Middle East Journal of Agriculture Research
ISSN 2077-4605

Volume : 08 | Issue : 03| July-Sept. | 2019
Pages:808-819

Reducing water requirement for tomato crop in late summer through field shading

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Received: 08 May 2019 / Accepted 02 June 2019 / Publication date: 20 July 2019

ABSTRACT

Field experiment was carried out during the two growing summer seasons of 2016 and 2017, in a private farm at El-Sadat City, El – Minufia Governorate, Egypt, in order to investigate the effect of deficit irrigation treatments (100%, 85% and 70% of ETo, reference evapotranspiration), using drip irrigation system under different levels of shading (60%, 40% and 0%), on vegetative growth, fruit yield and quality of tomato plants grown under sandy soil conditions.

Results indicated that deficit irrigation treatments (100%, 85% and 70% of ETo) significantly decreased the vegetative growth (plant length, number of leaves per plant, total leaves area per plant and fresh and dry weight of tomato per plant) and decreased total marketable yield by (11.34 % and 25.88 %) comparing with 100% ETo and as an average in both seasons. Where, the highest significant values were obtained by the full irrigation treatment 100% ETo (control) and the lowest values were noticed with 70%ETo treatment. Similarly, vegetative growth and fruit yield parameters were reduced with decreasing shading net levels (60%, 40% and 0%), the highest significant values were obtained by 60% shading net level and the lowest values were noticed with 0% (open field under full sun light). In contrast, there were positive effects on proline content of tomato leaf and fruit quality characteristics (TSS and ascorbic acid) for tomatoes, as well as on irrigation water use efficiency (IWUE). The interaction among deficit irrigation treatments and shading net levels illustrated that tomato plants were irrigated by 100% and 85% ETo under shading net level 60% had the highest significant values for vegetative growth, fruit yield and quality of tomato plants. Increasing water quantity applied to tomato plants up to the highest used level (5011.22 m^3 ha^{-1}) significantly increased vegetative growth characters, i.e., plant height, number of leaves, leaf area and fresh and dry weight as well as total N, P and K uptake by tomato plants. On the other hand, proline contents enhanced significantly with decreasing irrigation water supply. Tomato yield characters increased with increasing irrigation water quantity up to 5011.22 m^3 ha^{-1}. Under the low level of irrigation water (3507.86 m^3 ha^{-1}) TSS and ascorbic acids recorded the highest significant values with highest values of IWUE.

Keywords: growth, productivity, summer season, water use efficiency, evapotranspiration, proline content

Introduction

Tomato (*Lycopersicon esculentum* Mill) is an important crop worldwide (Xiukang and Yingying, 2016). Many products of tomato are used in kitchens e.g. ketchup, juice...etc. It has high nutritional values e.g. a good source of antioxidants such as carotenoids, ascorbic acid, phenolic compounds, and α-tocopherol (Abushita *et al*., 1997 and Beecher, 1998) besides bing rich in vitamin C and lycopene which can decrease the potentiality of breast and prostate cancer (Dimatira *et al*., 2016). Thus, tomato ranking comes second in importance after potatoes (Vaccari *et al*., 2015).

Egypt is one of the countries that face serious shortage of water resources (Fereres and Soriano, 2007), and therefore rationalizing the usage of the available resources is the optimum choice to overcome water scarcity problems (Farid *et al*., 2014). To attain higher (WUE) outcomes, many strategies can be followed i.e. deficit irrigation and partial root drying strategies (Morison *et al.,* 2008) without causing significant losses in the net yield (Kirda *et al.,* 2005). These appropriate strategies might decrease the level of irrigation requirements up to 20-40% (Dehghanisanij *et al.,* 2006), while the inappropriate ones may lead to water stress conditions on the grown plants which results in

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deleterious effects on growth and yield of crops (Ezzo *et al.*, 2010). In this connection, Kamal and El-Shazly (2013), Zaki *et al*. (2014), Abdelhady *et al*. (2017), Mostafa *et al*. (2018) and Malash *et al.* (2019), reported that water stress resulted in negative implications on tomato growth, chemical constituents and fruit yield.

One of the efficient and economic factors that reduce solar radiation and air temperature as well as increasing relative humidity is shading (Zaki *et al.*, 2014). This technique increased significantly the tomato growth, yield and quality compared with those grown under the open field conditions during the late summer season (Shehata *et al.*, 2013 and El-Bassiony *et al.*, 2014). To what extent adopting partial shading strategy during tomato production, to minimize the levels of water loses through evapotranspiration; thereby reduce the requirements of irrigation water, is the main target of the current research.

This study aims at investigating the influence of partial black shading net on minimizing the water requirement levels of tomato plants grown on a newly reclaimed sandy soil during the late summer seasons. The different growth parameters of tomato plants as well as the fruit yield quality issues and water use efficiency (WUE) calculations were considered in this study as markers to evaluate the effectiveness of both the deficit irrigation and shading net treatments.

Materials and Methods

Field experiments was performed during the two successive summer seasons of 2016 and 2017 at private farm of El-Sadat City, El-Minufia Governorate. Soil in the experimental site is sandy soil in texture with pH of 7.9 and EC of 1.74 ds/m. chemical analysis of soil and water are shown in Table 1. Climatic data were recorded (Table 2).

Table 1: Chemical analysis of soil and water

	pH	EC dSm^{-1}	Anions (mmolcL^{-1})				Cations ((mmolcL^{-1})			
			Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}	Na^+	K^+	Ca^{++}	Mg^{++}
Soil	7.9	3.04	15.8	3.6	0.0	11.0	12.2	1.2	10.0	7.0
Water	7.5	0.50	1.6	2.7	0.0	0.7	1.6	0.2	30.0	0.2

Table 2: Climatic data at Farm of El-Sadat city, Monofia Governorate during seasons of 2016 and 2017.

Months	Soil temperature [°C]		Solar radiation Dgt [MJ/m2]		HC Air temperature [°C]		HC Relative humidity [%]		ETo [mm]	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
May	27.0	24.8	589.64	582.16	23.9	23.8	57.0	62.1	4.3	4.0
June	26.6	24.6	577.42	599.30	27.9	26.7	61.4	65.0	4.5	4.3
July	26.0	25.7	551.25	557.13	27.6	28.2	70.7	73.0	4.2	4.1
August	25.8	25.5	419.95	464.82	27.6	27.6	72.2	74.8	3.3	3.3
September	24.6	24.0	194.19	369.90	26.2	25.7	68.7	72.2	1.9	2.7

Experimental design:

The experimental treatments were arranged in a split plot design where shading treatments were arranged in the main plots and irrigation treatments were arranged in the sub plots. All treatments were applied with three replicates. Randomize has been considered in the application of the studied treatment.

A- Shading treatments:

Two different levels of shade net (60% and 40%) were tested using black shading net and compared with non-shaded house (three treatments). All shading plastic net were fixed before transplanting

B- Irrigation treatments

Three irrigation treatments were tested as follow: 100%, 85% and 70% from class A pan which were calculated on basis of the agro meteorological station located in the site as follows:

- **The first step** was calculation of potential evapotranspiration which was made according to the following formula (FAO, 1977):

$$Et_o = K_p \text{ X } E_{Pan} \quad (\text{mm / day}) \qquad \text{Eq. 1}$$

Where:

Et_o = Potential evapotranspiration in mm / day.
K_p (Pan coefficient) = three stage (0.5, 0.75and1)
E_{Pan} = Pan evaporation in mm/day.

- **The second step** was to obtain values of crop water consumptive use (Et_{crop}) as follows (FAO, 1977).

$$Et_{crop} = Et_o \times K_c \quad \text{mm / day} \qquad \text{Eq 2}$$

Where:

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

K_c = Crop coefficient "between"(0.3 to 1).

- **The third step** is to calculate water requirements (WR) for each treatment as following:

$$WR = Et_{crop} \times L\% \text{ mm / day} \qquad \text{Eq 3}$$

Where:

L % = Leaching requirement percentage (L % = (E_{ciw} / E_{cdw}) x 100)

Where:

E_{ciw} = Electrical conductivity of irrigation water dS/cm^{-1}.
E_{cdw} = Electrical conductivity of drainage water mMoh. cm^{-1}
L % was estimated to be 1.25.

- **The fourth step** was to calculate irrigation requirement (IR)

As:

$$IR = WR \times R \qquad \text{Eq 4}$$

Where:

WR= Water requirement

R = Reduction factor for drip irrigation only covers apart of land and leaves the rest dry. Therefore, it was recommend by FAO (1977) to use R-value, which its estimated range is between 0.25 and 0.9 for drip irrigation system.

Finally, calculation of open field water duty (WD) was as follows:

$$WD = IR \times (\text{area} / 100)$$

Water use efficiency (WUE):

Water use efficiency was calculated for the different water regimes treatments using the following equation (Monteith, 1986)

$$WUE = \text{Total yield (kg)/Total water consumption (m}^3) \qquad \text{Eq. 5}$$

The field study

Tomato (*Lycoperscon esculentum* Mill.) F1 hybrid (V.T.916) transplants were sowing under net houses on the first of May during both seasons of 2016 and 2017 on the two sides of ridges (1 m in width and 30 m in length). The distance between transplants was 50 cm within the row. The current study was conducted in three single type net houses each of 270 m^2 (9 m width, 30 m length and 3.2 m height) to investigate the growth and productivity of tomato plants under the different levels of shading and deficient irrigation treatments. This experiment included nine treatments, which were the combinations of three shading levels (0%, 40 and 60 %) and three irrigation levels (70%, 85 and 100 % of ETo). Other agricultural practices were followed according to the recommendation of the Egyptian Ministry of Agriculture. Calculation of potential evapotranspiration (ETo) was made according to the original method of Penman (1948) and the amount of irrigation water was calculated according to Doorenbos and Pruitt (1977). The total seasonal irrigation water amounts were 3507.86, 4259.54 and 5011.22 m^3/ha for the low, medium and moderate irrigation level, respectively.

Vegetative growth

Sixty days after transplanting, five plants were sampled randomly from each plot to estimate the following growth parameters i.e. plant height, number of leaves, leaf area of the fifth leaf from the top was recorded by using a digital leaf area meter (LI-300 Portable Area Meter Produced by LI. COR, Lincoln, Nebraska, U.S.A). Representative samples of three plants were collected from each experimental plot 180 days from transplanting to measure fresh and dry weight.

Chemical analysis in leaves

Samples of tomato leaves were taken from each plot after sixty days from transplanting, oven dried at 70^o C for 48 h, weighed, ground, and then digested in a mixture of conc. sulphuric and perchloric acids (2:1 ratio) as mentioned by Page *et al.* (1982). N, P and K were determined in the plant digests according to AOAC (2000) as follows: N by micro-Keldahl, P by spectrophotometer (Jenway 6705 UV/Vis) using ammonium molybdate and ascorbic acid reagents, K by flame photometer (Jenway pfp7). Free proline content (µg/g DW) was extracted according to the method of Bates *et al.* (1973).

Yield and its components

At red stage of maturity fruits were harvested. The early yield, marketable and unmarketable as well as total fruit yield were estimated (early yield was determined on the basis of the first two harvests). The marketable yield includes all healthy fruits with good quality parameters, while the unmarketable fruit included all misshape, cricked and infected fruit from the total harvest collections.

Fruit properties

The chemical characteristics of tomato were determined according to the standard methods described by AOAC (2000) i.e. total soluble solids (TSS) was estimated by refractometer, ascorbic acid (vitamin C) was determined by titration in presence of 2, 6-di-chlorophenolindophenol as an indicator while total acidity was determined by titration with NaOH.

Statiscal analysis procedure

The obtained data were statistically analyzed using the analysis of variance method according to Gomez and Gomez (1984). Duncan multiple range test method at the 5% level of probability was used to compare means of treatments.

Results and Discussion

Growth parameters and proline content in leaves of tomato as affected by shading and water requirements solely or in combinations

Effect of shading

Concerning the effect of shading on vegetative growth aspects of tomato plants. Data in Table 3 indicate that all the studied growth measurements were significantly affected during both seasons. In this concern, increasing shade density 40 and 60% led to increases in all the determined morphological characters as a result of shading compared with the unshaded plants in both seasons of study. At the end of the harvesting period the total fresh weight of plant showed significant increase while whole plant dry weight was not affected. In this respect, such increments in studied morphological characters of tomato plants as a result of shading with different tested shade densities may be attributed to the decrement effect of shading on ambient temperature during the summer season under shading compared with the full sun shine during the growing period and in turn decreasing the respiration rate (catabolism process) which consequently may enhance the accumulation of nutritional and assimilated materials used in formation of new cells and tissues and finally increase the vegetative growth.

Table 3: Effect of shading levels, irrigation requirements and their interaction on vegetative growth characteristics and proline content in leaves of tomato plants during both seasons of study.

Shading net	Water requirement (WR)															
	First season				Second season				First season				Second season			
	WR 100%	WR 85%	WR 70%	Mean	WR 100%	WR 85%	WR 70%	Mean	WR 100%	WR 85%	WR 70%	Mean	WR 100%	WR 85%	WR 70%	Mean
	Plant height (cm)								Number of leaves per plant							
Control 0%	151.60 bc	137.95 cd	133.40 d	140.98 C	161.65 cd	148.85 de	145.00 e	151.83 C	19.00 abc	18.10 bc	16.60 c	17.90 B	21.85 abc	20.60 abc	18.85 c	20.43 B
Shading 40%	166.85 ab	143.55 cd	139.30 cd	149.90 B	178.60 ab	154.70 cde	150.20 de	161.17 B	20.45 ab	19.15 abc	18.45 abc	19.35 A	22.55 ab	21.55 abc	19.35 bc	21.15 B
Shading 60%	172.75 a	153.15 bc	146.65 cd	157.52 A	186.10 a	165.70 bc	159.05 cd	170.28 A	21.45 a	20.50 ab	19.70 abc	20.55 A	23.50 a	22.05 abc	20.70 abc	22.08 A
Mean	163.73 A	144.88 B	139.78 B		175.45 A	156.42 B	151.42 B		20.30 A	19.25 A	18.25 B		22.63 A	21.40 B	19.63 C	
	Fresh weight g per plant								Leaf area (cm^2)							
Control 0%	243.30 c	224.80 d	198.20 e	222.10 B	237.95 cde	222.20 e	200.90 f	220.35 B	121.10 cd	101.60 d	96.35 d	106.35 B	131.60 def	123.35 ef	105.25 f	120.07 C
Shading 40%	264.70 b	249.50 c	223.70 d	245.97 A	254.10 abc	243.45 bcd	224.15 de	240.57 A	169.20 ab	148.00 bc	135.50 c	150.90 A	183.70 ab	168.80 abc	138.85 cde	163.78 B
Shading 60%	287.40 a	272.45 ab	236.70 cd	265.52 A	271.65 a	263.00 ab	234.90 cde	256.52 A	182.10 a	166.75 ab	143.30 bc	164.05 A	197.50 a	178.60 ab	162.05 bcd	179.38 A
Mean	265.13 A	248.92 A	219.53 B		254.57 A	242.88 A	219.98 B		157.47 A	138.78 B	125.05 B		170.93 A	156.92 B	135.38 C	
	Dry weight g per plant								Proline (µg g^{-1} DW)							
Control 0%	52.70 ab	42.30 cd	35.65 d	43.55 A	49.40 bc	42.95 cde	35.20 e	42.52 B	3.50 ab	5.30 ab	5.60 a	4.80 A	4.30 ab	4.90 a	5.10 a	4.76 A
Shading 40%	57.25 a	43.90 bcd	39.50 cd	46.88 A	53.90 ab	44.50 bcde	39.00 de	45.80 A	2.27 ab	2.45 ab	2.63 ab	2.45 B	2.32 ab	2.34 ab	2.54 ab	2.40 B
Shading 60%	60.75 a	45.95 bc	39.20 cd	48.63 A	60.90 a	47.80 bcd	40.35 cde	49.68 A	0.41 b	0.43 b	0.51 b	0.45 C	0.45 b	0.49 b	0.56 b	0.50 C
Mean	56.90 A	44.05 B	38.12 C		54.73 A	45.08 B	38.18 C		2.06 B	2.72 A	2.91 A		2.35 B	2.57 A	2.73 A	

Increased plant height may be due to the elongation of the internodes to reaccept sun light radiation, more than to the increase of the number of the internodes. These results are in agreement with those reported by Adam *et al.* (2002) who found that shading rates were favorable for plant height and leaf area, but had a decrement effect on number of leaves as well as fresh and dry weight of leaves and stems. In addition, Liu *et al.* (2002) and Abdul Mateen *et al.* (2007) reported that shading tomato plant with 60% of total sun light in the first case and 55 or 75% in the second case produced the maximum values for plant height, number of leaves and leaf area and total dry weight production.

Effect of water requirements

Increasing the amount of irrigation water from 70 to 85 and 100% of water requirement enhanced all measured morphological aspects. Such enhancing effect did not reach the level of significance. Using the highest level of irrigation water (100% of water requirement) reflected the highest values in all determined growth parameters. Such results are in agreement with those reported by Harmanto *et al.* (2005) and Sibomana *et al.* (2013) on tomato growth as affected by environmental conditions.

Effect of treatment combinations

Shaded plant at 60% shade density and irrigated with the highest level of irrigation water (100% or 85 % of water requirement) exhibited the highest vegetative growth (number of leaves, leaf area and total fresh weight) and recorded the lowest values of proline content during both seasons of growth. Proline accumulation was reduced in plant leaves, this indicates that under these treatments plants were not exposed to any stress in presence of shade at 60% under 100% or at 85% WR .Therefore shaded plant at 60% led to saving 15% from of requirements with no stress in presence of water deficiency.

Plants during water shortage conditions have various physiological mechanisms. One of them is osmosis control, when osmosis potential of stressed tissues are reduced due to the accumulation of osmosis substances including mineral elements (e.g. potassium, sodium and calcium) and some of the metabolites as sugar ,amino acids (proline) and organic acids. Thus, turgor pressure of the cells is kept well (Irigoyen *et al.,* 1992). These metabolites don't have any contradiction with normal bio-chemical reactions of the cells and are called compatible solutes (Bohnert *et al.,* 1995). The increase of the concentration of proline helps osmosis control and is reported due to some factors including the prevention of proline disintegration , avoiding proline participate in protein structure or increase of protein disintegration (Kao, 2005). Proline via osmosis control, avoiding enzymes destruction and removal of hydroxyl radicals, increased the tolerance of the plants against stresses (Kuznetsov and Shevykova, 1999). Similarly, by applying of humidity super absorbent the reduced proline accumulation in tomato was found (Mostafa *et al.,* 2018)

N, P and K content of tomato leaves as affected by shading and water requirements solely or in combinations

Effect of shading

Table 4 reveals that shading increased all assayed mineral constituents compared with the unshaded plant. This did not reach the level of significance in case of phosphorus .Shaded plants with the highest level (60%) exhibited the highest content of total nitrogen, phosphorus and potassium , while the lowest was under the lowest level of shading 40%. The increase in contents of nutrients with increasing shade density was connected with the increasing in vegetative growth as shown in Table 3. The increase may be attributed to the decrement effect of shading on prevailing temperature during the summer. Obtained results agree with those reported by De Groot *et al*. (2002), Liu *et al*. (2003), Gent (2005) and Zaki *et al.* (2014) who reported that shading of tomato increased the contents of N, P and K in plant leaves.

Effect of water requirements

Increasing irrigation level from 70 to 100% increased the contents of N, P and K in leaves. The highest level 100% gave the highest values. This shows that there was increased nutrient solubility. These results are in agreement with those reported by Harmanto (2005) although Nahar and Ullah (2012) reported that increasing irrigation water decreased NPK contents tomato leaves.

Effect of treatment combinations

P was not significantly affected due to combination of treatments of shading density (60%) combined with the highest level of irrigation water (100%) but N and K showed their highest content under such conditions.

Table 4: Effect of shading levels, irrigation requirements and their interaction on N, P and K content in leaves of tomato plants during both seasons of study

Shading net	Water requirement (WR)							
	First season				Second season			
	WR 100%	WR 85%	WR 70%	Mean	WR 100%	WR 85%	WR 70%	Mean
	N g kg^{-1}							
Control 0%	13.70 de	13.10 de	12.69 e	13.16 C	13.70 d	13.15 d	13.95 cd	13.60 B
Shading 40%	15.50 bc	14.32 cd	13.92 de	14.58 B	15.54 bc	14.32 bcd	13.6 d	14.49 B
Shading 60%	18.15 a	16.25 b	15.57 bc	16.66 A	17.50 a	15.92 ab	14.84 bcd	16.09 A
Mean	15.78 A	14.56 B	14.06 B		15.58 A	14.46 B	14.13 C	
	P g kg^{-1}							
Control 0%	2.08 abc	1.50 bc	1.23 c	1.61 B	1.97 ab	1.57 ab	1.30 b	1.61 B
Shading 40%	2.32 ab	1.68 abc	1.40 bc	1.80 AB	2.17 ab	1.70 ab	1.38 ab	1.75 A
Shading 60%	2.53 a	1.77 abc	1.45 bc	1.92 A	2.32 a	1.70 ab	1.48 ab	1.83 A
Mean	2.31 A	1.65 B	1.36 B		2.15 A	1.66 B	1.39 C	
	K g kg^{-1}							
Control 0%	25.55 bc	19.95 cd	14.65 d	20.05 C	25.34 bc	20.55 cd	15.50 d	20.46 B
Shading 40%	32.17 ab	23.34 bcd	17.28 cd	24.26 B	31 ab	25.00 bcd	20.67 cd	25.56 A
Shading 60%	39.17 a	23.50 bcd	19.50 cd	27.39 A	36.34 a	25.34 bc	23.84 bcd	28.50 A
Mean	32.29 A	22.26 B	17.14 C		30.89 A	23.63 B	20.00 C	

Yield, yield components and water use efficiency of tomato plants as affected by shading and water requirements solely or in combinations

Effect of shading

Table 5 shows that there were significant differences in all measured yield components i.e., early, marketable and unmarketable as well as total produced fruit yield per square meter as a result of tested shading densities (40 and 60%) compared with unshaded treatment during the two growing seasons of study. The highest yield parameters were connected with shading plants at 60% except the unmarketable fruit yield where the highest occurred with the unshaded plants.

Plants grown under the low 40% and the high 60% shading produced 15.72 and 17.96 kg fruits m^{-2}, respectively compared with 13.24 given by plants grown under unshaded condition. The increase amounts to 18.73 and 35.65 %. The increments in total produced yield and its components as a result of shading plant with different densities are connected with the effect of shading on the vegetative growth parameters (Table 3) which in turn affect positively total produced fruit yield. Such increases may be due increased number of flowers per cluster and fruit setting. The obtained results agee with those of Wada *et al.* (2006), Gent (2007), Abdul Mateen *et al.* (2007), Kittas *et al.* (2009), Bibi *et al.* (2012), Shehata *et al.* (2013) and Sharaf-Eldin (2015) who observed that shading of tomato plants increased total yield and marketable fruits.

The water use efficiency (WUE) was highest under 60% shading. As average of both seasons 37.15 and 42.59 kg m^{-3} might be needed for producing tomato fruits from plants grown under full sun light, 40 and 60% shading density, respectively, during both seasons of growth. This improving effect of shading on water use efficiency is due to reducing sun light radiation and lowering the temperature reflected in reducing the transpiration.

Shehata *et al*. (2013) reported that growing tomato under 35 % shading increased total fruit yield and Zaki *et al*. (2014) studied the effect of shading densities of 40, 60 and 73% and found that shading gave positive results in yield and yield components.

Effect of water requirements

Date presented in Table 5 indicate that the irrigation treatments of 70, 85 and 100% showed differences in yield parameters (total yield, early and marketable yield) Increasing the level of irrigation water from 70 up to 100% decreased WUE .Such results are in agreement with those found by Ismail *et al.* (2007), Birhanu and Tilahun (2010), Panigrahi *et al.* (2010), Olanik and Madramootoo (2014).

Effect of treatment combinations:

Shading combined with the highest shad density (60%) and using the highest level of irrigation water had the highest values of yield and yield components .Under the same shading but using the low level of irrigation (70%) recorded comparable and slight increases. Shading at 60% with irrigation at 85% can save about 15% of water used in irrigation.

Table 5: Effect of shading levels, irrigation requirements and their interaction on total yield, water use efficiency, early, marketable and unmarketable yield of tomato plants during both seasons of study

Shading net	Water requirement (WR)							
	First season				Second season			
	WR 100%	WR 85%	WR 70%	Mean	WR 100%	WR 85%	WR 70%	Mean
	Total yield kg m^{-2}							
Control 0%	15.575 bc	13.160 cd	11.505 d	13.413 C	14.920 cde	13.000 ef	11.250 f	13.056 C
Shading 40%	17.330 ab	15.725 bc	13.750 cd	15.601 B	17.785 ab	15.885 bcde	13.835 def	15.835 B
Shading 60%	19.465 a	18.375 ab	16.095 bc	17.978 A	19.235 a	18.435 ab	16.150 bcd	17.940 A
Mean	17.456 A	15.753 B	13.783 C		17.313 A	15.773 B	13.745 C	
	Water use efficiency (WUE) (kg m^{-3})							
Control 0%	31.080 e	30.895 e	32.797 de	31.591 C	29.773 f	30.519 ef	32.070 def	30.787 C
Shading 40%	34.582 cde	36.917 cd	39.197 bc	36.899 B	35.490 cde	37.292 cd	39.440 bc	37.407 B
Shading 60%	38.842 bc	43.138 ab	45.882 a	42.621 A	38.383 bc	43.279 ab	46.039 a	42.567 A
Mean	34.835 B	36.983 AB	39.292 A		34.549 B	37.031 AB	39.183 A	
Table 5. Continue								
	Early yield kg m^{-2}							
Control 0%	2.035 bcd	1.954 cd	1.689 d	1.893 B	2.018 b	1.610 c	1.565 c	1.729 B
Shading 40%	2.451 ab	2.075 abcd	1.970 cd	2.165 AB	2.721 a	1.858 bc	1.623 bc	2.067 A
Shading 60%	2.520 a	2.060 bcd	2.347 abc	2.309 A	2.652 a	1.867 bc	1.560 c	2.028 A
Mean	2.335 A	2.030 B	2.002 B		2.464 A	1.778 B	1.583 B	
	Marketable yield kg m^{-2}							
Control 0%	13.744 bcd	11.014 de	09.085 e	11.281 C	12.946 cd	10.716 de	08.135 e	10.599 C
Shading 40%	16.215 ab	14.359 bcd	12.395 cde	14.323 B	16.412 abc	14.451 bc	12.000 cd	14.288 B
Shading 60%	18.341 a	17.133 ab	14.944 abc	16.806 A	18.153 a	17.276 ab	14.463 bc	16.631 A
Mean	16.101 A	14.168 B	12.142 C		15.837 A	14.147 B	11.532 C	
	Unmarketable yield kg m^{-2}							
Control 0%	1.830 abc	2.145 ab	2.419 a	2.131 A	1.973 bc	2.283 b	3.115 a	2.457 A
Shading 40%	1.114 c	1.365 bc	1.354 bc	1.278 B	1.372 cd	1.433 cd	1.834 bcd	1.546 B
Shading 60%	1.1230 c	1.241 c	1.150 c	1.171 B	1.081 d	1.158 d	1.686 bcd	1.308 B
Mean	1.355 B	1.584 AB	1.641 A		1.475 B	1.625 B	2.212 A	

Fruit quality of tomato as affected by shading and water requirements solely or in combinations

Effect of shading

With regard to the effect of shading on fruit chemical traits, data in Table 6 indicate that except total acidity which was not significantly affected, both ascorbic acid content and total soluble solids were significantly affected due to plant shading in both seasons of study. In this respect, increasing shading density from 40 up to 60% led to decreased total soluble solids percentage and the vitamin C content of tomato fruits. In addition, the highest values of T.S.S and ascorbic acid content were noticed in case of plants exposed to full sun light condition (without shading). Obtained results are similar during both seasons of study. Such decrement in T.S.S percentage and vitamin C content as a result of shading may be attributed to the effect of shading on photosynthetic assimilation rate which may affect produced sugars during the photosynthetic process and in turn affect negatively both T.S.S and vitamin-C assimilation. Also, the decrease in T.S.S and vitamin-C content may be attributed to the high nitrogen content (Table, 4) in plant tissues which combined with sugars to form new cells and tissues and consequently decreased the content of T.S.S and vitamin-C assimilation in fruits. Obtained results are in accordance with those reported by Shehata *et al*. (2013) and Zaki *et al.* (2014) all working on tomato.

Effect of water requirements

As for the effect of irrigation levels on chemical quality constituents of fruit, data in Table 6 reveal that all assayed chemical fruit quality indices (T.S.S and ascorbic acid) were gradually decreased with increasing the amount of irrigation water used from 70 up to 100% of water requirements during both seasons of study. In this regard, the increase of all assayed chemical fruit constituents in case of using the lowest level of irrigation water (70% of water requirement) may be due to the lower water accumulation of fruits which led to visible higher contents of T.S.S and vitamin C content. Obtained results are in the same line with those reported by Ibrahim (2005), Miguel *et al*. (2007) and Vijitha and Mahendran (2010) all working on tomato.

Effect of treatment combination

Regarding the effect of the interaction on assayed chemical constituents of tomato fruits, data recorded in Table 6 indicate that all assayed fruit chemical constituents, i.e., T.S.S, ascorbic acid and total acidity were significantly affected as a result of the interaction treatments during both seasons of study. In this connection, the highest values in both T.S.S and vitamin C content were recorded in case of the combination of the control treatment (without shade) and irrigation with the lowest rate of irrigation water (70% of water requirement). On contrast, the highest value of total acidity was noticed in case of the combination between the highest shade density (60%) and the lowest level of irrigation water (70% from water requirement). Obtained results are similar during both seasons of study.

Table 6: Effect of shading levels, irrigation requirements and their interaction on quality fruits of tomato plants during both seasons of study.

Shading net	Water requirement (WR)							
	First season				Second season			
	WR 100%	WR 85%	WR 70%	Mean	WR 100%	WR 85%	WR 70%	Mean
	Vitamin C (mg 100g^{-1} FW)							
Control 0%	27.79 bcd	31.02 abc	37.50 a	32.10 A	28.12 b	30.55 a	37.34 a	32.00 A
Shading 40%	24.04 cd	25.42 cd	34.50 ab	27.98 B	24.37 d	24.95 c	34.34 a	27.88 A
Shading 60%	21.90 d	23.67 d	32.83 ab	26.13 B	22.23 e	23.20 d	32.67 a	26.03 B
Mean	26.13 B	27.98 B	32.10 A		26.03 B	27.88 A	32.00 A	
	Total acidity (mg 100g^{-1} FW)							
Control 0%	17.25 b	20.57 ab	21.97 ab	25.03 A	17.85 b	20.64 ab	22.64 ab	25.47 A
Shading 40%	21.35 ab	23.43 a	24.49 a	23.09 A	21.95 ab	23.50 ab	25.15 a	23.53 A
Shading 60%	24.03 a	24.80 a	26.25 a	19.93 B	24.63 ab	24.87 a	26.92 a	20.37 A
Mean	20.88 A	22.93 A	24.23 A		21.48 A	23.00 A	24.90 A	
	Total soluble solids (TSS %)							
Control 0%	4.40 b	4.45 b	5.40 a	4.75 A	4.50 b	4.40 b	5.35 a	4.75 A
Shading 40%	4.35 b	4.35 b	5.30 a	4.67 A	4.40 b	4.40 b	5.15 a	4.65 A
Shading 60%	4.20 b	4.30 b	5.15 a	4.55 A	4.25 b	4.30 b	5.05 a	4.53 A
Mean	4.32 B	4.37 B	5.28 A		4.37 B	4.38 B	5.18 A	

Conclusion

It can be concluded that shading tomato plants grown on a sandy soil with a shading density of 60% and irrigation levels of 70, 85 or 100% of water requirements in late summer seasons, enhanced growth parameters, NPK content in leaves, total fruit yield and yield components as well as fruit chemical constituents. This can be recommend under similar circumstances to use the water level (85%) when combined with 60% shade density in order to get optimum yield with saving water.

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