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INFLUENCE OF REGULATED DRIP IRRIGATION ON PRODUCTIVITY AND PHYSICOCHEMICAL TRAITS OF TOMATO 'TOFANE' UNDER HOT DESERT CLIMATE

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Abstract

The impact of regulated drip-irrigation on productivity and fruit quality of tomato 'Tofane' has been studied under a warm dry desert climate in southern Algeria. Yield, fruit weight and size, water content and parameters of fruit quality – total soluble solids, phenolic compounds, carotenoids, vitamin C, pH and titratable acidity were determined. Two irrigation treatments were applied in 2012 and 2013: T1, optimal irrigation (100% evapotranspiration – ET_c) during the whole growth period (growth stages I, II and III); T2, optimal irrigation during I and II stages, and regulated deficit irrigation (67% ET_c) during stage III (from fruit set to full fruit maturity of first and second bunch). T1 treatment during the whole season showed the highest values of soil water potential (Ψ_{soil}), between −0.02 MPa and −0.06 MPa, on depths of 0.3 and 0.6 m, respectively. During stage III, regulated deficit irrigation caused the lowest Ψ_{soil} values, which were between −0.1 MPa and −0.12 MPa on a soil depth of 0.3 and 0.6 m, respectively. Deficit irrigation caused significant decrease of water content in fruits and not significant decrease of fruit weight and size, as well as fruit yield while water saving for irrigation amounted to 10%. Comfort-irrigated tomato plants produced fruits containing significantly higher titratable acidity, total soluble solids and vit. C content. There was a tendency to decrease carotenoid content and increase phenolic content in both years of the study. Due to the possibility of water saving with not significant yield decrease, it seems that the reduction of water use in growth stage III would be an adequate strategy for tomato cultivation in hot, dry climate.

Key words: physicochemical fruit parameters, tomato, deficit irrigation, fruit yield and quality, water saving

INTRODUCTION

Access to water resources is a major challenge for future agriculture. With climate change, water access might be more limited in the future and irrigation strategies, such as deficit irrigation, will become even more important. Considering the increasing world population, water can become a seriously limiting factor for socio-economic development of some regions, particularly in arid areas. In fact, in many regions of the world, plant growth and crop yields are limited when water is scarce, especially where rainfall is almost zero, like in Biskra (Algeria). In this context, the water productivity (WP) and irrigation efficiency must be optimized.

One of the most used methods to increase water productivity, here defined according to Molden et al. (2010) as the net benefit from the crop to the amount of water used to produce those benefits, is the application of regulated deficit irrigation (RDI) strategies. RDI can reduce water consumption, provided it is applied in the appropriate phenological stages and will not significantly decrease yield and fruit quality (Chenafi et al. 2019). RDI is considered a key water-saving practice for efficient use of the limited water resources (Chenafi et al. 2016).

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Tomato is one of the vegetable sources of antioxidants and vitamin C in human food (Toor et al. 2006). The nutritional composition of the tomato fruit is affected by the genotype, stage of ripeness, climatic growing conditions, light, temperature, soil, fertilization, and irrigation because water is one of the most important environmental factors affecting the fruit growth and production of tomato (Wang et al. 2011). According to the literature, tomato has high water requirements (Patanè et al. 2011). The influences of different irrigation intervals have been investigated on tomato in terms of yield and fruit quality (Harmanto et al. 2005). Water stress level and irrigation application timing significantly affect the tomato yield and fruit quality. Therefore, irrigation scheduling is crucial for increasing tomato yield and quality (Wang et al. 2011). The challenges that tomato production has to face extreme climatic conditions, such as persistent drought, must meet the expectations of consumers who sometimes are difficult to satisfy. Tests on different irrigation strategies on tomato help fruit growers to define their irrigation management strategy.

On the one hand, considering the high water demand of tomato and not enough information describing how the deficit irrigation of tomato under hot desert climate influence fruit yield and quality, and on the other hand, the absence of rainfall in this region makes it necessary and imperative to find the best irrigation strategies to minimize the water consumption. The main objective of this work was to study the influence of deficit drip irrigation on yield and physicochemical characteristics of tomatoes (‘Tofane’), under greenhouse condition.

MATERIALS AND METHODS

Experimental site and plant material

The experiment was conducted for two consecutive summer seasons (2012 and 2013) in an experimental greenhouse located at the Ain Naga (Biskra in the Algerian Sahara situated at latitude 34°68’ N, longitude 6°09’ E, and altitude 206 m. The tomato ‘Tofane’ a standard, large and vigorous cultivar was used for the experiment. Meteorological variables (temperature, solar radiation, relative humidity and precipitation) were measured according to the instruction of meteorological service of Algeria. The climate is hot desert type – BWh (Köppen–Geiger classification) and is characterized by very low rainfall, from 0 to 200 mm average over 30 years. The rain events are irregular and precipitation can be torrential. Maximum temperatures in September–February, during the fruit growth period (FGP), ranged from 23 to 39.2 °C in 2012 and from 22.5 to 37.6 °C in 2013, the minimum from 15.4 to 28.1 °C and from 14.2 to 29.7 °C, respectively. Total rainfall was quite negligible (<15 mm) in both years (Fig. 1).

Soil analyses were carried out from five samples randomly taken in March 2012 at three different depths (Table 1). According to the American Unified Soil Classification System (USCS), the soil is sandy loam, the pH ranges from 8.4 (upper soil) to 8.9 (lower soil). The soil poverty was compensated by a massive use of chemical fertilizers mainly nitrogen, phosphorus and potassium. Before transplanting, soil was fertilized with 75, 50, and 50 $kg \cdot ha^{-1}$ of N, P and K, respectively. A month after transplanting, 175 $kg \cdot ha^{-1}$ of N (as ammonium nitrate) was added (Nangare et al. 2016).

Table 1. Soil characteristics in 2012 at three different depths

Depth (m)	pH	Granulometry (%)		
		clay	silt	sand
0.00–0.25	8.4	10.2	16.7	73.1
0.25–0.50	8.7	09.1	18.9	72,0
0.50–0.75	8.9	11.7	22.8	65.5

Tomato seeds were sown on August 15, 2012 and August 6, 2013 in pots in the greenhouse. The plants were transplanted on September 23 after completing the initial growth stage (28 days), when they were 20 to 25 cm high and had a good bunch of leaves and an abundant root system. Planting density was 1.0 m × 0.4 m (25 000 plants per ha), and the rows were north–south oriented. During the tomato growth period (TGP), insecticides and fungicides were applied according to commercial recommendations. The plants were vertically supported with plastic wires running at different heights along the rows.

Irrigation treatments

The experimental design was a randomized complete block with three replications (plots) and two irrigation treatments. Each experimental plot was 15 m long and 2 m wide, with two rows per plot. A buffer zone of 2 m was provided between plots. Water was applied following the soil water balance, based on crop evapotranspiration (ET_c) estimated as $ET_0 \times K_c$, where reference evapotranspiration (ET_0) was obtained using the Penman–Monteith equation (Allen et al. 1998). The crop coefficient (K_c) was selected according to Allen et al. (1998) for the different TGP: T I – between 0.4 and 0.7 from transplanting to the beginning of flowering, 1–45 day; T II – between 1.1 and 0.8 from the beginning of flowering to beginning of fruit set, 46–90 day; T III – between 0.8 and 0.6 from beginning of fruit set to full maturity of the 1st and 2nd bunch of fruits, 91–150 day.

The flowering and fruit setting stages are the most sensitive to water deficits (Harmanto et al. 2005), therefore no water stress was applied during these periods but only during TGP III. The irrigation treatments were based on 100% ET_c (comfort) and 67% ET_c (deficit), according to Chen et al. (2013). T1 – comfort irrigation lasted for the three tomato growth periods; T2 – comfort irrigation lasted for I and II TGP and deficit irrigation during TGP III (Table 2).

In total, during 2012 and 2013, the following water volumes were applied: in T1 – 242.7 and 266.7 mm in TGP I, 169.8 and 193.2 mm in TGP II and 187 and 218.8 mm in TGP III. The T2 treatment received the same as T1, except that during TGP III only 125 and 140.6 mm, respectively. Irrigation was applied up to the end of the growing season (until the last harvest). Surface drip irrigation was carried out with one dripper line installed along the rows. The dripper flow rate was 2.5 $dm^3 \cdot h^{-1}$ and dripper spacing 0.8 m. For drip irrigation, a single lateral line of 16 mm diameter pipes was laid along each row of the crop. The system consisted of a centrifugal pump, control unit (a screen filter, manometers, valves and a water meter). Three irrigation events per day took place. Water productivity (yield per unit irrigation) was evaluated according to Howell (2001).

Measurements of soil water status

To determine the soil water status, granular matrix probes (Watermark, Irrometer, USA) were installed at 0.3 and 0.6 m depth to get the soil water potential (Ψ_{soil}), approximately vertically under the dripper line. The median value of three probes at each soil depth was considered contributed to schedule optimal irrigation.

Yield of tomato fruit

Fruits were harvested when the ripe fruit rate reached approximately 95% (Giordano et al. 2000) – March 24, 2012 and March 19, 2013. The main productive and qualitative aspects of the tomatoes were estimated on the plants of the central row. Several characteristics of the fruit were investigated based on the samples of 30 red fruits collected at random from each plot. Mean fruit weight (F_W, g) and fruit diameter (F_D, mm) were measured with the accuracy of 0.01 mm (Özcan & Haciseferogullari 2004). Fruit mass was calculated from 10 tomatoes randomly selected with the accuracy of 0.01 g (Shahnawaz & Sheikh 2011). To determine water content, about three grams of tomato homogenate (obtained with electric blender) were weighed and placed in an oven at 105 °C for 3 h.

Fruit quality parameters

The fruits of the first choice, according to the commercial quality, were selected on the basis of weight and color for analyses. Before starting, the fruits were washed with tap water and then twice with distilled water. The total soluble solids (TSS) were determined as described by Mazumdar and Majumder (2003) using ABBE Digital Refractometer (Zuzi 315 RS, France). Titratable acidity (TA) was determined by titrating the pulp of tomato (10 g of homogenized tomato mixed with 30 ml of distilled water) with 0.1 N NaOH solution up to a pH of 8.1 (ISO 750:1998). The result was given as grams equivalent of citric acid per 100 g of tomato. Ascorbic acid (AA) was determined according to the method of Klein and Perry (1982). 1 g of tomato homogenate was extracted using 10 ml of oxalic acid (1%) for 45 min and filtered. 1 ml of filtrate was mixed with 0.5 ml of 2.6-dichloroindophenol and the absorbance was read at 515 nm after 15 seconds. The AA concentration was calculated on the basis of the L-ascorbic acid calibration curve ($y = -29.185 x + 0.728$; correlation coefficient $R^2 = 0.994$) and expressed as mg per 100 g of tomato.

Carotenoids concentration was measured according to Sadler et al. (1990). Two grams of homogenized tomato sample were weighted in 50 ml flask and extracted with 20 ml n-hexane: acetone: ethanol (2 : 1 : 1) mixture for 30 min under magnetic stirring. The upper layer was separated and the procedure was repeated for the lower phase using 10 ml of pure hexane. The combined extracts were used to determine carotenoids content at 420 nm using calibration curve of β-carotene ($y = 119.764\ x + 2.154$, $R^2 = 0.999$) and the result was expressed as mg β-carotene equivalent per 100 g of tomato. Extraction of antioxidants was performed according to the procedure of Mau et al. (2005). Five grams of homogenized tomato were extracted with 50 ml of solvent (50% methanol) during 24 h and the mixture was filtered. The content of phenolic compounds was determined according to Singleton and Rossi (1965). The Folin–Ciocalteu reagent (750 µl) and sodium carbonate (400 µl, 7.5%) were added to 200 µl of the extract. After 90 min, the absorbance was measured at 720 nm. Total phenolic contents (TPC) was expressed as mg of gallic acid equivalent (GAE) per 100 g of tomato using calibration curve made with gallic acid ($y = 6.446\ x + 0.125$, $R^2 = 0.993$). The ferric reducing power was evaluated according to Oyaizu (1986). One ml of ethanolic extract was mixed with 2.5 ml of phosphate buffer (0.2 M, pH 6.6) and 2.5 ml of 1% potassium ferricyanide, and the mixture was incubated at 50 °C for 20 min. Subsequently, 2.5 ml of 10% trichloroacetic acid was added, and the mixture was centrifuged at 300 g for 10 min. The upper layer (2.5 ml) was mixed with 2.5 ml of distilled water and 0.5 ml of 0.1% ferric chloride, then the absorbance was measured at 700 nm. Water productivity was calculated as the ratio of marketable fruit yield (kg per ha) and total water applied (m^3 per ha) (Patanè et al. 2011).

Statistical data analysis

All data of measured variables was subjected to analysis of variance appropriate for the randomized complete block design (RCBD). The differences among the means were determined for significance at $p < 0.05$ using LSD (least significant difference) Post Hoc Test. All statistical analyses were carried out using Statistica 5.5.

RESULTS AND DISCUSSION

Soil water status and ET_c

During the TGP in 2012, 2013, ETc for the days after planting varied from 3.5 mm to 6.5 mm (Fig. 1). The maximum value was obtained at the day 6 after transplanting. However, after 20 days, ETc decreased up to 3 mm at day 90. The ETc results analysis revealed that the highest need for water occurred between days 10 and 50. Fig. 2 illustrates the Ψ_{soil} dynamics. At the beginning of the measurements all the treatments had the same values from −0.02 to −0.04 MPa at 0.3 and 0.6 m soil depth, respectively. Later on, during TGP I and II, the values of Ψ_{soil} ranged from −0.01 to −0.04 MPa at 0.3 m and from −0.02 to −0.06 MPa at 0.6 m. During TGP III, Ψ_{soil} for comfort treatment T1 decreased to −0.06 MPa at 0.3 m and −0.083 MPa at 0.6 m. Under regulated deficit irrigation at T2 treatment Ψ_{soil} reached −0.1 MPa and −0.119 MPa at 0.3 and 0.6 m, respectively. Even if the values in soil were still within the ones recommended for comfort irrigation (Thompson et al. 2007), the decrease of Ψ_{soil} suggests that the value of Kc used for this period (decreasing from 0.8 to 0.6) can eventually be underestimated.

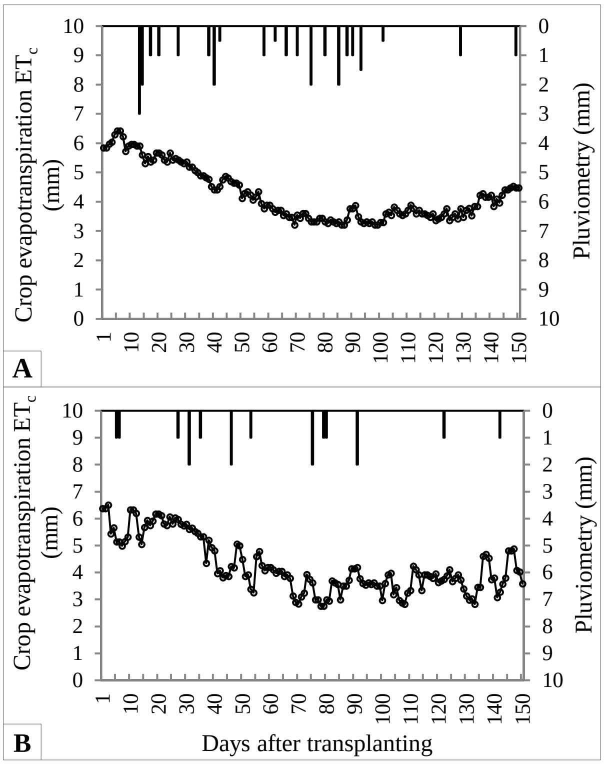

Fig. 1. Seasonal course of daily pluviometry (|) and the daily plant evapotranspiration (•) during the growth period in 2012 (A) and 2013 (B)

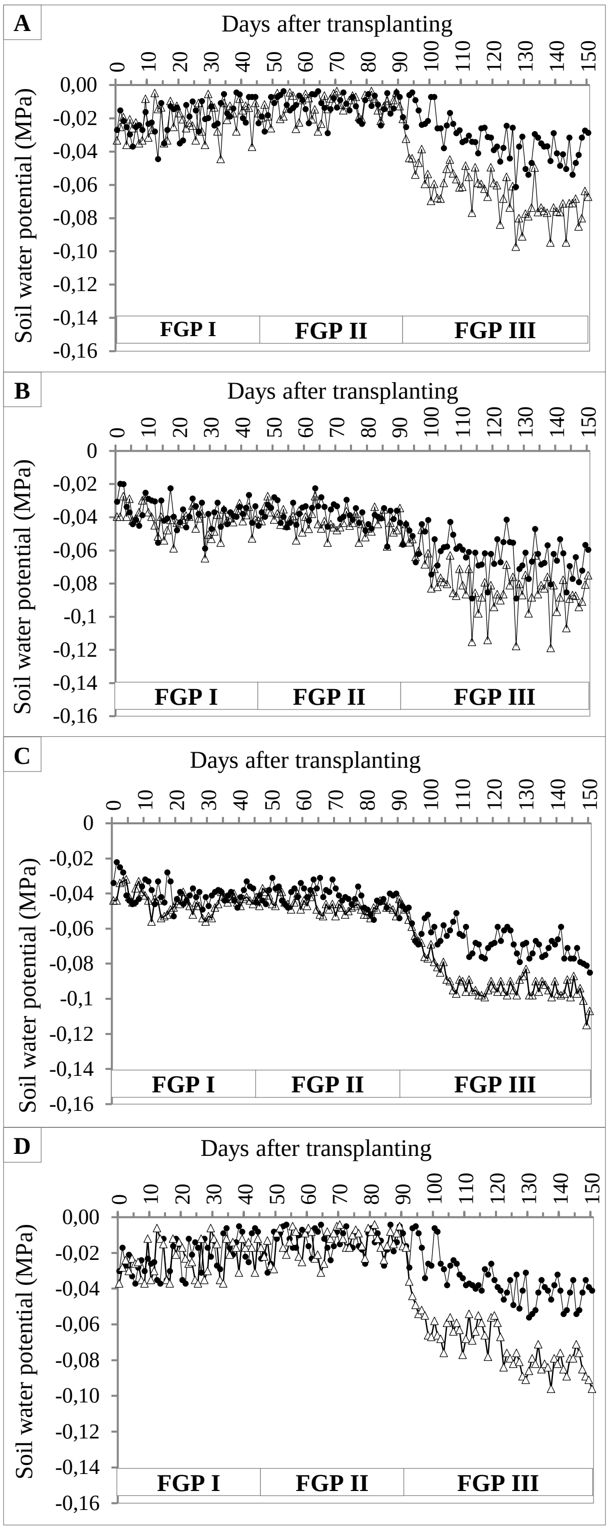

Fig. 2. Soil water potential in 2012 at 0.3 m (A) and 0.6 m (B), and in 2013 at 0.3 m (C) and 0.6 m (D) in relation to different irrigation strategies: T1 – comfort irrigation (•); T2 – comfort irrigation in TGP I, II and RDI during TGP III (△). Each point corresponds to the median of three measurements.

Water application, yield and physicochemical fruit characteristics

Reduction of amount of water given in irrigation for tomato plants by 10.5% in 2012 and 11.5% in 2013 (Table 2) caused reduction of all parameters of fruit, although no significant differences were found between comfort and reduced irrigation (Table 3). Single fruit weight was reduced by 19.8% and 19.6%, and fruit yield per plant by 10.4% and 4.4% in years 2012 and 2013, respectively. The fruits were smaller – fruit diameter was reduced by 8.7% and 7.1%. The above results were derived from the significant reduction of water content in fruits by 16.9% in 2012 and 5.7% in 2013 (Table 3). As a result of reduction of water use, a significant decrease of 20.5% was recorded for vit. C content in 2012. However, water deficit caused significant increase in titratable acidity – 16.7% and 15.7%, and in total soluble solids – 46.2% and 49.1% (Table 4). Non-significant increase was found in pH value (12.2%) and in vit. C content (11.4%) in 2013. The increase of above parameters under water deficit could be explained by the reduction of water in fruit and higher concentration of the pulp. Water deficit caused non-significant decrease of carotenoids content (by 20.7% and 13.6%).

Compared comfort to deficit irrigation not significant yield reduction 4.4% in 2013 and 10.5% in 2012 should be considered in relation to water consumption that was reduced by 10.5% and 11.5%, respectively. Similar dependencies between characteristics analyzed here and deficits of irrigation were reported by Patanè et al. (2011), Wang et al. (2019), and Harmanto et al. (2005).

Table 2. Amounts of water (mm) applied in 2012 and 2013 for comfort (T1) and deficit irrigation (T2) during the fruit growth periods

TGP	Days after transplanting	Treatment			
		2012		2013	
		T1	T2	T1	T2
I	1–45	242.7	242.7	266.7	266.7
II	46–90	169.8	169.8	193.2	193.2
III	90–150	187.5	125.0	218.8	140.6
I, II, III	1–150	600.0	537.5	678.6	600.5
Reduction of water use		−10.5%		−11.5%	

Table 3. Tomato fruit weight, yield, diameter, fruit moisture, amount of water and water productivity in relation to comfort irrigation and deficit irrigation in 2012 and 2013

Treatments	Single fruit weight (g)		Yield (kg per plant)		Water applied (mm)	
	2012	2013	2012	2013	2012	2013
T1	244.3 ± 36.5a	231.7 ± 21.3a	10.5 ± 0.9a	11.4 ± 0.7a	600	678.6
T2	195.9 ± 7.9a	186.3 ± 09.8a	09.4 ± 1.3a	10.9 ± 1.7a	537	600.5
% of reduction (−) or increase (+)	−19.8	−19.6	−10.5	−4.4	−10.5	−11.5
Treatments	Fruit diameter (mm)		Fruit moisture (%)		Water productivity ($kg \cdot m^{-3}$)	
	2012	2013	2012	2013	2012	2013
T1	90.7 ± 9.7a	87.5 ± 9.0a	92.5 ± 3.1a	89.8 ± 3.0a	43.9	42.1
T2	82.8 ± 5.5a	81.3 ± 4.5a	76.9 ± 5.9b	84.7 ± 4.8b	43.8	45.7
% of reduction (−) or increase (+)	−8.7	−7.1	−16.9	−5.7	0	+8.6

Each data value corresponds to the mean (± SD) with three replications. In parenthesis reduction in comparison to comfort irrigation. Means followed by different letters for each parameter were significantly different by Student's t-test ($p \leq 0.05$).

Table 4. Chemical characteristic of tomato fruit in relation to comfort and deficit irrigation in 2012 and 2013

Treatments	Titratable acidity ($g \cdot dm^{-3}$)		pH		Total soluble solids (°Brix)	
	2012	2013	2012	2013	2012	2013
T1	4.2 ± 0.3b	5.1 ± 0.1b	4.4 ± 0.2a	4.1 ± 0.1a	5.2 ± 0.9b	5.5 ± 1.2b
T2	4.9 ± 0.2a	5.9 ± 0.4a	4.2 ± 0.2a	4.6 ± 0.3a	7.6 ± 0.9a	8.2 ± 0.9a
% of reduction (−) or increase (+)	+16.7	+15.7	−4.5	+12.2	+46.2	+49.1

Treatments	Carotenoids content ($mg \cdot 100\ g^{-1}$)		Total phenolic content ($mg \cdot 100\ g^{-1}$)		Vitamin C content ($mg \cdot 100\ g^{-1}$)		Reducing power ($mg \cdot 100\ g^{-1}$)	
	2012	2013	2012	2013	2012	2013	2012	2013
T1	23.7±2.9a	28.5±1.9a	23.8±1.3a	25.5±1.1a	12.2±0.6a	10.5±0.8a	36.4±2.60a	34.2±3.02a
T2	18.8±2.4a	24.6±1.8a	25.5±3.6a	28.6±3.0a	09.7±0.9b	11.7±1.6a	31.9±2.49a	30.1±2.67a
% of reduction (−) or increase (+)	−20.7	−13.6	+7.1	+12.2	−20.5	+11.4	−12.4	−12

Each data value corresponds to the mean (± SD) of three replications. Means followed by different letters for each parameter were significantly different according to Student's t-test ($p \leq 0.05$).

Increase of the values of titratable acidity and total soluble solids in two years of experiment as compared with the comfort irrigation tomatoes was similar to results of Coyago-Cruz et al. (2017), Patané et al. (2011) and Vinha et al. (2014). Decrease in vit. C content in fruits produced under water deficit was reported by Patanè et al. (2011) and Chen et al. (2013). Lack of significant differences in values of the pH, contents of carotenoids and phenolics between comfort and deficit irrigation was also reported in a research of Pernice et al. (2010), Rosa et al. (2011) and Lahoz et al. (2016).

Decrease of irrigation positively affected water productivity. Application of 11.5% less water in 2013 increased water productivity by 8.6%, whilst reducing the amount of water by 10.5% in 2012 did not change water productivity (Table 3).

In the present study, higher water productivity could be achieved with $RDI_{0.67}$, whereas Nangare et al. (2016) showed in an experimental tomato study that WP is maximal with $RDI_{0.6}$ and $RDI_{0.8}$. Patanè et al. (2011) concluded that tomato plants consumed water more efficiently at lower irrigation than at optimal water quantities. These results were also consistent with the former research by Kirnak et al. (2005) and Sensoy et al. (2007), which considered that lowering the amount of irrigation water increased the irrigation water use efficiency.

Our study is another example confirming that regulated deficit irrigation in a proper growth stage is a good strategy for tomato cultivation under desert climate because it allows to save approximately 11% of water with not significant decrease of fruit yield and quality. This confirms results obtained for tomato by Nangare et al. (2016). Nevertheless, further study enabling more precise planning of water application strategy is necessary.

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