of irrigation causes a significant increase in fruit yield, in contrast to the significant reduction caused in TSS. In this study, the RDI technique was applied in three different tomato growth stages, to achieve the optimum benefit per unit of water by drip irrigation in processing tomatoes. The objectives of this study were to (i) assess tomato yield, irrigation water use efficiency and water use efficiency responses to regulated deficit irrigation strategies; (ii) propose irrigation management guidelines for tomato farming in the semi-arid area

3 MATERIAL AND METHODS

A field experiment was conducted on a clay soil at the Agricultural Experimental Research Field of the Harran University (Sanliurfa, Turkey) during the growth periods of 2010 and 2011. The site is located at 37°08' N and 38°46' E and is 464 m above the sea level. Table 1 shows the climatic variables for the experiment years and long-term averages, especially for the months in which the experiments were conducted. The gravimetric water content of the soil was measured in each of three soil layers, at depths of 0 to 0.3 m, 0.3 to 0.6 m, and 0.8 to 0.9 m, with two replicates per treatment. These measurements were repeated at 15-day intervals.

Table 1: Climatic variables for experimental years and long-term averages.

Years		T_a (°C)	RH (%)	P (mm)	u_2 (m s^{-1})
Long run average (1929-2011)	May	22.0	44.7	25.7	2.2
	June	28.0	32.3	3.1	3.0
	July	33.1	29.6	0.6	3.0
	August	31.3	32.2	0.9	2.6
	September	26.7	35.3	2.3	2.4
	October	20.1	45.0	24.0	1.7
2010	May	24.0	34.3	7.1	1.8
	June	29.4	31.2	0.5	2.4
	July	34.0	26.7	0.0	2.0
	August	33.7	27.5	0.0	1.6
	September	28.5	38.8	2.2	1.4
	October	23.7	46.4	2.3	1.5
2011	May	21.3	46.6	39.2	1.5
	June	28.3	30.3	4.6	2.1
	July	33.0	24.0	0.8	1.7
	August	31.9	27.0	0.0	1.7
	September	27.7	31.4	10.3	1.4
	October	20.5	53.7	12.3	1.2

T_a: Average temperature, RH: Average relative humidity, P: precipitation, u2: Average wind speed at a height of 2 m (Meteorological Station, 1929–2011. Sanliurfa, Turkey)

The soil water contents (w/w; %) in the three soil layers at field capacity were 31.72, 30.89 and 31.06%, respectively, and the soil water contents at the permanent wilting point were 21.14, 20.62 and 19.96%, respectively. The corresponding bulk densities were 1.36, 1.38 and 1.35 g cm^{-3}.The cultivar "AB 2 F1" (Monsanto seeds) of processing tomato was used as the plant material for the experiments. The tomato-growing season was divided into three phenological stages: S_1, from the planting of seedlings to first fruit set; S_2, from the first fruit set to the first harvest; and S_3, from the first harvest to the last harvest. Fifteen different irrigation treatments (listed in Table 2) involved 66%, 100% and 133% ratios of total irrigation water applied (IW)/cumulative pan evaporation (CPE, total evaporation) during the three different growth stages. Irrigation was applied in three-day intervals. The CPE values were obtained by the use of a class-A evaporimetric pan located in the experimental field.

Table 2: Plant growth stages and irrigation treatments (IW/CPE).

Irrigation treatments	Growth stages		
	S_1	S_2	S_3
T1	133	133	133
T2	100	100	100
T3	66	66	66
T4	66	100	100
T5	66	100	133
T6	66	133	100
T7	66	133	133
T8	100	66	100
T9	100	66	133
T10	100	100	66
T11	100	133	66
T12	133	66	100
T13	133	66	133
T14	133	100	66
T15	133	133	66

S_1: from the planting of seedling to first fruit set,
S_2: from the first fruit set to the first harvest,
S_3: from the first harvest to the last harvest

To calculate the amount of irrigation water applied, a pan evaporation equation was applied (James *et al*., (1982) (Equation 1 and 2) :

$$ET = P + I \pm \Delta S - R - D \quad (1)$$

$$I = Ax\Sigma E_{pan}xk_{cp}xP \quad (2)$$

Where P is precipitation, I is irrigation amount (mm), $\pm\Delta S$ is soil water content, R is runoff, D is deep percolation (mm) below the root zone, A is the plot area (m^2), ΣE_{pan} is the pan evaporation (mm), k_{cp} is the pan coefficient and P is the percentage of wetted area or percentage of canopy cover. Water use efficiency (WUE) is ratio of fruit yield to seasonal crop ET_c. Irrigation water use efficiency (IWUE) is fruit weight per unit of irrigation water applied.

The below equation (3) (Doorenbos and Kassam, 1979) was used to calculate the crop yield response factor k_y

where Y_a=actual yield kg ha^{-1}, Y_m=maximum yield kg ha^{-1}, Y_a/Y_m=relative yield, $(1–Ya/Ym)$=relative yield decrease, ET_a/ET_m=relative crop ET (mm), $(1–T_a/ET_m)$=relative evapotranspiration deficit

$$\left(1-\frac{Y_a}{Y_m}\right)=k_y\left(1-\frac{ET_a}{ET_m}\right) \qquad (3)$$

Each plot is consisted of double rows. The spacing between wide row was 150 cm and between narrow row was 0.5 m and plants were spaced 0.4 m apart in each row. The seedlings were planted in the field on May 26. Irrigation water was applied equally to all plots as pretreatment irrigation to ensure that the seedlings became well established. RDI irrigation treatments were initiated on the same date in both years of the experiment. The plants were fertilized with 220, 120, 250, 150 and 50 kg ha^{-1} of N, P_2O_5, K_2O, CaO and MgO, respectively. The total fruit yield (TFY) per ha was determined from the four harvests. The marketable yield (MY) was measured considering only red-ripened fruits. Ripened fruits were sampled to determine mean fruit weight (FW), fruit diameter (FD), fruit length (FL), total soluble solids (TSS) and fruit dry matter (DM). Three randomly selected plants from each experimental plot were cut above the soil surface a hundred days after being planted. The plants were weighed for fresh biomass (FB), the leaves were separated from the stems and the leaf area (LA) was measured using a leaf area meter. The plant parts (leaves and stems) were then dried in an oven at 70 °C until they reached a constant weight to measure dry biomass (DB). The leaf chlorophyll index (CI) was measured three times at the end of the S_1, S_2 and S_3 growth stages.The field experiment was developed using a randomized complete block design with three replications. The data were subjected to standard analysis of variance using the TARIST (Acikgoz *et al*., 2004) statistical software. The least significant difference (LSD) test was used to detect significance of differences in means.

4 RESULTS

Irrigation water was applied (Fig. 1) equally to all plots as pretreatment RDI from 26 May to 19 June to ensure good seedling establishment. The irrigation scheduling for the experiments began on 19 June for S_1, 6 July for S_2, and 19 August for S_3 in both years. A total of 21 RDI treatments were performed in each experimental year. Total water applied (IW) ranged from 1,760.4 to 1,004.3 mm. IW were recorded as 1760.4, 1388.0, and 1004.3 mm for T_1, T_2 and T_3 respectively. Actual evapotranspiration of treatment (ETa) values have been found to give similar responses to the IW and were determined to be 1055.4 mm for T_1 and 1556.2 mm for T_3 treatment. The values of IW for the all treatment group except T_3 were found to be higher than ETa values. Increasing irrigation water caused lower water productivity, however, it increased fruit yield. The greatest impact of RDI was observed on TFY and MFY. Increased irrigation water amounts contributed to increased yields and improved market efficiency. The lowest yield (27.82 t ha^{-1}) was obtained in the T_3 treatment, which involved the lowest amount of irrigation water applied during the three growth stages (throughout the growing season). The maximum yield was obtained from highest water consumption in treatment T1. Thus, increased irrigation was a waste of water. As a result of this, it could be said that the irrigation water applied to the plants in these group was more than the crop's need and occurrence of deep percolation. The highest yield was obtained in the T_1 treatment, which involved the application of irrigation water at a rate of 133% of the IW/CPE ratio throughout the growth season. TFY ranged from 83.59 t ha^{-1} to 33.34 t ha^{-1}. Total water consumption in the total growth stage had a greater impact on the crop yield compared with deficit irrigation in any growth stage (Table 3). MFY was highly correlated with the ET_a (R^2=0,83) more than IW (R^2=0,66) (Fig. 2a and 2b).

Fig. 1. Tomato plants subjected to RDI in experimental field.

Table 3: Seasonal irrigation (IW), seasonal evapotranspiration (ET_a) total fruit yield (TFY), marketable yield (MY), relative evapotranspiration deficit [1-(ET_a/ET_m)], relative fruit yield decrease [1-(Y_a/Y_m)], irrigation water use efficiency (IWUE), water use efficiency (WUE), yield response factor (k_y) and water saving of tomato under regulated deficit irrigation.

Treatments	IW (mm)	ET_a (mm)	TFY ($t\ ha^{-1}$)	MY ($t\ ha^{-1}$)	1-(ET_a/ET_m)	1-(Y_a/Y_m)	IWUE ($kg\ m^{-3}$)	WUE ($kg\ m^{-3}$)	k_y	Water Saving (%)
T_1	1760.40	1556.20	83.59 a	73.26 a	0.00	0.00	4.16	4.71	0.00	0.00
T_2	1388.00	1305.00	63.21 b	56.47 b	0.16	0.23	4.07	4.33	1.42	21.15
T_3	1004.30	1055.40	33.34 g	27.82g	0.32	0.62	2.77	2.64	1.93	42.95
T_4	1316.60	1255.00	42.71 f	37.71df	0.19	0.49	2.86	3.00	2.51	25.21
T_5	1480.20	1385.40	53.76 cd	46.66cd	0.11	0.36	3.15	3.37	3.31	15.92
T_6	1527.50	1389.80	55.19 cd	49.85bc	0.11	0.32	3.26	3.59	2.99	13.23
T_7	1619.70	1344.80	60.61 bc	53.76bc	0.14	0.27	3.32	4.00	1.96	7.99
T_8	1170.70	1109.70	42.421 f	36.95ef	0.29	0.50	3.16	3.33	1.73	33.50
T_9	1263.00	1260.40	51.69 de	45.21ce	0.19	0.38	3.58	3.59	2.01	28.25
T_{10}	1293.00	1180.40	46.07ef	38.70df	0.24	0.47	2.99	3.28	1.95	26.55
T_{11}	1503.80	1205.60	40.92 f	36.74eg	0.23	0.50	2.44	3.05	2.21	14.58
T_{12}	1240.00	1201.70	41.58 f	35.90fg	0.23	0.51	2.90	2.99	2.24	29.56
T_{13}	1332.30	1300.80	53.66 cd	46.57cd	0.16	0.36	3.50	3.58	2.22	24.32
T_{14}	1362.30	1304.60	59.24 bc	51.52bc	0.16	0.30	3.78	3.95	1.84	22.61
T_{15}	1573.10	1375.80	56.98 bd	51.45bc	0.12	0.30	3.27	3.74	2.57	10.64
LSD (0.01)			7.11	9.08						

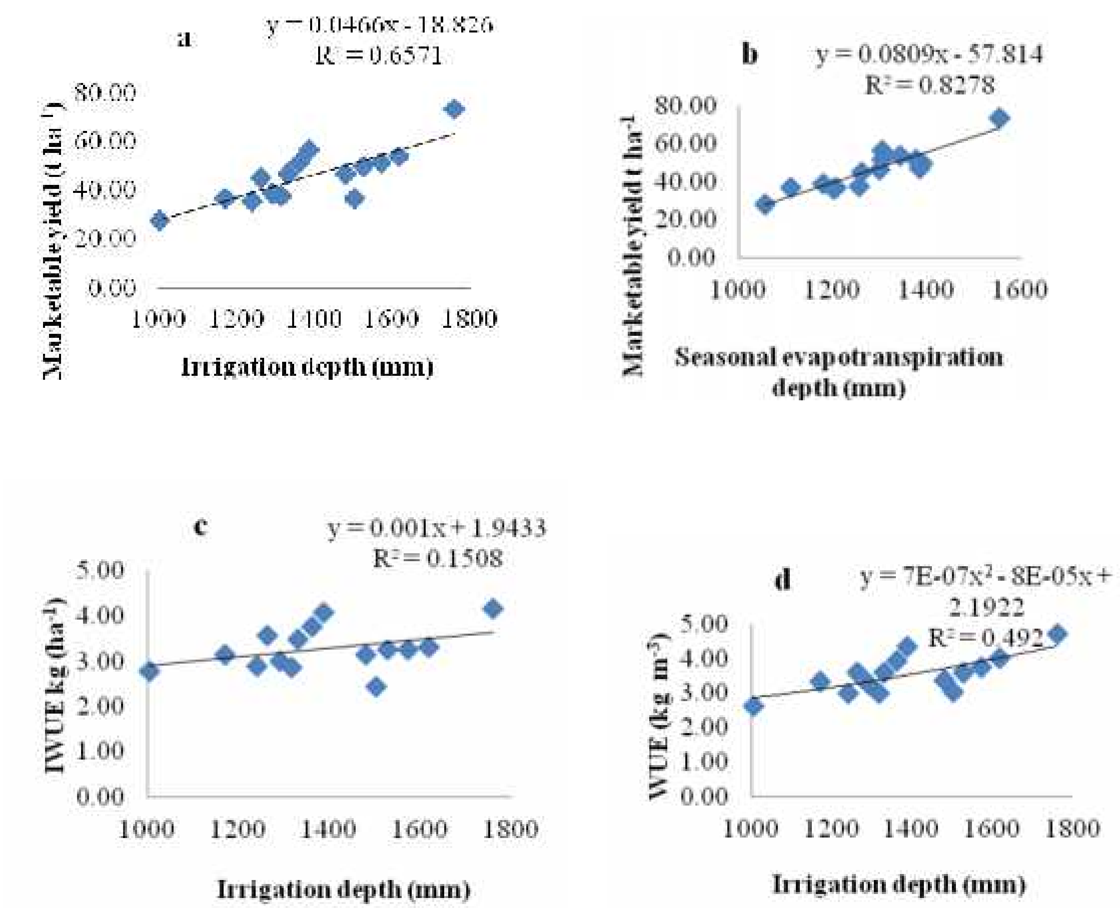

Fig 2. Relationship between tomato marketable yield and irrigation depth (a), marketable yield and seasonal evapotranspiration (b), irrigation water use efficiency and irrigation depth (c), water use efficiency and irrigation depth (d)

Relative evapotranspiration deficit [1-(ET_a/ET_m)] and relative fruit yield decrease [1-(Y_a/Y_m)] were determined to range between 0.11-0.32 and 0.24-0.60 respectively. Decreasing irrigation water to 66% ET caused very high water saving, however, it decreased crop yield up to 62% in T_3 (Table 3). IWUE and WUE values ranged between 4.16-2.44 kg m^{-3}, and 4.71-2.64 kg m^{-3} respectively. The highest IWUE and WUE values obtained in T_1 treatment involved the highest amount of irrigation water applied while the lowest IWUE and WUA values determined from T_{11} and T_3, respectively. When relationship between IWUE and water saving rates examined water saving was achieved only 14.58% corresponds to the lowest IWUE. The IWUE and irrigation depth showing no significant relationship (R^2=0.15), while relationship between the WUE and irrigation depth (R^2 = 0.49) was stronger (Fig. 1c and 1d). Water use efficiency was calculated as the yield (kg) produced per cubic meter of water used (ET). Increasing the amounts of irrigation applied showed decreasing values of WUE, confirming that deficit irrigation can improve WUE in processing tomatoes. Recently, RDI technique has been used by researchers because of the positive response and increases WUE (Table 3). k_y was determined as 2.12 for whole growing season, in other words, 2.12-yield reduction was occurred per unit water decrease. The maximum water savings were calculated as 21% and 43% for the T_2 and T_3 treatments, respectively, compared to the T_1 treatment, which involved the highest level of water application. However, the yield losses were up to 24% for T_2 and up to 60% for T_3. The rest of the irrigation treatments resulted in higher yield reduction at lower water saving rates (Table 3). Irrigation treatment has highly significant effects on FW, similar to those on fruit size (FD and FL); a considerable reduction was measured as a result of the RDI treatments (Table 4). The heaviest (110.12 g) and largest fruit in size (54.03 mm FD and 68.72 mm FL) was obtained from plants subjected to the T_1 and T_2 treatments, in contrast to the T_3 treatment, which resulted in dramatic decreases in fruit size (66.13 g FW, 45.94 mm FD and 58.13 mm FL) (Table 4). RDI also affected the TSS and DM. The TSS was changed between 5.15 and 6.47 Brix and DM changed between 5.71% and 6.87%. Contrary to expectations, the concentration of fruit TSS associated with the T_3 treatment was found to be lower than the one associated with the T_1 and T_2 treatments (Table 4).

Table 4. Average of weight, diameter, length, soluble solid and dry matter of fruit for the irrigation treatments.

Treatments	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Total soluble solid (Brix)	Fruit dry matter (%)
T_1	108.26 a	53.67ab	68.72 a	6.27 b	6.67ab
T_2	110.12 a	54.03 a	67.30 ab	6.25 b	6.53 a-c
T_3	66.13 g	45.94 e	58.13 f	5.73 de	6.32 b-d
T_4	79.99 f	46.35 de	59.30 ef	5.72 d-f	6.28 b-d
T_5	84.06 ef	49.42 c-e	60.87 d-f	5.15 h	5.71 e
T_6	89.54 d-f	49.97 b-d	63.83 b-d	6.00 c	6.30 b-d
T_7	102.82 a-c	51.96 a-c	68.70 a	5.78 d	5.99 de
T_8	89.91 c-f	50.06 b-d	65.68 a-c	6.47 a	6.87 a
T_9	105.47 ab	53.43 ab	67.52 ab	6.07 c	6.51 a-c
T_{10}	108.93 a	53.82 a	67.39 ab	5.50 g	5.90 de
T_{11}	97.68 a-d	51.61 a-c	64.07 b-d	5.57 fg	6.07 c-e
T_{12}	84.87 d-f	48.76 c-e	62.79 c-e	5.58 e-g	6.12 c-e
T_{13}	94.75 b-e	51.87 a-c	64.68 a-d	6.02 c	6.52 a-c
T_{14}	93.44 b-e	51.22 a-c	63.01 c-e	6.12 bc	6.69 ab
T_{15}	104.57 ab	52.49 a-c	66.32 a-c	5.73 de	5.94 de
LSD (0.01)	13.10	3.76	4.22	0.15	0.48

Different letters within columns indicate differences found to be significant by the LSD test at the stated P level.

LA was significantly reduced by a reduction in the irrigation water. LA decreased by 48% with treatment T_3, relative to treatment T_1. FB decreased by 37% for the same treatment, and DB decreased by 33.5%. Since LA, FB and, DB were measured as the total production throughout the growth period, the volume of water applied was effective rather than it was in growth stage (Table 5).

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Table 5: The values of leaf area, plant fresh and dry biomass and chlorophyll index.

Treatments	Leaf area (cm^2)	Plant fresh biomass (g)	Plant dry biomass (g)	Chlorophyll index		
				I. Stage	II. Stage	III. Stage
T_1	21091 a	1523 a	344 a	410,67 a	375,67 a	225,00 ab
T_2	18121 ab	1313 ab	324 ab	329,67 b	299,67 cd	238,00 a
T_3	10936 bc	961 bc	229 c	300,00 b	256,33 e	192,67 bc
T_4	10843 bc	1090 bc	260 abc	300,00 b	293,33 cde	175,00 cd
T_5	11717 bc	956 bc	240 bc	300,00 b	303,33 cd	170,00 cd
T_6	13115 bc	855 c	207 c	300,00 b	228,33 bc	166,00 cd
T_7	12675 bc	930 bc	235 c	300,00 b	304,67 cd	154,67 d
T_8	11275 bc	841 c	232 c	329,67 b	268,33 de	156,67 cd
T_9	13602 abc	1118 abc	271 abc	329,67 b	285,33 de	149,33 d
T_{10}	13859 abc	983 bc	230 c	329,67 b	300,33 cd	155,00 d
T_{11}	9680 c	990 bc	223 c	329,67 b	289,33 de	144,00 d
T_{12}	9872 c	1101 bc	251 bc	410,67 a	301,00 cd	154,67 d
T_{13}	10474 c	928 bc	248 bc	410,67 a	288,00 de	163,67 cd
T_{14}	12119 bc	966 bc	221 c	410,67 a	298,00 cd	157,67 cd
T_{15}	9836 c	805 c	208 c	410,67 a	362,67 ab	153,67 d
LSD (0.01)	7563,41	431	85	37,26		

Values within columns followed by the same letter are not significantly different at the stated P level

CI values were measured at the end of the S_1, S_2 and S_3 growth stages. At the end of the S_1 stage, higher CI values were measured at the 133% IW/CPE ratio (the T_1, T_{12}, T_{13}, T_{14} and T_{15} treatments) than for the other treatments. At the end of the S_2 stage, the highest CI value was obtained with treatment T_1, in which excess water application continued, and the second highest CI value was obtained with treatment T_{15}. At the end of S_3 (the end of the RDI treatments), although the plants were at the end of their growth, the highest CI values were again measured for the full or excess irrigation levels (Table 5).

5 DISCUSSION

The yield results demonstrated that deficit irrigation always had a significant effect on the fruit yield because tomato plants cannot recover themselves completely, due to water stress at any growth stage. The study area was located in a region with a semi-arid climate. Because tomato plants continue to set fruit periodically, full irrigation up to first fruit set but limited irrigation in later stages, or vice versa, resulted in greatly reduced fruit yield compared to the yield achieved with full or excessive irrigation throughout the growth period. This yield reduction is the result of the negative impact of the limited irrigation on fruit set, as well as inhibition of the growth of the fruits. The results of this experiment show that tomato plants are sensitive to water stress throughout the growing season. Tomato is a crop with a high water demand throughout its growth season, and; therefore inadequate irrigation decreases yield and reduces processing efficiency (Topcu, 2007; Savic *et al.*, 2008; Prieto, 1996; Mukherjee *et al.*, 2010; Patane *et al.*, 2011). Agele *et al.* (2011) reported that in the humid tropics, tomato is cultivated mainly in the wet rainy season, a period characterized by high incidence of pests and diseases, low fruit set and poor fruit quality. Over rainfed tomato, plant biomass (root and shoot dry weights), leaf area, growth, fruit yield and WUE were increased by irrigation. It has been reported that irrigation treatment has significant effects on fruit yield; however, the effects are different for fruit quality traits (Mahajan and Singh, 2006; Wang *et al*., 2011). Pulvento *et al*. (2008) reported that fruit yield in tomato changed in parallel to the total amount of water applied during the growing period rather than the length of the irrigation treatment. Patane *et al*. (2011) also stated that deficit irrigation at an early growth stage results in 44% yield reduction. Irrigation strategies should be planned with objectives of high yield and water savings as well as optimization of fruit quality traits. Stikic *et al*. (2003) determined that deficit irrigation caused a reduction in the number of fruit but did not have a large impact on fruit weight or fruit diameter. Patane *et al*. (2011) reported that the largest fruit was being obtained from fully irrigated processing tomato plants; however, fruit weight did not significantly differ from deficit irrigation. In contrast, many researchers have reported that fruit weight is reduced as the irrigation water amount is decreased during the fruit development period (Sanders *et al*., 1989). It is generally accepted that water deficit increases TSS and DM in tomato (Hanson and May, 2004; Zegbe Dominguez *et al*., 2003; Patane *et al*., 2011). Noor (2011) stated that the mineral, organic acid and soluble solids contents of tomato fruit are related to the age of the fruit. Most likely because the number of days from flowering to harvest was not the same for all fruit samples; no clear correlation was determined between the irrigation treatments and the TSS or DM. Favati *et al*. (2009) reported that irrigation treatment significantly affected TSS content in tomatoes in the first year but did not result in significant differences in the second year of their experiment. In contrast, Hanson and May (2007) reported that the amount of water does not affect the TSS content significantly. For this reason, even though the TSS and DM concentrations are correlated with the irrigation treatment, they cannot be explained only by the irrigation treatments. In inadequate water level conditions (Fig. 3), there are various indicators of plant water stress. The amount of chlorophyll in plants can be used as a measure of water stress (Gercek *et al*., 2009). Because of stomatal closure in a plant is subjected to a water deficit, CO_2 entry into the plant and thus photosynthetic activity are blocked. Water stress significantly limits plant growth and its development, resulting in reductions in shoot elongation, leaf area and chlorophyll content. Chaves *et al*. (2002) reported similar results for chlorophyll. Important results have been obtained in this study concerning the effects of deficit irrigation on fruit yield and certain quality characteristics of tomatoes by comparing different irrigation regimes consisting of combinations of growth periods and amounts of irrigation water applied. It was found that occurrence of a water deficiency is more important than that in which growth stage the deficiency occurred. That is, tomato fruit yield decreases if the amount of water applied is decreased during any stage in the growth period. It is clear that among all the resources needed to sustain yield, growth and development of plants, water is the most limiting and influential factor in agricultural productivity. It is important to determine the highest yield per unit of irrigation water used. However, in this study, the maximum fruit yield was obtained in irrigation treatment T_1 (133% IW/CPE ratio), and the average crop water requirement was 1,760.4 mm. The rate of the reduction in the yield in response to RDI ranged from 11 to 32% for water savings of 8 to 43%, compared to excessive or full irrigation (the T_1 and T_2 treatments). The results of this study demonstrated that tomato plants are sensitive to water stress and have high water demands during both the vegetative and reproductive growth periods. The results suggest that an IW level is greater than the evaporation level (133% IW/CPE) or at least full irrigation (100% IW/CPE) should be applied to the crop throughout the growing season to achieve adequate fruit yield and to maintain high fruit quality levels. In tomatoes, the water saved with deficit irrigation does not compensate for the resulting yield reduction, under the conditions of this experiment.

Fig. 3: Tomato grown at inadequate water level conditions (irrigation treatment T_3)

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