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Effect of Mulching on Some Characteristics of Tomato (*Lycopersicon esculentum* Mill.) under Deficit Irrigation

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ABSTRACT

The aim of the study was to evaluate the sole and interactive effect of drip irrigation regimes (50, 70, and 100% of Crop Water Requirement, CWR) and different mulches [No Mulch (NM); Mood Chip Mulch (WCM); Composted Wood Chip Mulch (CWCM), and Plastic Mulch (PM)] on some morphological and physiological traits of tomato, Water Use Efficiency (WUE), and soil properties (soil moisture and temperature) under field conditions. Results showed that yield and its components were significantly influenced by different levels of irrigation. Different mulches increased fruit yield by 12–46% over non-mulch conditions. The highest marketable yield (5.78 kg plant $^{-1}$) and total yield (5.77 kg plant $^{-1}$) were obtained by the plants under the highest water level (100% CWR) along with PM and WCM, respectively. The lowest percentage of cracked fruits and blossom-end rot fruits was observed in the plants under 100 and 70% CWR along with WCM. In addition, the highest WUE (18.27 kg m^{-3}) was obtained with 70% water application under WCM. In general, the study revealed that drip irrigation with wood chip mulch had a significant role in increasing the yield of tomato and saving irrigation water under field conditions.

Keywords: Water deficit stress, Water use efficiency, Wood chip mulch, Yield.

INTRODUCTION

To meet the food needs of the rapidly growing population, a substantial increase (about 50%) in essential food products by agricultural production is needed (Godfray *et al.*, 2010). However, the portion of fresh water currently available for agriculture is decreasing as the allocation of water to different uses increases. Due to having shallow roots, vegetable crops are sensitive to water shortage; therefore, irrigation is important for these crops. As an important commercial vegetable, tomato (*Lycopersicon esculentum* Mill.) has the highest area under cultivation among vegetables in the world. This vegetable has high water requirement and scarcity of water limits its production in the arid and semi-arid areas (Nangare *et al.*, 2016) such as Iran. Managing water resources and optimizing water use in agriculture is the only way to deal with water scarcity crisis (Alomran *et al.*, 2012; Rzayev, 2017). Across the globe, priority is now to adopt irrigation strategies that help save irrigation water without compromising on yield (Favati *et al*., 2009; Nangare *et al*., 2016). Deficit Irrigation (DI) is a strategy that includes irrigation of the root zone with less water than necessary for evapotranspiration, which reduces the cost of

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water production and consumption (Zegbe-Domınguez *et al.*, 2003). The DI influence on water productivity and quality traits of tomato plant and other plants at various growth stages has been previously investigated (Mousavi *et al.*, 2010; Nangare *et al*., 2016).

Mulching (organic and inorganic) is also an appropriate approach to enhance efficiency level of irrigation (Khurshid *et al.*, 2006; Sarkar and Singh, 2007). Many studies have been conducted to experiment the effect of mulch on yield improvement of many crops in different agro-climatic regions and soil conditions (Li *et al.*, 2004). Tomato is also suited to drip irrigation in combination with the different types of mulches (Ngouajio *et al.*, 2007), but little work has been performed to study the interactive effects of deficit drip irrigation and different mulches, especially wood chip mulch, on crop yield and Water Use Efficiency (WUE) of vegetable crops such as tomato in semiarid lands of Iran. In India, in a study by Mukherjee *et al*. (2010), the effect of irrigation frequencies and mulches on tomato growth indices and WUE was evaluated. The researchers showed that mulches can be used to improve crop performance and can be a good option for using water resources effectively without significantly reducing the crop yield. Identifying critical irrigation stage of crops and irrigation scheduling based on crop water status seem to be the most effective way to improve WUE (Ngouajio *et al.*, 2007). Therefore, a better understanding of the relationship among soil water scarcity, physiological manifestations, and fruit yields should enable growers to effectively manage irrigation water (Renquist and Reid, 2001).

The objectives of the study were to determine the sole and interactive effect of deficit drip irrigation with mulching treatments on some characteristics of tomato under field production system and to compare mulch materials with respect to water conservation in the culture of tomato under supplementary irrigation. In addition, their effects on soil moisture and temperature and WUE were also assayed.

MATERIALS AND METHODS

Experimental Site and Climatic Conditions

The study was carried out for five months (from May 22 to October 23 in 2015) at the research farm of University of Tehran, Karaj, Iran (latitude: 35° 044' N, longitude: 50° 54' E, elevation of 1,234.44 m). No rainfall occurred throughout the season. The mean annual precipitation in the area is 247.3 mm per year. More than 70% of the total annual rainfall falls only in November and December. The mean annual air temperature and the average temperature of winter and summer are about 24.4, 20.8, and 34.6°C, respectively.

Soil Sampling and Analysis

Before starting the experiment, soil samples (five soil cores) were collected from 0-30 cm depth from each plot and then pooled together to characterize the soil characteristics after being air-dried and sieved (2 mm mesh sieve). This soil had Field Capacity (FC) of 21.3%, Permanent Welting Point (PWP) of 11.45%, pH of 7.7, texture of clay loam, Organic Carbon (OC) of 6.4 g kg^{-1}, soil bulk density of 1.41 g cm^{-3}, Electrical Conductivity (EC) of 1.42 dS m^{-1}, total Nitrogen (N_{tot}) of 0.09 g kg^{-1}, available Phosphorus (P_{avail}) of 53.1 mg kg^{-1}, iron (Fe) of 7.5 mg kg^{-1}, Zinc (Zn) of 2.34 mg kg^{-1}, Copper (Cu) of 2.28 mg kg^{-1}, Manganese (Mn) of 2.32 mg kg^{-1}, available potassium (K_{avail}) of 390 mg kg^{-1}, and Calcium Carbonate Equivalent (CCE) of 87 g kg^{-1}.

Experimental Design and Treatments

The experiment was laid out in a split plot design. The treatments were replicated three times. The three irrigation regimes (50, 70, and 100% of Crop Water Requirement, CWR)

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were assigned to the main plots and the four mulch treatments [No Mulch (NM), Wood Chip Mulch (WCM), Composted Wood Chip Mulch (CWCM), and Plastic Mulch (PM)] were in the subplots. Each treatment combination was distributed randomly to minimize the effect of the difference between the plots. A week before transplanting, the experimental site was ploughed and harrowed to depth of 30 cm. According to the results of soil test, basal application of fertilizers was worked in the soil. The experimental plots were 2.5 m long and 0.5 m wide. There were 36 experimental plots. Tomato plants were planted at a spacing of 0.5 m in a plot. The space between plots was 1.5 m. The PM was placed after land preparation, marking out and laying drip irrigation lines before planting. Tomato (*Lycopersicon esculentum* Mill.) cultivar *Commodoro*, a high-yielding hybrid cultivar, was used in this study.Tomato plants were planted through holes made on the mulch. Other mulches were placed seven days after planting. The mulches were 10 cm thick and were spread to cover the whole cropped area.

Preparation of Wood Mulches

Wastes or residual substances of apple trees were turned into wood chip by chopper equipment. Without making any change to them, these chips were used as one of the treatments in this study. Wood chip and compeletly decomposed cow manure were used as the primary substrate for composting. To increase composting speed, fungus *Phanerochaete chrysosporium* was used as inoculum to degrade wood chips. The inoculum of this fungus was prepared on sorghum grains according to the method described by Gaind *et al*. (2009). After 60 days of inoculation, the prapared compost was used as a treatment in this study. Some of the chemichal properties of this compost were determined following the standard procedure. This compost had *EC*, 1.63 dS m^{-1}; pH, 7.5; Fe, 5600 mg kg^{-1}; Zn, 98 mg kg^{-1}; Mn, 410 mg kg^{-1}; Cu, 16 mg kg^{-1}; Ca, 2.8%; Mg, 2.13%; Na, 0.25%; K, 0.81%; P, 0.41%; OC, 31%; and N, 1.74%.

Deteminaton of Water Requirement for Drip-Irrigated Tomato

In this study, a drip irrigation system was used. The water requirment of the tomato was determined according to the FAO Penman-Monteith method. Reference Evapotranspiration (ET_o) was computed from meteorological data and the water requirment of tomato was determined after introducing a proper crop coefficient (Kc) for tomato plant. Meteorological data such as minimum and maximum temperature, minimum and maximum Relative Humidity (RH), Dew Point Temperature (DPT), wind speed at a height of 2 m, and daily sunshine hours were collected from a nearby weather station to determine ET_0. Comparison of those graphs explicitly showed that there was no source of moisture other than irrigation in the study period. The ET_0 was calculated using Modified FAO Penman–Monteith method (Allen *et al*., 1998) and CROPWAT computer programme. After calculating ET_0 and crop Evapotranspiration (ETc), the gross volume of irrigation water (l d^{-1}) was computed.

Measurments

After 141 days, the tomato was harvested by hand. In this study, the first harvest in all treatments was considred as early ripening yield. Vitamin C (mg 100 g^{-1} FW as ascorbic acid) was determined by titration of homogenate tomato samples. A sample of 5 mL of the filtered fruit extracts was titrated with a standard iodine solution (0.01 N potassium iodine solution) using 2 mL of 1% starch solution as indicator till the appearance of blue color and then the amount of ascorbic acid was calculated. Fruit firmness (kg cm^{-2}) was measured using a universal penetrometer (Humboldt, Co., Chicago 31, IL, USA). Total Soluble Solids Content (TSSC) was

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determined on juice using a handheld refractometer (ATC-1 Atago, Tokyo, Japan). The pH of fruit extract was measured by digital pH meter (PHB-4, China). Titrable acidity was measured by titrating against standard NaOH solution 0.1 mol L^{-1} until pH 8.1, using phenolphthalein as an indicator and expressed as anhydrous citric acid per 100 g (AOAC, 1990). Chlorophyll a and b and carotenoids were estimated in fresh leaf samples according to Arnon (1967). The content of total soluble phenol in tomato leaves was extracted as described by Chang *et al*. (2002). Total soluble phenol content was standardized against gallic acid and expressed as mg gallic acid per 1 g of fresh leaf extract. Measurement of Relative Water Content (RWC) was performed on the youngest leaves collected from tomato plants grown in different plots.

When the fruits turned yellowish red, they were harvested at a regular interval from each plot. In total, five times plucking were made during the cropping season. Yield from all pluckings were summed up and total yield was expressed as kg $plant^{-1}$. Fruits were picked by hand at 2–4 days interval. The fruit number and the total weight per plot were checked at each harvest time. Marketable and non-marketable fruit yields were determined at harvest from the five pickings during the cropping season. Marketable yield was calculated as total harvested yield minus cracked fruits, unripe fruits, tiny fruits, and fruits having blossom-end rot. In addition to measuring plant height in cm, stem diameter in mm using a digital caliper (Digimatic Caliper, Shengli Co., Ltd., Beijing, China), number of lateral stem per plant, and mean leaf area in cm^2 were measured at the end of tomato growing season. Water Use Efficiency (WUE) for the cropping season was calculated based on total yield (sum of yields of different pluckings). Soil temperature in each plot was also measured for the entire observed periods (once a week), before irrigation at 10 cm depth, with portable LCD soil temperature meter (Mod, TPJ-21, Zhejiang Top Instrument Co., Ltd, China). Soil moisture (0–20 cm) on volumetric basis was recorded with soil moisture meter (Mod., PMS-714) in each measurement before irrigation.

Statistical Analysis

Using MSTAT-C (Ver. 2.1, Michigan State University, USA), data were subjected to Analysis Of Variance (ANOVA) (compound analysis). Statistically significant differences based on a two-way ANOVA were reported. Tukey's least significant difference test was used to compare treatment means at the 0.05 probability level.

RESULTS AND DISCUSSION

Morphological Traits

As shown in Table 1, the measured morphological traits were affected by water deficit stress. The number of lateral stem, stem diameter, plant height, and mean leaf area varied significantly with different levels of irrigation and were maximum with 100% CWR and minimum with 50% CWR. However, there was no significant difference between 100 and 70% CWR treatments in terms of the effect on the number of lateral stem and stem diameter. Enormous increase in mean leaf area under 100% CWR may be due to the increased rate of cell division and cell size enlargement under high availability of soil water (Nandan and Prasad, 1998). The results obtained from this study are in agreement with of those of Biswas *et al*. (2015) and Seng (2014). It has been well known that tomato is very sensitive to water deficit stress, initially during vegetative development and, later, when the tomato is reproductive (Wudiri and Henderson, 1985). Sánchez-Rodríguez *et al*. (2010), Mishra *et al*. (2012), and Majnoun *et al*. (2009) stated that water stress caused a significant reduction in stem elongation, leaf expansion (leaf area), number of leaves, and seedling emergence. Mahajan and Tuteja (2005) also suggested that the reduction in leaf expansion is a form of response showing that plants have adapted to lower transpiration.

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Irrespective of type of applied mulches, use of mulches enhanced the morphological traits measured in this study (Table 1). Among applied mulches, the highest number of lateral stem, stem diameter, and mean leaf area were recorded in WCM (Table 1). In addition, effect of mulch treatments on plant height was not significant. The positive effect of mulching on improving the morphological traits of crops in previous studies has been reported (Liang *et al*., 2011; Mukherjee *et al*., 2012).

Physiological Traits of Leaf

As indicated in Figure 1-A and Table 1, the highest chlorophyll a, carotenoids (0.4163 mg g^{-1} FW), and RWC (71.5%) were observed in 100% CWR treatment, showing these traits were affected by water deficit stress. As shown in Table 1, the decrease in amount of irrigation water from 100 to 70% CWR did not result in a significant reduction in total chlorophyll content. However, this parameter showed a significant decrease in 50 % CWR compared to 70 and 100 % CWR. Irrespective of mulching, chlorophyll b content was found to be the highest in 100% CWR. The highest chlorophyll b content was observed in CWCM (0.3414 mg g^{-1} FW) and followed by PM (0.3378 mg g^{-1} FW) under full irrigation (100% CWR) conditions (Figure 1-A).

Water stress is an important environmental factor that can affect the physiological properties of plants (Ren *et al*., 2007). Yuan *et al*. (2016) reported that water stress reduced chlorophyll a, chlorophyll b, and total chlorophyll at all stages of tomato growth. Owen and Aung (1990) showed that with increasing water stress from 30 to 15 % available water, chlorophyll content in leaves was increased. Taiz *et al*. (2015) also stated that since leaf area is decreased under stress conditions, chlorophyll content per unit leaf area is increased. In addition, at the beginning of water stress, leaf expansion is reduced due to stopping cellular growth. However, chlorophyll production is inhibited by strong stress. In some studies, with increasing stress level, chlorophyll content (chlorophyll a, chlorophyll b, total chlorophyll content, carotenoids) was decreased (Seng, 2014; Silva *et al*., 2007; Yuan *et al*., 2016). It has been found that water stress has had different effects on chlorophyll content depending on the experimental plant and environmental conditions (Taiz *et al*., 2015). The photosynthesis limiting factors can be either stomatal factors or non-stomatal factors. Reduction or cessation of synthesis of photosynthetic pigments such as chlorophyll and carotenoids are among the non-stomatal factors (Oliveira Neto *et al*., 2009). It has been known that the decrease in chlorophyll content may be due to metabolic changes, rapid senescence of leaves, chlorophyllase, peroxidase, and phenolic compounds, resulting in decomposition of chlorophyll (Silva *et al.*, 2007).

The highest RWC (69.68%) was recorded in WCM treatment and the lowest RWC (60.98 %) was observed in control without mulch (Table 1). It has been reported that water stress resulted in reductions in tomato plant water status (leaf relative water content and leaf water potential) and leaf gas exchange (photosynthesis, stomatal conductance, and transpiration) (Seng, 2014; Yuan *et al*., 2010). Sinclair and Ludlow (1985) reported that the appropriate RWC of leaf for plants is 85 to 95 %. According to these authors, in this RWC, uptake of water by root is equal to the amount of water loss by transpiration. Hence, plants can survive and continue to grow naturally. In general, the present study showed that mulches significantly increased the magnitude of RWC. Thus, mulches can be used to improve the crop performance. This result is in agreement with that of a previous study (Chakraborty *et al.*, 2008).

The highest total soluble phenol content (212.1 mg gallic acid g^{-1} FW) was produced in WCM with 50% CWR supply, which did not have any significant difference with other mulches. The lowest total soluble phenol content (142.5 mg gallic acid g^{-1} FW) was also observed in this mulch but with 100% CWR supply. According to Figure 1-B, with

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Table 1. Main effects of irrigation regimes and mulching treatments on morphological and physiological traits and yield of tomato under field conditions. [a]

Measured parameters	Irrigation (I) treatment			Mulching (M) treatment				Source of variation			*CV* (%)
	100% CWR	70% CWR	50% CWR	NM	PM	CWCM	WCM	I	M	I × M	
Mean leaf area per plant (cm^2)	80.04a	75.11b	67.79c	69.57b	74.51ab	73.65ab	79.52a	*	*	ns	7.67
Stem diameter (mm)	22.43a	21.44a	19.01b	19.86b	21.92a	20.92ab	21.64a	**	*	ns	6.28
Number of lateral stem per plant	9.38a	8.05b	7.60b	7.33c	8.36b	8.14b	9.55a	*	**	ns	7.23
Plant height (cm)	49.34a	47.34a	41.33b	ns	ns	ns	ns	**	ns	ns	6.78
Relative water content (%)	71.50a	65.64b	56.30c	60.98c	65.03b	62.23bc	69.68a	**	**	ns	6.04
Carotenoids (mg g^{-1} FW)	0.4163a	0.3990a	0.3439b	ns	ns	ns	ns	**	ns	ns	6.45
Total chlorophyll (mg g-1 FW)	2.039a	1.991a	1.706b	ns	ns	ns	ns	**	ns	ns	3.65
Chlorophyll a (mg g^{-1} FW)	1.708a	1.664a	1.435b	ns	ns	ns	ns	**	ns	ns	3.79
Vitamin C (mg 100 g^{-1} FW)	32.54a	31.73a	26.06b	28.35b	30.56a	30.73a	30.80a	*	**	ns	6.39
Titratable acidity	0.39c	0.42b	0.45a	0.44a	0.41ab	0.43a	0.38b	**	*	ns	6.48
pH	4.06c	4.26b	4.34a	4.27a	4.20ab	4.27a	4.13b	**	**	ns	1.99
Fruit firmness (kg cm^{-2})	5.26c	5.56b	6.04a	5.77a	5.58ab	5.77a	5.35b	*	**	ns	4.51
Total soluble solids content (Brix)	4.28b	4.41b	5.23a	4.86a	4.60ab	4.75a	4.35b	**	*	ns	6.61
Total yield (kg $plant^{-1}$)	6.040a	5.373b	3.677c	4.067d	5.492b	4.784c	5.778a	**	**	ns	5.25
Total number of fruit per plant	66.83a	65.00a	60.50b	58.11d	69.56a	66.11b	62.67c	**	**	ns	4.3
Mean weight of fruit (g $plant^{-1}$)	90.68a	82.32b	60.02c	69.10c	78.38b	71.41c	91.81a	**	**	ns	6.21
Chlorophyll b (mg g^{-1} FW)								**	**	**	3.82
Total soluble phenol (Gallic acid eq g^{-1} leaf extract)								**	ns	**	1.57
Early ripening yield (kg $plant^{-1}$)								**	**	**	10.19
Marketable yield (kg $plant^{-1}$)								**	**	**	6.75
Blossom-end rot fruit per plant (%)								**	**	**	18.82
Cracked fruit per plant (%)								**	**	**	23.17

[a] Crop Water Requirement: CWR; No Mulch: NM; Wood Chip Mulch: WCM; Composted Wood Chip Mulch: CWCM; Plastic Mulch: PM; *CV*: Coefficient of Variation. [a-c] Values followed by different letters are significantly different ($P < 0.05$; Tukey's least significant difference test; n= *3*).
** Significant at $P < 0.01$; * Significant at $P < 0.05$; and ns: Not significant at $P < 0.05$.

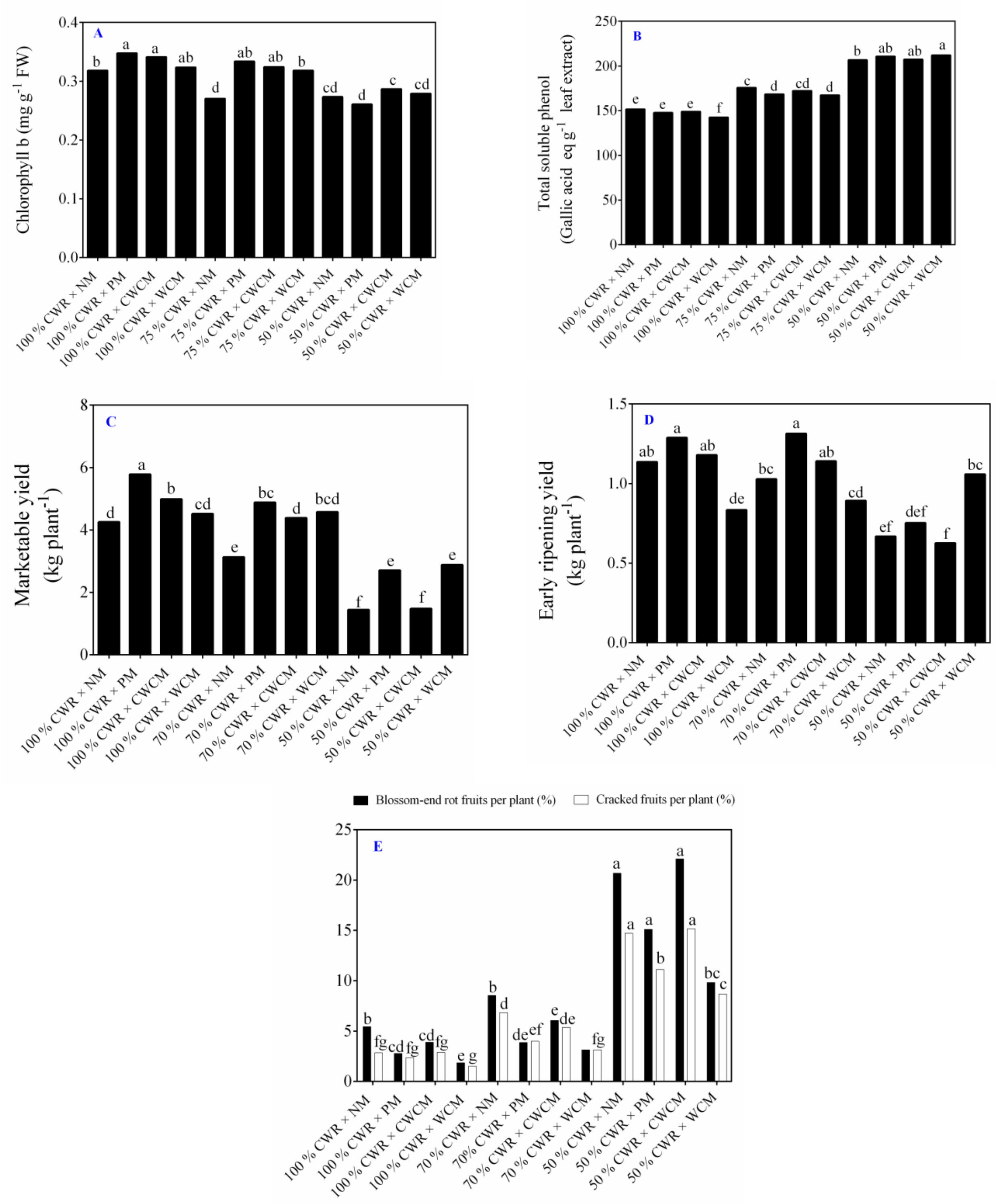

Figure 1. Effect of irrigation regimes (50, 70, and 100% of crop water requirement, CWR) and mulching treatments [No Mulch (NM), Wood Chip Mulch (WCM), Composted Wood Chip Mulch (CWCM), and Plastic Mulch (PM)] on morphological and physiological traits and yield of tomato under field conditions. Values followed by different letters are significantly different (P< 0.05; Tukey's least significant difference test; n= 3).

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increasing level of water deficit stress, total soluble phenol content of leaf increased, however, this increase was lower in mulched plants compared to un-mulched plants. According to Smirnoff (1993), low water availability is often associated with increased levels of Reactive Oxygen Species (ROS), which are highly reactive species and seriously disrupt normal metabolism of the plant. Plants contain several low molecular weight antioxidants such as phenolic compounds, which are water soluble (Grace, 2005). It has been reported that water stress induced the accumulation of phenolic compounds, suggesting their role as antioxidants (Król *et al*., 2014; Petridis *et al.*, 2012). It has been known that production of phenolic compounds in plant was different and was affected by various factors such plant genotypes, environmental conditions, type of plant tissue, and type of soil (Smirnoff, 1993). Therefore, the production of these compounds by tomato plant studied in this research may be dependent on physiologically adverse conditions.

Qualitative Traits of Fruit

As shown in Table 1, the lowest vitamin C was observed in fruit of the plants not treated with mulch and in fruit of the plants irrigated with 50% CWR. The fruit of the plants treated with WCM and the fruit of plants irrigated with 50% of CWR had the lowest and highest Total Soluble Solids Content (TSSC), respectively. In addition, the lowest pH, titratable acidity, and fruit firmness were measured in the fruit of plants treated with WCM and in the fruit of plants irrigated with 100% CWR (Table 1). These results (except for vitamin C) are confirmed by previous studies (Abdel-Razzak *et al*., 2013; Abdel-Razzak *et al*., 2016; Patanè *et al*., 2011). For example, Abdel-Razzak *et al*. (2016) found that water stress treatment (50% ETc) increased tomato fruit quality traits (total soluble solids, titratable acidity, vitamin C, and total sugars). It has been known that water stress in reproductive stage decreased content of vitamin C, while water stress in vegetative stage and then full irrigation in generative stage promoted plant to produce vitamin C, which shows the sensitivity of generative stage to water stress (Pouzesh *et al*., 2014). One of

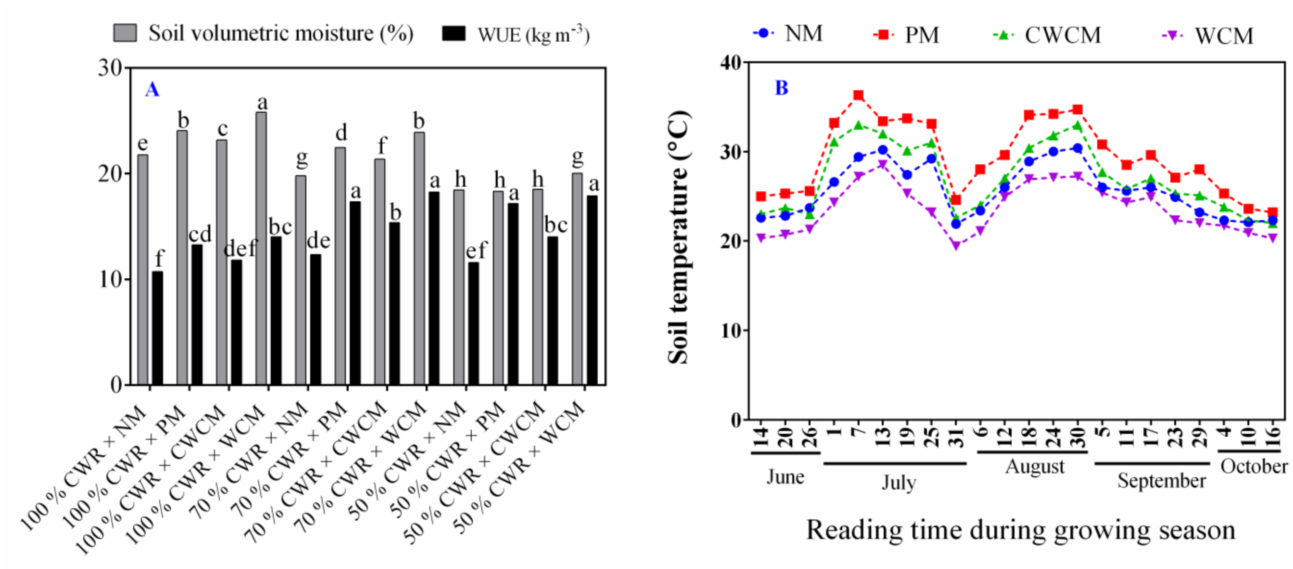

Figure 2. Effect of irrigation regimes and mulch treatments on water use efficiency and soil temperature and moisture. Symbols are defined in the text and Figure 1. Values followed by different letters are significantly different (P< 0.05; Tukey's least significant difference test; *n* = 3).

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the reasons for accumulation of TSSC in cell under water deficit stress is to increase osmotic potential, which results in decreasing the stored water in tomato and thereby TSSC and sugar percentage increase (Mitchell *et al*., 1991). The pH and acidity are one of the most important indicators of tomato quality as the lower the pH of the fruit, the greater its spoilability. In addition, the lower pH of fruit helps, to some extent, selling this fruit in markets (Atherton and Rudich, 2012). Among the applied mulches, WCM had the most effect on increasing qualitative traits of fruit (except for vitamin C) studied in this research (Table 1) due to enhancing the maintenance of soil moisture (Figure 2-A).

Fruit Yield

The yield of tomato increased with increasing the amount of irrigation water in un-mulched treatment. As shown in Table 1 and Figure 1 (C and D), yields (total, marketable, early ripening), number of fruit in plant, and mean weight of fruit per plant were significantly influenced by different levels of irrigation, as they were reduced with decreasing the quantity of water applied during the crop season. The highest significant values of total yield, marketable yield, early ripening yield, number of fruit in plant, and mean weight of fruit per plant were found under the highest water level (100% CWR), followed by 70% CWR treatment, while the lowest values of these traits were recorded with the lowest water level (50% CWR) treatment (Table 1, Figures 1-C and -D). However, irrespective of mulching, the highest significant values of percentage of cracked fruits per plant and percentage of blossom-end rot fruits per plant were found under the lowest water level (50% CWR), while the lowest values of these traits were recorded with the highest water level (100% CWR) treatment (Figure 1-E). All the drip treatments with mulch resulted in significantly higher yield (total, early ripening and marketable) and yield components than un-mulched drip treatments. Different mulches increased fruit yield by 12–46% over non-mulch conditions (Table 1). With 100% water application, PM produced higher early ripening and marketable yield than other mulched treatments. The early ripening yield of tomato increased with the increase in water supply without mulch. The effect was reverse when drip irrigation coupled with WCM: there was a decrease in tomato yield with the increase in irrigation regime (Table 1, Figures 1-C and -D). An explanation for the reverse effect of irrigation levels with WCM is that with increasing soil moisture (irrigation levels), reproductive growth of tomato (decrease in yield) decreases, but vegetative growth of the plant increases. Since WCM prevents evaporation of the water, it can increase soil moisture. These results are confirmed by previous studies *(*Abdel-Razzak et al., 2013; Abdel-Razzak *et al.*, 2016; Biswas *et al*., 2015; Chen *et al.*, 2013; Mukherjee *et al*., 2012). For example, results of Abdel-Razzak *et al*. (2016) showed that the highest irrigation level (100% ETc) increased fruit weight and size, and total and marketable yield. In general, drip irrigation at 100 and 70% CWR with PM produced better early ripening yield over 70 and 100% CWR irrigation levels with other mulches. It has been known that synthetic mulches reduce weed problems and certain insect pests and stimulate higher crop yields by more efficient utilization of soil nutrients and water, (Biswas *et al*., 2015; Kashi *et al*., 2004; Roy *et al*., 1990).

The highest marketable yield (5.78 kg plant^{-1}) and total yield were obtained by the plants under the highest water level (100% CWR) along with PM and WCM, respectively (Table 1 and Figure 1-C). As amount of water increased, the improvement of marketable yield of the tomato resulted mainly from the increase in average fruit weight (Table 1). These findings are supported by Pulvento *et al*. (2008) and Abdel-Razzak *et al*. (2016). They found that the marketable yield enhancement of the tomato cultivars was correlated to irrigation water volume. In the study of Kuşçu *et al*. (2014), DI strategies also adversely affected fruit weight of processing tomato and marketable yield. The lowest percentage of

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cracked fruits and blossom-end rot fruits was observed in the plants under 100 and 70% CWR along with WCM and the highest percentage of which was recorded in CWCM under the lowest irrigation level (50% CWR) (Figure 1-E).

Blossom end rot, rotten spot on the bottom of tomato, is due to the lack of sufficient available Ca in the fruit at the blossom end. As the soil moisture decreases, the Ca movement decreases to the root surface. In addition, uptake of Ca by plant depends on rate of transpiration (Liping, 2007). It is known that reducing the amount of transpiration reduces Ca absorption. Therefore, it is possible that WCM could improve uptake of Ca under water deficit stress and thereby increase blossom-end rot in tomato. Decreased uptake of Ca under water stress in different plants has been previously reported (Ashraf and Naz, 1994; Bartels and Sunkar, 2005; Kaya *et al*., 2006). In general, the present study showed that both irrigation and mulch caused a significant ($P< 0.05$) variation in fruit yield of tomato (Figure 1). According to the results, total yield of fruit observed in WCM can be due to higher WUE, better maintenance of moisture (Figure 2-A), and more production of fruit with this mulch.

Water Use Efficiency (WUE)

As shown in Figure 2-A, WUE varies both with irrigation regimes and with mulches. Mulches with irrigation gave higher WUE compared to irrigation alone under all levels of irrigation regimes. The highest WUE at all three levels of irrigation regimes was observed in WCM treatment, due to having higher total yield and maintaining higher soil moisture (Table 1 and Figure 2-A). WCM along with 70% of CWR showed the best WUE (18.27 kg m^{-3}), while the lowest WUE (10.73 kg m^{-3}) was obtained from treatment of 100% CWR without any mulch (control). When the irrigation level increased from 100 to 70% CWR, the WUE increased considerably. When the irrigation level increased from 100 to 70% CWR, the WUE increased considerably. Both plants treated with PM and WCM and irrigated with 70% CWR and plants treated with PM and WCM and irrigated with 50% of WRC had the same WUE statistically. In other words, larger effect of mulches on WUE was observed when they were combined with lower irrigation regime. It has been reported that evaporation rate rapidly decreases due to the rapid drying of soil surface under lower irrigation regime, but transpiration rate is not affected for a long time (Biswas *et al.*, 2006). This may be the probable cause of high WUE and fruit yield in this irrigation regime. In a study (Jain *et al*., 2000), water use and WUE were remarkably affected by plastic mulch and drip irrigation. WUE is an indicator for measuring the productivity of using water resources relative to crop production. Under limited water supply conditions, this index plays an important role in the proper screening of irrigation management. Decrease in the irrigation level increases the root system of plants. This allows the plants to absorb water and nutrients from deeper soil, thus increasing both irrigation and nutrient use efficiency (Ngouajio *et al*., 2007). In general, WUE increased under all mulch conditions. Mulches reduced the rate of water loss through evaporation from soil surface. Therefore, the soil-water-plant relationship was better in low irrigation regime than high irrigation regime that might help produce higher yield and thereby higher WUE. In drip alone treatment, the highest WUE was also recorded in low irrigation regime treatment. The trends for the WUE related to the total water use for various drip treatments showed that the lower the amount of water use, the higher was the WUE. Besides, low irrigation regime reduced deep percolation and increased water use from root zone soil (Ayars *et al*., 1999). This result is in agreement with those of previous studies (Biswas *et al*., 2015; Jolaini, 2011; Li *et al.*, 2013). For example, in a study, Liang *et al*. (2011) also investigated effect of three types of mulches including wheat straw mulch, plastic film mulch, and combined mulch, on hot pepper (*Capsicum annuum* L.) yield under greenhouse conditions. Their results showed that WUE was strongly

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affected by mulches, as WUE increased by 97.9, 60.1, and 104% in wheat straw mulch, plastic film mulch, and combined mulch compared to control, respectively.

Soil Properties

As shown in Figure 2-A, the soil treated with WCM and irrigated with 100% CWR had the highest soil moisture as compared with other treatments. Soil temperature was affected significantly by mulching. As mentioned above, mulches had considerable role in maintaining soil moisture. According to Figure 2-B, the highest soil temperature was observed in the soil treated with PM (29.4ºC), while the lowest soil temperature (23.6ºC) was measured in the soil treated with WCM. In addition, the soil treated with CWCM had higher temperature than the control (NM) and less than PM. It has been known that the values of soil temperature with mulching were much higher than soil without mulching (Anisuzzaman *et al*., 2009; Liang *et al*., 2011; Yaghi *et al*., 2013). This may be because mulching prevents cooling of the soil surface by evaporation.

CONCLUSIONS

This study clearly indicated that water deficit stress could adversely affect some of qualitative and quantitative traits of tomato at the beginning of reproductive growth stage. However, the results obtained from this study showed that use of mulching can improve the growth of tomato plant by maintaining soil moisture, regulating soil temperature, and positively influencing morphological and physiological traits of this plant. In addition, PM and WCM could increase WUE. Among mulches used in this study, PM resulted in the highest marketable yield in tomato by decreasing evaporation from soil surface, which resulted in maintaining soil moisture, and increasing soil temperature. Since PM increases the temperature of the soil, it is more suitable for cold regions. However, WCM can be more suitable for warmer areas. In conclusion, the use of mulch with drip irrigation may be a good option not only for saving water but also for improving yield. Further studies are needed on the effects of levels of mulching and water stress on different cultivars of tomato in other growth stages to achieve results that are more accurate.

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اثر خاکپوش بر برخی خصوصیات گوجه فرنگی (*Lycopersicon esculentum* Mill.) تحت تنش کم آبیاری

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چکیده

این تحقیق با هدف ارزیابی اثر مجزا و ترکیبی رژیم های آبیاری قطره ای (۵۰٪، ۷۰٪ و ۱۰۰ درصد نیاز آبی گیاه، CWR) و خاکپوش های مختلف (بدون خاکپوش ، NM، خاکپوش تراشه چوب، WCM، خاکپوش تراشه چوب کمپوست شده، CWCM؛ و خاکپوش پلاستیکی، PM) بر برخی از

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ویژگی های مورفولوژیکی و فیزیولوژیکی گوجه فرنگی، کارایی مصرف آب (WUE) و خواص خاک (رطوبت و دمای خاک) در شرایط مزرعه انجام گرفت. نتایج تحقیق نشان داد که عملکرد و اجزای آن به طور معناداری تحت تاثیر سطوح مختلف آبیاری قرار گرفتند. خاکپوش های مختلف در مقایسه با شرایط بدون خاکپوش، عملکرد میوه گوجه فرنگی را ۴۶-۱۲٪ افزایش دادند. بالاترین عملکرد بازار پسند (۵/۷۸ کیلوگرم در هر بوته) و عملکرد کل (۵/۷۷ کیلوگرم در هر بوته) به ترتیب در گیاهان آبیاری شده با ۱۰۰ درصد نیاز آبی گیاه و خاکپوش شده توسط PM و WCM به ثبت رسید. کمترین درصد میوه های ترک خورده و درصد پوسیدگی گلگاه در گیاهان آبیاری شده با ۱۰۰٪ و ۷۰٪ نیاز آبی گیاه همراه با WCM مشاهده شد. علاوه بر این، بیشترین مقدار WUE(۱۸/۲۷ کیلوگرم بر متر مکعب) در تیمار ۷۰ درصد نیاز آبی همراه با WCM به دست آمد. به طور کلی، نتایج این مطالعه نشان داد که آبیاری قطره ای با استفاده از خاکپوش تراشه چوب می تواند نقش قابل ملاحظه ای در افزایش عملکرد تولید گوجه فرنگی و صرفه جویی در آب آبیاری تحت شرایط مزرعه ای ایفا نماید.

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