

Effects of different irrigation practices using treated wastewater on tomato yields, quality, water productivity, and soil and fruit mineral contents

Azize Dogan Demir¹ · Ustun Sahin²

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Abstract Wastewater use in agricultural irrigation is becoming a common practice in order to meet the rising water demands in arid and semi-arid regions. The study was conducted to determine the effects of the full (FI), deficit (DI), and partial root-zone drying (PRD) irrigation practices using treated municipal wastewater (TWW) and freshwater (FW) on tomato yield, water use, fruit quality, and soil and fruit heavy metal concentrations. The TWW significantly increased marketable yield compared to the FW, as well as decreased water consumption. Therefore, water use efficiency (WUE) in the TWW was significantly higher than in the FW. Although the DI and the PRD practices caused less yields, these practices significantly increased WUE values due to less irrigation water applied. The water–yield linear relationships were statistically significant. TWW significantly increased titratable acidity and vitamin C contents. Reduced irrigation provided significantly lower titratable acidity, vitamin C, and lycopene contents. TWW increased the surface soil and fruit mineral contents in response to FW. Greater increases were observed under FI, and mineral contents declined with reduction in irrigation water. Heavy metal accumulation in soils was within safe limits. However, Cd and Pb contents in fruits exceeded standard limits given by FAO/WHO. Higher metal pollution index values determined for fruits also indicated that TWW

application, especially under FI, might cause health risks in long term.

Keywords Irrigation practices · Treated municipal wastewater · Water use efficiency

Introduction

Agriculture uses about 70% of water withdrawals from the freshwater resources, which makes it to be the top consumer. Freshwater withdrawals have accelerated based on population growth and rapid economic developments (Connor et al. 2009). However, the reserve of good quality water resources in many arid and semi-arid countries is not enough for the steadily increasing demand of agricultural production. Therefore, water scarcity is one of the factors limiting sustainable and economic agricultural production on the earth. Wastewater is being used for agricultural purposes particularly in water-scarce areas of the world, and wastewater irrigation is unregulated, but common application is seen in many developing countries (Mateo-Sagasta et al. 2013).

Wastewater normally has a higher nutrient potential for providing effective and economic crop growth compared to freshwater. Crop productivity may be enhanced due to reducing of chemical fertilization requirement with the supply of nutrients contained in the wastewater (Vergine et al. 2017). Therefore, farmers prefer wastewater irrigation because it reduces the need for chemical fertilizers, resulting in net cost savings (Hussain et al. 2002). Wastewater besides having a suitable agricultural input can also cause major problems depending on the contents. Many ions and heavy metal concentrations above threshold values are toxic to plants (Pescod 1992). Heavy metals are also dangerous for health if they are taken at enough concentrations from the polluted foods.

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✉ Azize Dogan Demir
azizedogandemir@yahoo.com

¹ Faculty of Agriculture, Department of Biosystem Engineering, Bingöl University, 12000 Bingöl, Turkey

² Faculty of Agriculture, Department of Agricultural Structures and Irrigation, Ataturk University, 25240 Erzurum, Turkey

Improving of water productivity in irrigated agriculture is important to protect freshwater sources and nature. Deficit irrigation (DI) and partial root-zone drying (PRD) irrigation techniques are the most common practices to provide effective water use (Sadras et al. 2009). In PRD and DI practices, plants receive lesser amount of water than applied water in full irrigation. The essence of PRD modified from DI approach is to create alternate wet–dry regions in two halves of the root system (Sepaskhah and Ahmadi 2010).

Tomato is one of the most important crops cultivated throughout the world. In Turkey, tomato is the most produced vegetable. The sowing area and production amount of the fresh tomato in 2014 crop production statistics in Turkey are shown as 123,097.6 ha and 7,935,110 t, respectively. The production amount for the processed tomato with 599,313.4 ha sowing area is also 3,914,890 t (TUIK 2015). It is important for human health as a food that includes many minerals and vitamins (Sun et al. 2014). Tomato is a crop with high water demand, and it is sensitive to water stress (Zheng et al. 2013). Therefore, results of several studies showed that limited irrigation by PRD and/or DI practices decreased tomato fruit yield (Ismail and Phizackerley 2009; Savić et al. 2008; Stikic et al. 2003). However, numerous studies indicated that these irrigation practices increased the water productivity despite tomato yield losses (Affi et al. 2012; Akhtar et al. 2014; Kirda et al. 2004; Nardella et al. 2012; Psarras et al. 2014; Savic et al. 2011; Zegbe et al. 2004). Even better or reasonable fruit quality results in the limited irrigation conditions were reported in many studies. Sun et al. (2014) concluded that PRD is better than DI in terms of improving tomato fruit quality. Yang et al. (2012) expressed that compared to the full irrigation conditions, PRD improved fruit quality of tomato. It was reported that tomato yield and fruit quality attributes were same for both DI and PRD treatments (Zegbe-Domínguez et al. 2003). The quality of tomato fruits was better in moderate or mild water deficits (Zheng et al. 2013). Akhtar et al. (2014) and Savic et al. (2011) also indicated that reduced irrigation (i.e., PRD and DI) improved tomato fruit quality.

Tomato fruit yields in the wastewater irrigation were higher than the freshwater irrigation considering the results determined by Aiello et al. (2007), Cirelli et al. (2012), Li et al. (2012), and Najafi (2006). However, Disciglio et al. (2015) and Gatta et al. (2015) found non-significant lower marketable yield values in the wastewater-irrigated tomato compared to groundwater. Moreover, non-significant changes for fruit quality in wastewater-irrigated tomato were determined in some previous studies (Cirelli et al. 2012; Disciglio et al. 2015; Gatta et al. 2015; Li et al. 2012; Psarras et al. 2014). Nevertheless, Al-Lahham et al. (2007), Al-Momany et al. (2014), and Khan et al. (2011) reported that wastewater irrigation caused heavy metal

accumulation in tomato fruits. Looking at the results in different studies, considerable increases for heavy metal concentrations were observed also in wastewater-irrigated soils (Areola et al. 2011; Khaskhoussy et al. 2015; Singh and Agrawal 2012; Singh et al. 2012).

Wastewater application with less irrigation quantities can reduce toxic metal pollution in crop and soil. Possible yield increase potential under wastewater application conditions can support improving of water productivity. Tomato production and fruit quality traits can be influenced significantly from environmental conditions. Moreover, comprehensive studies on water use and productivity, fruit quality, soil, and fruit heavy metal pollution of the wastewater-irrigated tomato under less irrigation quantities with different practices in different growing regions are needed. Therefore, this study was conducted to determine the effects of the wastewater application with the deficit irrigation and partial root-zone irrigation practices in a region with hot and dry growing period as comparative with full irrigation on tomato yield, water use efficiency, fruit quality and physical properties, soil fertility, and fruit and soil heavy metal contents.

Material and methods

Experimental site description

Tomato plants were grown in Bingöl, Turkey, for two seasons (2013 and 2014). Experimental field is located (38.8839° N, 40.5492° E, and 1030 m above sea level) near to wastewater plant in Bingöl city. The climate in Bingöl is a continental climate (Dsa) according to the Köppen climate classification, with hot and dry summers and cold and snowy winters (Kottek et al. 2006). The annual mean temperature and total precipitation in Bingöl considering period of 1950–2015 are 12.1 °C and 944.1 mm, respectively. While July and August are the driest months, February and December are the wettest months. The growing periods for tomato plants in the experiment were 20 May–10 October in 2013 and 31 May–4 October in 2014. Table 1 shows climatic data in the experimental site over the growing periods. Monthly total precipitation and evaporation values were collected from the measured data by using pluviometer and class A pan located in experimental site, respectively. Monthly mean temperature, relative humidity, wind speed, and daily sunshine values were taken from the Bingöl Meteorological Station, approximately 4 km away from the experimental site.

The treatment plots were installed on a well-drained clay soil. The soil type at the experimental site is classified as Vertisol according to USDA soil taxonomy. Prior to the experiments, results of basal physical and chemical properties of the disturbed and undisturbed soil samples collected from the

Table 1 Certain climatic data in the experimental region during growing periods of tomatoes in 2013 and 2014

Year	Month	Temperature (°C)	Relative humidity (%)	Wind speed (m s ⁻¹)	Daily sunshine (h)	Evaporation (mm)	Precipitation (mm)
2013	May ^a	18.7	47.8	0.87	7.20	12	7.0
	June	22.8	33.3	1.04	8.84	181	6.2
	July	27.2	26.4	1.28	9.39	278	–
	August	26.4	26.2	1.08	9.19	255	–
	September	20.3	34.5	0.83	7.95	111 ^e	10.9
	October ^b	13.6	43.5	1.06	6.58	No data	–
2014	May ^c	22.0	44.7	1.20	9.50	1	0.4
	June	22.0	34.6	1.01	8.58	215	23.4
	July	27.2	25.9	0.95	8.54	217	4.9
	August	27.4	23.4	0.93	8.77	204	7.5
	September	20.9	35.3	0.75	7.76	114 ^f	–
	October ^d	16.9	53.2	0.65	2.28	No data	–

^a Calculated from the data in the period of 20–31 May

^b Calculated from the data in the period of 1–10 October

^c The data of 31 May

^d Calculated from the data in the period of 1–4 October

^e Sum of the data in the period of 1–24 September

^f Sum of the data in the period of 1–25 September

soil layers of 0–30, 30–60, and 60–90 cm are summarized in Table 2. Mineral contents of the topsoil layer of 30 cm before experiment are also given in Table 3. Considering the values in these tables, the soils of slightly alkaline had low electrical conductivity, organic matter, carbonates, and total N contents. While K₂O content in surface soil layer (0–30 cm) was high level, the P₂O₅ content was low level. Available soil moisture content was calculated as 142.6 mm for 90-cm soil depth considering field capacity, wilting point, and bulk density values of three soil layers given in Table 2.

Table 2 Basal properties of experimental field soil prior to the trial

Parameter	Soil layer (cm)		
	0–30	30–60	60–90
Texture	Clay	Clay	Clay
Sand (%)	30.2	26.4	27.4
Silt (%)	28.6	29.1	27.9
Clay (%)	41.2	44.5	44.7
Bulk density (mg m ⁻³)	1.30	1.31	1.36
Field capacity (% of weight)	28.5	30.3	30.8
Wilting point (% of weight)	17.2	18.1	18.4
pH	8.01	7.94	7.92
EC (dS m ⁻¹)	0.528	0.509	0.450
Organic matter (%)	1.6	1.3	1.1
CaCO ₃ (%)	4.6	3.4	2.1

Plant cultivation and experimental design

Joker-F1 (*Lycopersicon esculentum*) hybrids were used as plant material in the experiments. Tomato seedlings were planted on experimental plots as five rows with 1-m intervals. There were nine plants with 0.50-m interval on each row. Prior to the seedling planting, diammonium phosphate as 500 kg per hectare was applied to the experimental field. Moreover, compound (NPK15:15:15) and potassium nitrate (13:0:46) fertilizers were applied to all plots, at the doses of 50 kg per hectare, by drip irrigation system for five times with approximately 1-week intervals up to scheduled irrigation period after planting. Weed control was made by hand for three times

Table 3 Contents of macro, micro, and trace mineral in top soil layer (0–30 cm) of experimental field soil prior to the trial

Macro minerals	Value	Micro and trace minerals	Value (mg kg ⁻¹)
Total N (%)	0.08	B	0.57
P ₂ O (kg daa ⁻¹)	8.30	Fe	14.5
K ₂ O (kg daa ⁻¹)	71.3	Zn	0.60
Ca (cmol kg ⁻¹)	25.1	Cu	0.60
Mg (cmol kg ⁻¹)	5.60	Mn	13.2
Na (cmol kg ⁻¹)	0.50	Cd	0.20
		Ni	1.90
		Pb	0.09

up to first harvest. Additionally, insecticide was used against *Gryllotalpa gryllotalpa* in both experiment years.

The plants were irrigated with reclaimed wastewater and freshwater. Irrigation water was applied with different practices as FI, DI, and alternate PRD irrigation. Therefore, experiment was conducted as a randomized complete block design (three replicates), in a 2×5 factorial arrangement, corresponding to two different water resources [treated wastewater (TWW) and freshwater (FW)] and five different irrigation practices: FI, 25% deficit irrigation (D25), 50% deficit irrigation (D50), 25% deficit irrigation with PRD (PRD25), and 50% deficit irrigation with PRD (PRD50).

Irrigation water qualities, irrigation applications, and plant water use

TWW was collected from the discharge waters of Bingöl city wastewater plant, and it was conveyed to the experimental field near the wastewater plant with a PVC pipe. Bingöl city with quite low industrialization has few low-scale food plants. Therefore, almost entire wastewater source is domestic. FW was provided from open irrigation channel near the experimental field. Waters with different qualities were stored in separate tanks before each irrigation process and conveyed to the plants by a drip irrigation system. The main physical–chemical and microbial properties of irrigation waters (TWW and FW) were monitored in intervals of 1 month as the total of three periods during the irrigation period. The quality characteristics determined of the irrigation waters in experiment years are given in Table 4. The quality result of each parameter in the Table 4 shows the average of three sampling periods (June, July, and August). The analysis of water samples collected with standard procedures was carried out using general methods. The pH and electrical conductivity (EC) in water samples were measured directly by a pH meter (Orion 3-Star) and electrical conductivity meter (Orion 3-Star), respectively (Tüzüner 1990). Total suspended solids and 5-day biochemical oxygen demand (BOD₅) were determined according to procedures described by the American Public Health Association (APHA 1995). Determination of total N was made by Kjeldahl method (EPA 2001). Total P was determined with measuring of orthophosphate (Nollet 2000). HCO₃ and CO₃ with sulphuric acid and Cl with silver nitrate were detected by titration (Richards 1954). SO₄ was measured in a spectrophotometer (Specord 200 Plus) using barium chloride solution (Eltan 1998). Calcium and Mg were determined by the titration with EDTA solution of water samples. Sodium and K were analyzed by flame photometric method. Boron was determined by carmine method (Richards 1954). The mineral contents (Fe, Cu, Ni, Cd, Mn, Zn, Pb, Cr, and Co) were analyzed by an atomic absorption spectrophotometer (PerkinElmer) using water samples diluted with HNO₃ of 2.5% as described in Karadede and Ünlü (2000). Fecal

coliforms were determined by the membrane filtration method (TSI 2011). The sodium adsorption ratio (SAR) were calculated using the below equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \tag{1}$$

where Na, Ca, and Mg are in me l⁻¹.

Drip irrigation system was installed with a pump, control unit (hydrocyclone, fertilizer tank, disc filter, pressure regulator, manometer), and pipelines (main, manifold, and driplines). Irrigations were controlled manually by valves located inlet of driplines. Polyethylene driplines of 16-mm diameter had in-line emitters installed at 25-cm intervals with 4 l h⁻¹ flow rate under 0.1 MPa operation pressure. Total six driplines were placed between plant rows in each experimental plot. Therefore, the horizontal distance between plant rows and driplines was 0.5 m.

Irrigations in all experimental plots were done when consumed about 40% of available water in the control plots (full-irrigated plots with freshwater). In the first seven irrigations, all plots were fully irrigated with equal water amounts using freshwater. Then, scheduled irrigation application was initiated considering experimental design, and it was continued until the end of September in both experiment years. In the scheduled irrigation period, the plots irrigated with the DI and alternate PRD irrigation practices received lesser water of 25% (in the D25 and PRD25 treatments) and of 50% (in the D50 and PRD50 treatments) compared to the full-irrigated plots. While irrigation water was applied from all driplines in the FI and DI treatments in the scheduled irrigation period, it was applied alternately with three driplines in the PRD treatment. One half of the rooting zone in each irrigation in the PRD treatments received water. In the subsequent irrigation, irrigation water was applied from the other half of rooting zone. Therefore, irrigated sides of the root zone were replaced with every other irrigation.

Irrigation quantity applied to full-irrigated plots was calculated by below equation:

$$I = (FC - WP) \times \gamma_s \times D \times DF \times P / 10 \tag{2}$$

where *I* is the irrigation quantity (mm), FC is the water retention in soil at the field capacity (%), WP is the water retention in soil at the wilting point (%), γ_s is the soil bulk density (mg m⁻³), *D* is the soil depth (90 cm), DF is the depletion fraction of available soil water (0.40), and *P* is the plant cover ratio. *P* was determined by the ratio of plant average cover width measured before each irrigation process to the plant row interval. It was considered as the minimum 0.30 and as the maximum 0.70 in the growing period. Irrigation quantities in the scheduled irrigation period were corrected using a coefficient of 0.50 for the D50 and PRD50 treatments and using a coefficient of 0.75 for the D25 and PRD25 treatments.

Table 4 Quality properties (mean \pm SEM) of irrigation waters used in the study

Parameter		2013		2014	
		TWW	FW	TWW	FW
pH	–	7.76 \pm 0.34	8.15 \pm 0.22	7.73 \pm 0.24	7.57 \pm 0.08
EC	(dS m ⁻¹)	0.514 \pm 0.017	0.163 \pm 0.005	0.424 \pm 0.033	0.239 \pm 0.032
TSS	(mg l ⁻¹)	21.4 \pm 3.5	20.1 \pm 1.2	16.7 \pm 3.3	12.1 \pm 2.3
Total N	(mg l ⁻¹)	13.8 \pm 0.6	–	12.6 \pm 0.5	–
Total P	(mg l ⁻¹)	1.94 \pm 0.04	–	1.65 \pm 0.09	–
Ca	(me l ⁻¹)	2.09 \pm 0.29	1.10 \pm 0.10	1.75 \pm 0.37	1.50 \pm 0.40
Mg	(me l ⁻¹)	1.32 \pm 0.28	0.78 \pm 0.03	0.89 \pm 0.17	0.65 \pm 0.06
Na	(me l ⁻¹)	1.17 \pm 0.44	0.17 \pm 0.03	1.47 \pm 0.12	0.19 \pm 0.01
K	(me l ⁻¹)	0.35 \pm 0.11	0.05 \pm 0.01	0.33 \pm 0.02	0.11 \pm 0.02
CO ₃	(me l ⁻¹)	0.03 \pm 0.03	0.01 \pm 0.01	–	–
HCO ₃	(me l ⁻¹)	0.37 \pm 0.07	0.28 \pm 0.03	0.35 \pm 0.08	0.26 \pm 0.06
SO ₄	(me l ⁻¹)	3.21 \pm 0.34	1.35 \pm 0.07	2.51 \pm 0.43	1.64 \pm 0.03
Cl	(me l ⁻¹)	1.24 \pm 0.41	0.44 \pm 0.12	1.50 \pm 0.40	0.50 \pm 0.26
B	(mg l ⁻¹)	0.43 \pm 0.12	0.25 \pm 0.11	0.41 \pm 0.13	0.19 \pm 0.10
Fe	(mg l ⁻¹)	0.23 \pm 0.11	0.13 \pm 0.05	0.12 \pm 0.01	0.15 \pm 0.01
Zn	(mg l ⁻¹)	0.06 \pm 0.01	0.04 \pm 0.00	0.02 \pm 0.00	0.01 \pm 0.00
Cu	(mg l ⁻¹)	0.09 \pm 0.02	0.05 \pm 0.02	–	–
Mn	(mg l ⁻¹)	0.07 \pm 0.03	0.03 \pm 0.01	0.04 \pm 0.003	0.01 \pm 0.00
Cd	(mg l ⁻¹)	0.06 \pm 0.03	0.04 \pm 0.02	0.08 \pm 0.01	0.07 \pm 0.01
Ni	(mg l ⁻¹)	0.04 \pm 0.01	0.04 \pm 0.003	0.05 \pm 0.01	0.02 \pm 0.01
Pb	(mg l ⁻¹)	0.06 \pm 0.02	0.05 \pm 0.01	0.04 \pm 0.00	0.03 \pm 0.00
Co	(mg l ⁻¹)	0.19 \pm 0.00	0.17 \pm 0.003	0.19 \pm 0.01	0.15 \pm 0.02
Cr	(mg l ⁻¹)	0.41 \pm 0.03	0.34 \pm 0.05	0.34 \pm 0.04	0.29 \pm 0.04
SAR	–	0.95 \pm 0.42	0.18 \pm 0.04	1.32 \pm 0.19	0.19 \pm 0.01
BOD ₅	(mg l ⁻¹)	28.3 \pm 3.8	–	22.7 \pm 4.3	–
FC	(cfu/100 ml)	636 \pm 66	–	718 \pm 75	–

SEM standard error of the mean, TWW treated wastewater, FW freshwater, EC electrical conductivity, TSS total suspended solids, SAR sodium adsorption ratio, BOD₅ 5-day biochemical oxygen demand, FC fecal coliform

Tensiometers (IRROMETER Company, Inc.) calibrated to experimental field were installed at two soil depths (20 and 60 cm), mid-way between the emitter and plant rows, for determining of approximately irrigation time in three control plots full irrigated with freshwater. However, soil samples to determine the current water contents in all experimental plots were collected from three soil layers (0–30, 30–60, and 60–90 cm) before each irrigation application. Water status in the samples was analyzed by gravimetric method. Additionally, soil water contents at the beginning and end of growing period in all experimental plots were determined as gravimetrically. Gravimetric samples were taken from the area between plant rows and driplines in the middle of plots. The sampling in the PRD treatments was done on the side to be irrigated of the plant rows. The crop evapotranspiration of tomato was calculated considering irrigation quantity and precipitation values and the changes in soil water content. The calculations were done by the below equation given by Allen et al. (1998):

$$ET_c = I + P + CR - R - DP \pm \Delta SW \quad (3)$$

where ET_c is the crop evapotranspiration, *I* is the irrigation quantity, *P* is the precipitation, CR is the upward capillary rise from water table, *R* is the runoff, DP is the deep percolation, and ΔSW is the change in the root zone soil water content. The units of identified terms in the above equation are in millimeter. Capillary rise was neglected because of the deep water table level. Runoff was not observed due to the use of the drip irrigation method. Deep percolation was not considered because precipitation and the irrigation water amounts in excess of the field capacity were not determined when considering existing soil water contents before each irrigation or precipitation.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were used to evaluate comparative benefits of different irrigation treatments. The WUE and IWUE values were calculated using below equations (Howell 2001):

$$WUE = \frac{Y}{ETc} \quad (4)$$

$$IWUE = \frac{Y}{I} \quad (5)$$

where WUE is the water use efficiency (kg m^{-3}), IWUE is the irrigation water use efficiency (kg m^{-3}), Y is the total marketable tomato yield (kg daa^{-1}), ETc is the seasonal crop evapotranspiration (mm), and I is the seasonal irrigation quantity (mm).

Soil and plant sampling, measurement, and analysis

Experimental field was sampled for determining first physical and chemical soil properties prior to the experiment. After the last harvesting in experiment years, all plots were sampled separately to determine the changes of the chemical properties in surface soil layer (0–30 cm) in the middle region of each plot. All parameters (soil particle size; bulk density; water retention at the field capacity and wilting point; pH; EC; organic matter; CaCO_3 ; total N; P_2O_5 ; K_2O ; exchangeable Na, K, Ca, and Mg; and B, Fe, Zn, Cu, Mn, Cd, Ni, and Pb contents) were determined by common methods used in practice. Bouyoucos hydrometer method was used to determine proportions of sand, silt, and clay fractions as described by Gee and Bauder (1986). The cylinder method was used to determine bulk density (Blake and Hartge 1986). The water contents retained at field capacity (-0.033 MPa) and wilting point (-1.5 MPa) were determined using pressure plate apparatus in the laboratory (Cassel and Nielsen 1986). The pH was measured in the saturation extract by a pH meter (McLean 1982). Electrical conductivity was also measured in the saturation extract by an electrical conductivity meter (Rhoades 1996). Organic matter was determined by using Walkley–Black method (Nelson and Sommers 1982). The CaCO_3 content was measured with a Scheibler calcimeter after addition of dilute acid to the samples (Nelson 1982). Total nitrogen was detected using the Kjeldahl method (Kacar 2009). The available P_2O_5 was estimated by phosphorus amounts determined by Olsen method (Olsen and Sommers 1982). Exchangeable Na and K contents were measured using a flame photometer (BWP XP), in solution extracted with ammonium acetate of 1 N, and exchangeable Ca and Mg determined by EDTA titration method (Black 1965). K_2O amounts were estimated using K values. The azomethine-H method for determining of boron amount in soil was used (Kacar 2009). An extract for analyzing of Fe, Zn, Cu, and Mn contents was prepared using DTPA solution considering the procedure described by Lindsay and Norwell (1978). Moreover, soil samples were extracted for Cd and Ni with DTPA solution and for Pb with ammonium acetate solution (Kacar 2009). All minerals (Fe,

Zn, Cu, Mn, Cd, Ni, and Pb) in the extracts were analyzed by an atomic absorption spectrophotometer (PerkinElmer).

Harvest of tomato crops by hand was initiated in 17 August in 2013 and 24 August in 2014. The latest harvesting dates were 10 and 4 October in 2013 and 2014 years, respectively. Three rows in the middle of the plots were considered for plant measurement and analysis. First and latest plants in these rows also were not evaluated. Numerous measurements and analysis in the physical, physiological, quality, and chemical aspects were done for tomato plants and fruits. Plant height (using a ruler), stem diameter (using a caliper), and number of leaves were measured 30, 60, and 90 days after transplanting. Total marketable yield in each experimental plot was determined with weighing of the marketable crops in all harvesting dates separately. The yield per unit area (ha) was calculated by multiplying of the average marketable yield per plant with plant number per hectare. On a sample of 20 marketable fruit randomly collected from each plot in all harvest, the following parameters were measured: mean diameter (equatorial diameter) and height, mean fruit weight, and fruit firmness (Özbay and Ateş 2015). The numbers of fruits in each harvest were also determined as mean considering total number of fruits and plants harvested. While fruit diameter and height were measured by a caliper, fruit firmness on the equatorial part of fruits was measured by a hand penetrometer. New mature leaves below the stem-growing tip before first harvesting were used for analysis of dry matter and relative water content in leaves. The leaves were dried for 48 h at 65 °C to determine the dry matter in leaves, and then, they were weighted (Kacar and İnal 2010). Leaf relative water content was calculated with an equation by using the fresh mass, turgor mass, and dry mass of sampled leaves as described by Yamasaki and Dillenburg (1999). Random 24 fruit in second harvest were collected from each plot for determining fruit dry matter amount, pH, EC, titratable acidity, soluble solids, vitamin C, and lycopene contents. Dry matter in fruit was determined by drying of the samples at 65 °C in an oven until constant weight (Kacar and İnal 2010). pH, EC, titratable acidity, soluble solids, vitamin C, and lycopene contents were analyzed considering standard methods in Cemeroglu (2010). The pH and EC were measured, respectively, by a pH meter and a conductivity meter in tomato juice collected from fruits washed and blended. Titratable acidity was determined with NaOH titration in fruit juice samples. The soluble solid content was measured using a digital hand refractometer (ATC 0–90%brix). Vitamin C content was determined by using 2,6-dichlorofenol indofenol dye. Lycopene analysis was done by high-performance liquid chromatography (HPLC) method.

Macro (total N, K, Ca, Mg, and Na), micro, and trace mineral (B, Fe, Zn, Cu, Mn, Cd, Ni, Pb, Co, Cr) contents in tomato fruits were analyzed as described in Kacar and İnal (2010). While Na and K were determined by flame photometry (BWP XP), Ca and Mg analyses were done with titration. Total N

was analyzed by Dumas method. Azometin-H spectrophotometric method was used for B analysis. The Fe, Zn, Cu, Mn, Cd, Ni, Pb, Co, and Cr analyses were made by atomic absorption method.

Metal pollution index (MPI) to evaluate the overall heavy metal concentrations of fruits was calculated by the equation below (Tunc and Sahin 2016):

$$\text{MPI (mg kg}^{-1}\text{)} = \left(\text{Cf}_1 \times \text{Cf}_2 \times \dots \times \text{Cf}_n \right)^{1/n} \quad (6)$$

where Cf_n is the concentration of heavy metal n in the sample.

Statistical analysis

Statistical analysis of data measured in soil, plant, and fruit was made with SAS software (version 8.1) (SAS 2000). ANOVA model was used for assessing significant effects of the different factors. Treatment means were separated using Duncan's multiple range test.

Results and discussion

Irrigation water quality and quantity, and crop water use

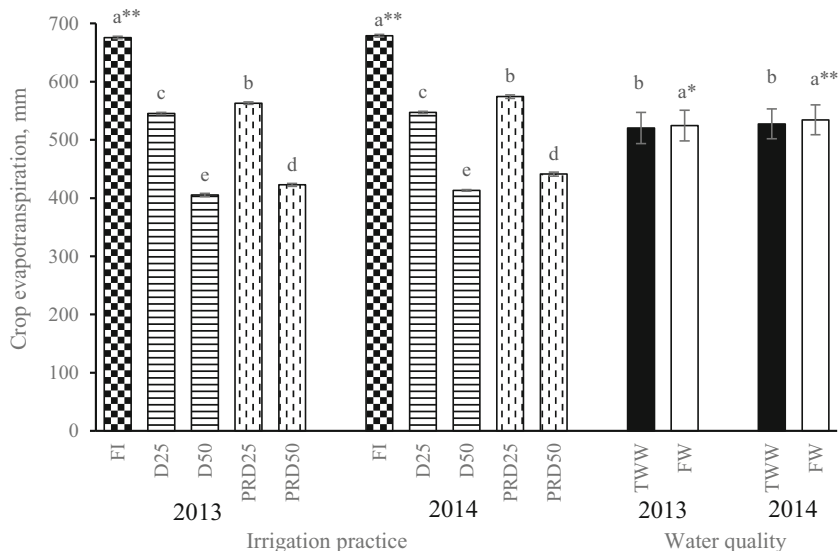
The pH and EC values and total suspended solids (TSS), B, Cl, Na, and HCO_3 contents in the waters used were proper for irrigation considering the FAO standards (pH 6.5–8.4, $\text{EC} < 0.7 \text{ dS m}^{-1}$, $\text{TSS} < 50 \text{ mg l}^{-1}$, $B < 0.7 \text{ mg l}^{-1}$, $\text{Cl} < 3 \text{ me l}^{-1}$, $\text{Na} < 3 \text{ me l}^{-1}$, and $\text{HCO}_3 < 1.5 \text{ me l}^{-1}$) (Ayers and Westcot 1985). The contents of many trace minerals in irrigation waters were below the maximum permissible limits given in Ayers and Westcot (1985) ($\text{Fe} < 5 \text{ mg l}^{-1}$, $\text{Zn} < 2 \text{ mg l}^{-1}$, $\text{Cu} < 0.20 \text{ mg l}^{-1}$, $\text{Mn} < 0.20 \text{ mg l}^{-1}$, $\text{Ni} < 0.20 \text{ mg l}^{-1}$, and $\text{Pb} < 5 \text{ mg l}^{-1}$). However, Cd, Co, and Cr contents indicated low quality for irrigation ($\text{Cd} > 0.01 \text{ mg l}^{-1}$, $\text{Co} > 0.05 \text{ mg l}^{-1}$, and $\text{Cr} > 0.10 \text{ mg l}^{-1}$) (Pescod 1992). Total N ($> 5 \text{ mg l}^{-1}$), P ($> 0.65 \text{ mg l}^{-1}$), and BOD_5 ($> 20 \text{ mg l}^{-1}$) contents in treated wastewater were higher than the values given in national water pollution control regulation in Turkey (WPCR 2008). The SO_4 contents ($< 4 \text{ me l}^{-1}$) in the waters resulted no problem (WPCR 2008). Fecal coliform (FC) amounts in treated wastewater were lower than the permissible maximum value ($< 1000 \text{ cfu } 100 \text{ ml}^{-1}$) for raw-eaten crops (Pescod 1992).

Tomato plants were irrigated 23 times in both experiment years. The FI plots achieved to seasonal irrigation water of 640.2 mm in 2013 and 648.1 mm in 2014. While D25 and PRD25 practices were irrigated with lower seasonal water amount of 23.2%, D50 and PRD50 practices were irrigated with lower seasonal water amount of 46.5% based on 2-year averages. Total amount of precipitation in the growing periods

in the experiment years was so low (24.1 mm in 2013, 36.2 mm in 2014) compared to the seasonal irrigation quantities applied (Table 1). Therefore, irrigation water was the main resource for plant water consumption during growing period. Calculated crop evapotranspiration (ETc) values for the FI practice in 2013 and 2014 were 675.8 and 678.8 mm, respectively (Fig. 1). The ETc values in the TWW applications in both years were lower than the values in the FW applications. Although the differences between the ETc values in the TWW and FW applications were statistically significant, the difference ratios were approximately 1%. Plant heights, stem diameter, and number of leaves were statistically similar in the FW and TWW applications. However, this study results showed that TWW applications increased the yield but decreased tomato water consumption compared to FW applications (Figs. 1 and 3). Exposure to toxic metals causes negative effects on plant traits important in terms of plant-water relationship (de Silva et al. 2012). Therefore, relatively low ET values in the TWW applications could be associated with relatively high heavy metal contents in treated wastewater (Table 4). This idea also is supported with results of some researches. Vijayarengan and Mahalakshmi (2013) determined that the increase in the zinc content in the soil led to a decrease in stomatal conductance in the leaves of tomato. Tunc and Sahin (2016) discussed that the water consumption of red cabbage might be decreased with effects on stomatal conductivity of some heavy metals in the applied water. A few research results reported lower or similar water use values in the wastewater application conditions compared to cleaner water. Li et al. (2012) proved that sewage water caused a decline in tomato plant water consumption compared with blend water and groundwater. The observed evapotranspiration data by Misra et al. (2010) showed that the water consumption of tomato plant irrigated with the gray water and tap water was similar.

Different irrigation practices also significantly affected water consumption of tomato plants. The lowest ETc values were obtained in the D50 practice in both years (Fig. 1). It caused significantly lower values of 40.0% in 2013 and 39.1% in 2014 compared to FI practice. Generally, decreasing irrigation water applications resulted in lower ETc values in this study. Ismail and Phizackerley (2009), Sobeih et al. (2004), and Wang et al. (2010a) showed that stomatal conductance was higher in full-irrigated tomato plants compared to the plants irrigated with deficit and partial root-zone drying practices. It could be said that lower water consumption in lower irrigated conditions might be due to lower stomatal conductance. Our findings showed that reduced irrigation water significantly decreased leaf relative water content (Fig. 7). On the other hand, although the PRD practices received the same irrigation amounts as the DI practices, they provided significantly higher ETc compared to the DI practices in both experimented years. Tomato crop yields in the PRD practices were

Fig. 1 Tomato seasonal evapotranspiration values in different irrigation practices and water qualities. The mean values marked with *same letters* in columns in each trial year are not significantly different (** $P < 0.01$ or * $P < 0.05$). *TWW* treated wastewater, *FW* freshwater, *FI* full irrigation, *D25* and *D50* 25 and 50% deficit irrigation, *PRD25* and *PRD50* 25 and 50% deficit irrigation with PRD



statistically similar with the yields in the DI practices (Fig. 3). The vegetative growth of tomato plants was also similar in the PRD and DI practices considering the data measured in this study. However, the findings for soil water content of this study showed that the current soil moisture in the PRD practices during the scheduled irrigation period reached a level closer to the wilting point (Fig. 2). Therefore, it could be argued that higher water uptake from the soil in the PRD practices might be a result of the increase in root growth. Prokić and Stikić (2011) and Savić et al. (2008) indicated that the tomato root growth increased under the PRD practices. Therefore, higher amounts of soil available water in the PRD practice plots were consumed. Consistent with the results of this study, Kirda et al. (2004) found that although tomato plant evapotranspiration was higher in the PRD practice with 30% water deficit compared to the conventional deficit irrigation practice that received 30% less water, and

tomato yield and vegetative growth were also similar. Wang et al. (2010a) determined that while water use of tomato plants in PRD and DI practices with 25% water deficit was lesser than the values of FI practices, PRD practice led to higher plant water use compared with DI practice.

Tomato total marketable yield and fruit physical properties

Tomato total marketable yield values were significantly affected with both irrigation water qualities and irrigation practices (Fig. 3). The marketable yield values determined for two experiment years were statistically similar to each other. Considering averages of 2-year practices for two water qualities, marketable yield in the TWW application (62.16 mg ha^{-1}) was 1.21-fold higher than the value of the FW application, and the difference was significant. Treated wastewater had higher

Fig. 3 Total marketable tomato yield values in different irrigation practices and water qualities. The mean values marked with *same letters* in columns in each trial year are not significantly different (** $P < 0.01$ or * $P < 0.05$). Explanations of abbreviations are as in Fig. 1

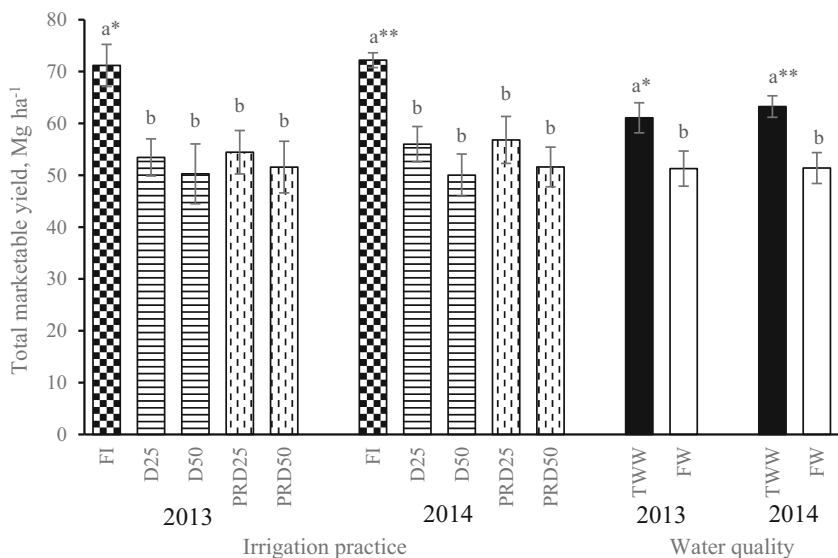
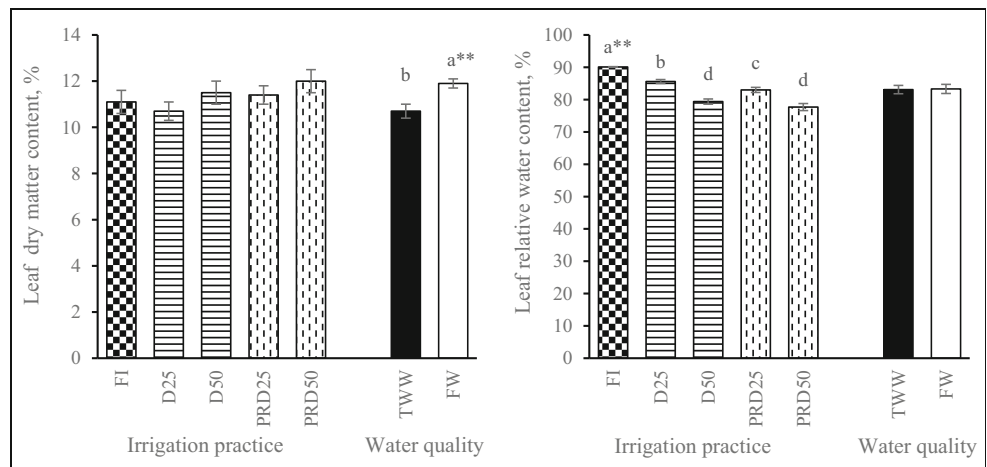


Fig. 7 Leaf dry matter and relative water contents in different irrigation practices and water qualities. The mean values marked with *same letters* in columns are not significantly different (** $P < 0.01$). Explanations of abbreviations are as in Fig. 1



macro, micro, and trace minerals compared to freshwater values (Table 4). However, soil macronutrient contents after the experiments showed non-significant increases under the TWW application conditions compared to the FW application conditions (Table 5). Therefore, higher yield values in TWW applications could be explained directly with more fertility effect of the treated wastewater. Higher yield results observed in the wastewater applications are compatible to results obtained in many experimental trials. Najafi (2006) observed significant increases in tomato yield with wastewater applications using surface and sub-surface drip irrigation. Aiello et al. (2007) determined that *Incas* tomato genotype irrigated with wastewater in the bare soil showed an increase in total

marketable yield of about 53% with respect to the same genotype irrigated with freshwater. Cirelli et al. (2012) found that tomato marketable yield significantly increased in the treated wastewater application compared to freshwater application. Gatta et al. (2015) indicated that the total tomato marketable yield under the treated agro-industrial wastewater application conditions was 4.9% higher than the yield obtained from the groundwater application conditions. Zavadil (2009) also expressed that primary-treated wastewater significantly increased the yield of many crops (lettuce salad, radish, carrot, potato, and sugar beet).

The PRD and DI practices caused statistically similar marketable yield values, and all of them were significantly lower

Fig. 2 Changes in moisture content before irrigations in 90-cm soil layer in different irrigation practices and water qualities during tomato growing periods. FC and WP: the water amount holding at the field capacity and wilting point, respectively. The explanations of other abbreviations are as in Fig. 1

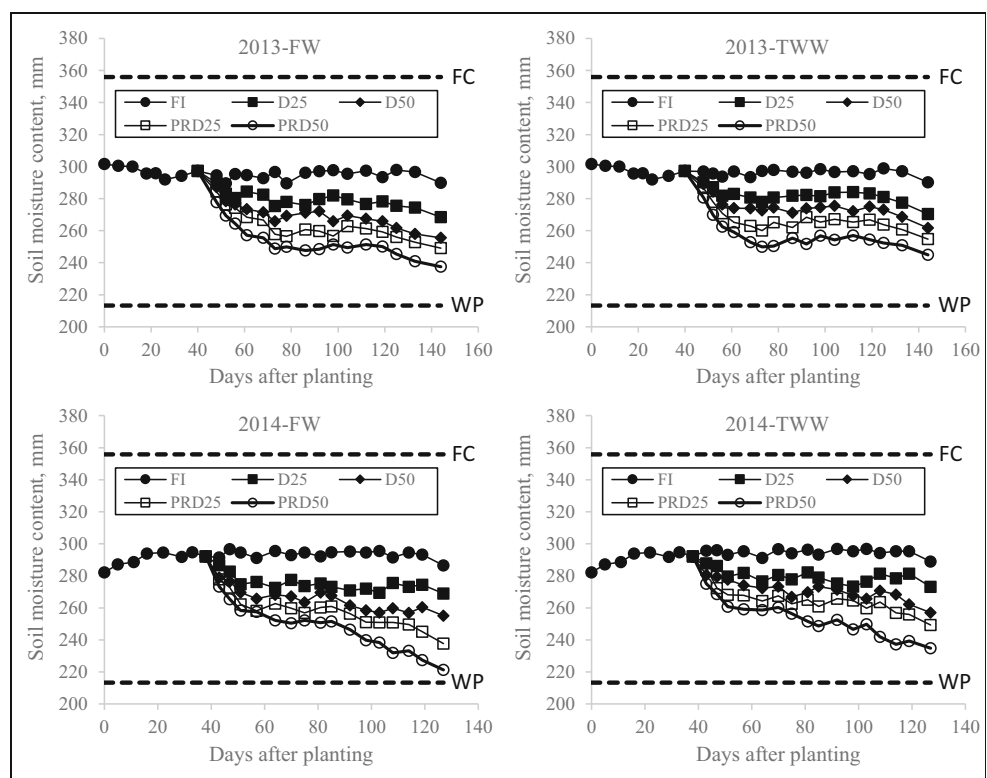


Table 5 Macro, micro, and trace mineral contents (mean ± SEM) in the surface layer (0–30 cm) of soil irrigated with different quality waters under different irrigation practices in 2013 and 2014

Year	Parameter	FI		D25		D50		PRD25		PRD50	
		TWW	FW	TWW	FW	TWW	FW	TWW	FW	TWW	FW
2013	Total N (%)	0.14 ± 0.02	0.11 ± 0.01	0.10 ± 0.02	0.10 ± 0.02	0.10 ± 0.01	0.09 ± 0.01	0.10 ± 0.03	0.09 ± 0.01	0.10 ± 0.03	0.09 ± 0.01
	P ₂ O ₅ (kg da ⁻¹)	14.8 ± 0.6	14.2 ± 0.4	11.8 ± 0.3	12.9 ± 1.0	12.8 ± 1.2	11.6 ± 1.2	12.3 ± 0.6	13.5 ± 0.5	12.3 ± 0.6	11.2 ± 1.3
	K ₂ O (kg da ⁻¹)	87.5 ± 7.9	72.8 ± 7.8	65.9 ± 4.3	56.8 ± 3.9	67.5 ± 2.6	51.8 ± 4.5	67.8 ± 3.9	65.2 ± 3.0	65.2 ± 3.0	67.5 ± 7.8
	Ca (cmol kg ⁻¹)	26.4 ± 2.1	25.6 ± 1.1	27.0 ± 0.7	26.9 ± 0.8	25.8 ± 1.6	24.1 ± 0.4	26.5 ± 1.9	25.0 ± 0.3	25.0 ± 0.3	25.8 ± 1.3
	Mg (cmol kg ⁻¹)	4.72 ± 0.17	4.68 ± 0.64	3.92 ± 0.18	4.96 ± 0.57	5.94 ± 1.15	4.96 ± 0.92	4.98 ± 0.35	4.85 ± 0.44	4.85 ± 0.44	5.81 ± 1.83
	Na (cmol kg ⁻¹)	0.69 ± 0.02	0.58 ± 0.05	0.71 ± 0.01	0.52 ± 0.04	0.58 ± 0.03	0.61 ± 0.15	0.76 ± 0.04	0.73 ± 0.05	0.73 ± 0.05	0.65 ± 0.07
	B (mg kg ⁻¹)	0.80 ± 0.02	0.78 ± 0.06	0.59 ± 0.04	0.63 ± 0.04	0.45 ± 0.01	0.58 ± 0.06	0.66 ± 0.02	0.73 ± 0.01	0.73 ± 0.01	0.38 ± 0.04
	Fe (mg kg ⁻¹)	18.9 ± 2.2	17.9 ± 2.6	17.0 ± 1.6	16.9 ± 1.5	14.9 ± 0.10	14.3 ± 1.9	18.9 ± 3.2	14.9 ± 0.3	14.9 ± 0.3	15.9 ± 1.5
	Zn (mg kg ⁻¹)	0.54 ± 0.09	0.43 ± 0.07	0.58 ± 0.06	0.35 ± 0.01	0.51 ± 0.07	0.44 ± 0.08	0.40 ± 0.04	0.46 ± 0.09	0.46 ± 0.09	0.50 ± 0.04
	Cu (mg kg ⁻¹)	1.18 ± 0.15	1.08 ± 0.20	1.01 ± 0.28	0.80 ± 0.09	0.88 ± 0.05	0.74 ± 0.05	0.76 ± 0.07	0.74 ± 0.04	0.74 ± 0.04	0.97 ± 0.11
	Mn (mg kg ⁻¹)	13.5 ± 0.2	13.0 ± 0.8	13.1 ± 0.8	13.1 ± 0.4	13.0 ± 0.9	13.1 ± 1.1	12.7 ± 0.6	11.6 ± 1.3	11.6 ± 1.3	12.6 ± 0.1
	Cd (mg kg ⁻¹)	0.43 ± 0.004	0.38 ± 0.003	0.35 ± 0.03	0.36 ± 0.05	0.32 ± 0.03	0.32 ± 0.04	0.36 ± 0.04	0.36 ± 0.01	0.36 ± 0.01	0.33 ± 0.06
	Ni (mg kg ⁻¹)	2.37 ± 0.14	2.06 ± 0.07	2.00 ± 0.02	1.45 ± 0.02	1.81 ± 0.12	1.54 ± 0.19	1.96 ± 0.10	1.56 ± 0.30	1.56 ± 0.30	1.78 ± 0.03
	Pb (mg kg ⁻¹)	0.11 ± 0.01	0.11 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.09 ± 0.01	0.08 ± 0.01
	2014	Total N (%)	0.17 ± 0.01	0.13 ± 0.03	0.16 ± 0.02	0.15 ± 0.003	0.12 ± 0.03	0.12 ± 0.03	0.15 ± 0.02	0.13 ± 0.01	0.15 ± 0.02
P ₂ O ₅ (kg da ⁻¹)		17.8 ± 1.1	17.5 ± 2.1	15.4 ± 1.0	16.0 ± 1.3	14.2 ± 1.3	12.3 ± 1.3	17.1 ± 1.0	16.8 ± 0.2	16.8 ± 0.2	13.7 ± 2.1
K ₂ O (kg da ⁻¹)		107 ± 14.7	91.5 ± 6.4	81.5 ± 8.6	76.1 ± 6.5	83.6 ± 5.6	85.0 ± 24.6	88.8 ± 6.7	82.9 ± 3.7	82.9 ± 3.7	81.3 ± 13.1
Ca (cmol kg ⁻¹)		25.8 ± 1.8	30.1 ± 0.9	22.9 ± 2.8	24.3 ± 0.8	24.0 ± 1.0	28.0 ± 0.1	26.6 ± 0.9	27.8 ± 1.4	27.8 ± 1.4	23.5 ± 0.4
Mg (cmol kg ⁻¹)		4.66 ± 0.65	4.12 ± 0.29	5.86 ± 1.09	6.54 ± 0.82	4.69 ± 0.18	4.14 ± 1.03	7.63 ± 0.88	4.42 ± 0.47	4.42 ± 0.47	4.62 ± 0.43
Na (cmol kg ⁻¹)		0.73 ± 0.03	0.57 ± 0.01	0.55 ± 0.02	0.56 ± 0.04	0.55 ± 0.08	0.54 ± 0.05	0.60 ± 0.01	0.51 ± 0.02	0.51 ± 0.02	0.46 ± 0.06
B (mg kg ⁻¹)		0.88 ± 0.03	0.83 ± 0.03	0.79 ± 0.06	0.77 ± 0.01	0.64 ± 0.09	0.66 ± 0.09	0.82 ± 0.10	0.80 ± 0.03	0.80 ± 0.03	0.56 ± 0.05
Fe (mg kg ⁻¹)		23.0 ± 0.4	16.7 ± 0.9	21.8 ± 0.9	14.2 ± 1.2	17.2 ± 1.2	13.8 ± 1.6	19.1 ± 0.4	13.3 ± 1.2	13.3 ± 1.2	17.6 ± 0.9
Zn (mg kg ⁻¹)		0.95 ± 0.02	0.86 ± 0.07	0.89 ± 0.08	0.64 ± 0.07	0.74 ± 0.13	0.65 ± 0.14	0.84 ± 0.20	0.84 ± 0.15	0.84 ± 0.15	0.78 ± 0.03
Cu (mg kg ⁻¹)		1.17 ± 0.03	0.73 ± 0.05	0.82 ± 0.09	0.79 ± 0.18	0.90 ± 0.08	0.76 ± 0.02	0.88 ± 0.12	0.78 ± 0.02	0.78 ± 0.02	0.73 ± 0.14
Mn (mg kg ⁻¹)		13.1 ± 0.3	13.5 ± 0.2	12.8 ± 0.3	12.4 ± 0.7	12.9 ± 0.2	12.3 ± 0.6	12.6 ± 0.8	12.3 ± 0.5	12.3 ± 0.5	12.9 ± 0.8
Cd (mg kg ⁻¹)		0.44 ± 0.003	0.41 ± 0.01	0.39 ± 0.03	0.36 ± 0.01	0.34 ± 0.03	0.31 ± 0.03	0.37 ± 0.02	0.34 ± 0.03	0.34 ± 0.03	0.36 ± 0.02
Ni (mg kg ⁻¹)		2.70 ± 0.10	2.61 ± 0.16	2.43 ± 0.36	1.70 ± 0.15	2.48 ± 0.29	1.93 ± 0.27	2.31 ± 0.45	1.89 ± 0.39	1.89 ± 0.39	2.33 ± 0.52
Pb (mg kg ⁻¹)		0.14 ± 0.01	0.14 ± 0.01	0.12 ± 0.01	0.11 ± 0.01	0.06 ± 0.02	0.11 ± 0.02	0.13 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	0.09 ± 0.01
2013–2014		Total N (%)	0.15 ± 0.01	0.12 ± 0.02	0.13 ± 0.02	0.13 ± 0.01	0.11 ± 0.04	0.10 ± 0.02	0.13 ± 0.02	0.11 ± 0.01	0.13 ± 0.02
	P ₂ O ₅ (kg da ⁻¹)	16.3 ± 0.9	15.9 ± 1.2	13.6 ± 0.9	14.4 ± 1.0	13.5 ± 0.8	12.0 ± 0.8	14.7 ± 1.2	15.1 ± 0.8	15.1 ± 0.8	12.4 ± 1.2
	K ₂ O (kg da ⁻¹)	97.4 ± 8.7	82.2 ± 6.2	73.7 ± 5.5	66.5 ± 5.5	75.5 ± 4.5	68.4 ± 13.4	78.3 ± 5.8	74.0 ± 4.5	74.0 ± 4.5	74.4 ± 7.5
	Ca (cmol kg ⁻¹)	26.1 ± 1.2	27.8 ± 1.2	24.9 ± 1.6	25.6 ± 0.8	24.9 ± 0.9	26.0 ± 0.9	26.6 ± 1.0	26.4 ± 0.9	26.4 ± 0.9	24.7 ± 0.8
	Mg (cmol kg ⁻¹)	4.69 ± 0.30	4.40 ± 0.34	4.89 ± 0.66	5.75 ± 0.57	5.31 ± 0.59	4.55 ± 0.65	6.30 ± 0.73	4.63 ± 0.30	4.63 ± 0.30	5.21 ± 0.88
	Na (cmol kg ⁻¹)	0.71 ± 0.02	0.58 ± 0.02	0.63 ± 0.04	0.54 ± 0.03	0.56 ± 0.04	0.58 ± 0.07	0.68 ± 0.04	0.62 ± 0.06	0.62 ± 0.06	0.56 ± 0.06
	B (mg kg ⁻¹)	0.84 ± 0.02	0.80 ± 0.03	0.69 ± 0.06	0.70 ± 0.04	0.55 ± 0.06	0.62 ± 0.05	0.74 ± 0.06	0.76 ± 0.02	0.76 ± 0.02	0.47 ± 0.05
	Fe (mg kg ⁻¹)	20.9 ± 1.4	17.3 ± 1.3	19.4 ± 1.3	15.5 ± 1.1	16.0 ± 0.8	14.0 ± 1.1	19.0 ± 1.4	14.1 ± 0.7	14.1 ± 0.7	16.7 ± 0.9
	Zn (mg kg ⁻¹)	0.74 ± 0.10	0.64 ± 0.11	0.73 ± 0.08	0.49 ± 0.07	0.63 ± 0.08	0.54 ± 0.08	0.62 ± 0.13	0.65 ± 0.11	0.65 ± 0.11	0.64 ± 0.07
	Cu (mg kg ⁻¹)	1.17 ± 0.07	0.90 ± 0.12	0.92 ± 0.14	0.80 ± 0.09	0.89 ± 0.04	0.75 ± 0.03	0.82 ± 0.07	0.76 ± 0.02	0.76 ± 0.02	0.85 ± 0.09
	Mn (mg kg ⁻¹)	13.3 ± 0.2	13.2 ± 0.4	12.9 ± 0.4	12.7 ± 0.4	12.9 ± 0.4	12.7 ± 0.6	12.6 ± 0.4	12.0 ± 0.6	12.0 ± 0.6	12.8 ± 0.4
	Cd (mg kg ⁻¹)	0.43 ± 0.003	0.39 ± 0.01	0.37 ± 0.02	0.36 ± 0.02	0.33 ± 0.02	0.32 ± 0.03	0.37 ± 0.02	0.35 ± 0.01	0.35 ± 0.01	0.34 ± 0.02
	Ni (mg kg ⁻¹)	2.53 ± 0.11	2.34 ± 0.14	2.21 ± 0.19	1.57 ± 0.09	2.14 ± 0.20	1.73 ± 0.17	2.14 ± 0.22	1.72 ± 0.23	1.72 ± 0.23	2.06 ± 0.27
	Pb (mg kg ⁻¹)	0.12 ± 0.01	0.12 ± 0.01	0.11 ± 0.01	0.10 ± 0.01	0.06 ± 0.01	0.10 ± 0.01	0.11 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.08 ± 0.01

Table 5 (continued)

Year	PRD50		Mean		FW	FI	D25	D50	PRD25	PRD50
	FW	PRD50	TWW	Mean						
2013	0.09 ± 0.01		0.11		0.10	0.13	0.10	0.09	0.09	0.09
	10.4 ± 0.6		12.6		12.5	14.5a**	12.3bc	12.2bc	12.9ab	10.8c
	62.9 ± 8.1		71.2		61.9	80.2a*	61.3b	59.6b	66.5ab	65.2ab
	25.5 ± 0.6		26.3		25.4	26.0	26.9	24.9	25.8	25.7
	4.90 ± 0.32		5.07		4.87	4.70	4.44	5.45	4.91	5.36
	0.63 ± 0.02		0.68		0.62	0.64	0.61	0.59	0.75	0.64
	0.58 ± 0.10		0.58b*		0.66a	0.79a**	0.61bc	0.52 cd	0.69ab	0.48d
	14.5 ± 2.0		17.1		15.7	18.4	16.9	14.6	16.9	15.2
	0.55 ± 0.18		0.51		0.45	0.48	0.46	0.48	0.43	0.53
	0.68 ± 0.02		0.96		0.81	1.13	0.91	0.81	0.75	0.83
	12.6 ± 1.7		13.0		12.7	13.2	13.1	13.0	12.1	12.6
	0.31 ± 0.02		0.36		0.35	0.40	0.35	0.32	0.36	0.32
	1.34 ± 0.12		1.98a**		1.59b	2.21a**	1.72b	1.68b	1.76b	1.55b
	0.08 ± 0.003		0.09		0.09	0.11a*	0.10 ab	0.07c	0.09ab	0.08bc
2014	0.10 ± 0.03		0.14		0.13	0.15	0.16	0.12	0.14	0.10
	10.6 ± 0.5		15.6		14.6	17.7a**	15.7ab	13.3bc	17.0a	12.2c
	84.7 ± 9.7		88.5		84.1	99.4	78.8	84.3	85.8	83.0
	23.8 ± 0.8		24.6b*		26.8a	28.0a**	23.6b	26.0ab	27.2a	23.6b
	5.75 ± 0.28		5.49		4.99	4.39b*	6.20a	4.41b	6.02a	5.18ab
	0.51 ± 0.09		0.58		0.54	0.65a*	0.56ab	0.55ab	0.55ab	0.48b
	0.63 ± 0.11		0.74		0.73	0.86a**	0.78ab	0.65bc	0.81a	0.59c
	12.8 ± 1.0		19.7a**		14.1b	19.8a**	18.0ab	15.5c	16.2bc	15.2c
	0.57 ± 0.06		0.84		0.71	0.90	0.77	0.69	0.84	0.68
	0.71 ± 0.06		0.90a*		0.75b	0.95	0.81	0.83	0.83	0.72
	11.7 ± 0.1		12.8		12.5	13.3	12.6	12.6	12.5	12.3
	0.28 ± 0.03		0.38a*		0.34b	0.42a**	0.37ab	0.33bc	0.36bc	0.32c
	1.49 ± 0.44		2.45a*		1.92b	2.65	2.06	2.20	2.10	1.91
	0.11 ± 0.003		0.11		0.12	0.14a**	0.12ab	0.09c	0.12ab	0.10bc
2013–2014	0.09 ± 0.01		0.12		0.11	0.14a*	0.13ab	0.11bc	0.12abc	0.10c
	10.5 ± 0.3		14.1		13.6	16.1a**	14.0bc	12.7 cd	14.9ab	11.5d
	73.8 ± 7.5		79.9		73.0	89.8a*	70.1b	72.0b	76.2b	74.1b
	24.6 ± 0.6		25.4		26.1	27.0	25.3	25.5	26.5	24.7
	5.32 ± 0.27		5.28		4.93	4.54	5.32	4.93	5.47	5.27
	0.57 ± 0.05		0.63a*		0.58b	0.64	0.58	0.57	0.65	0.56
	0.60 ± 0.07		0.66		0.70	0.82a*	0.69b	0.58c	0.75ab	0.54c
	13.6 ± 1.0		18.4a**		14.9b	19.1a**	17.4ab	15.0c	16.5bc	15.2bc
	0.56 ± 0.09		0.67a*		0.58b	0.69	0.61	0.58	0.64	0.60
	0.70 ± 0.03		0.93a**		0.78b	1.04a*	0.86b	0.82b	0.79b	0.77b
	12.2 ± 0.8		12.9		12.6	13.3	12.8	12.8	12.3	12.5

Table 5 (continued)

Year	PRD50		Mean						
	FW	FW	TWW	FW	FI	D25	D50	PRD25	PRD50
	0.30 ± 0.02	0.37a*	0.37a*	0.34b	0.41a**	0.36b	0.32bc	0.36b	0.32c
	1.41 ± 0.21	2.22a**	2.22a**	1.76b	2.43a**	1.89b	1.94b	1.93b	1.73b
	0.09 ± 0.01	0.10	0.10	0.10	0.12a**	0.11b	0.08c	0.11b	0.09c

The values marked with the same letters for water qualities or irrigation practices in each line of the “Mean” column of each trial year are not significantly different TWW treated wastewater, FW freshwater, FI full irrigation, D25 and D50 25 and 50% deficit irrigation, PRD25 and PRD50 25 and 50% deficit irrigation with PRD *** $P < 0.01$; * $P < 0.05$

than the FI practice values in trial years. Considering the average values in 2013–2014 trial years, the D25, D50, PRD25, and PRD50 practices provided 23.7, 30.1, 22.4, and 28% lower marketable yield values compared to the FI practice, respectively. Although there were no significant differences among the marketable yields in the PRD25, PRD50, D25, and D50 practices, the yield values in the PRD practices were slightly higher than the DI practice values. The PRD practices gave 1.7 and 2.9% higher marketable tomato yields under 25 and 50% water-deficit conditions, respectively, compared to the DI practices. Sepaskhah and Ahmadi (2010) expressed as a practical result that crop yields under partial root-zone drying irrigation conditions were higher than the yields under deficit irrigation conditions when the same amount of water is applied. Some study results based on partial root-zone drying irrigation and deficit irrigation practices in tomato supported results of this study. Zegbe-Domínguez et al. (2003) determined significantly lower fruit fresh mass per tomato plant in the partial root-zone drying irrigation and deficit irrigation practices compared to full irrigation practice. However, yields in partial root-zone drying irrigation and deficit irrigation practices were similar. Kirda et al. (2004) indicated that although higher yield benefits were obtained from the partial root-zone drying irrigation practices under 30 and 50% water deficit compared to conventional deficit irrigation practices with same amount of water deficit, there were no significant differences among practice yields. Nardella et al. (2012) also obtained similar tomato marketable yield values in the partial root-zone drying irrigation and deficit irrigation with 28% irrigation water deficit.

Although tomato fruit height and equatorial diameter, mean fruit weight, and number of fruits per plant in the TWW applications were higher than the values in the FW applications considering 2-year average values, significant differences for fruit equatorial diameter were observed only (Fig. 4). Equatorial diameter in the TWW application was 2.8% higher than the FW application value. Similarly, Al-Lahham et al. (2003) observed important increases in the fruit diameter of tomato irrigated with wastewater compared to the potable water.

Mean fruit weight and number of fruits per plant were significantly changed with different irrigation practices (Fig. 4). The PRD25 practice had second important mean fruit weight value (141.4 g) after FI practice, and fruit weight obtained from PRD25 was significantly higher than D25 values. However, numbers of fruits in the D25 and PRD25 practices were statistically similar. Higher mean fruit weight and number of fruits per plant supported obtaining of higher marketable yields. Significant positive linear relationships ($P < 0.01$) were obtained between the total marketable tomato yield and the mean fruit weight ($r^2 = 0.607$), and the total marketable tomato yield and the number of fruits per plant ($r^2 = 0.845$) considering the data of two experimental years.

Findings of different studies confirm results of fruit physical properties obtained from this study. The results of Savić et al. (2008) showed that higher tomato fruit fresh weight values were obtained in the full-irrigated tomato. Moreover, partial root-zone drying practice provided significantly higher fruit weights compared to deficit irrigation practice. Ismail and Phizackerley (2009) determined higher fruit fresh weight for full-irrigated tomato plants compared with partial root-zone drying and deficit-irrigated plants. Marjanović et al. (2015) indicated that fruit growth parameters were the maximal in full-irrigated plants compared to the plants irrigated with the partial partial root-zone drying practice. Stikic et al. (2003) found that the number of tomato fruits was statistically similar under partial root-zone drying and well-watered conditions. Zegbe-Domínguez et al. (2003) determined that while deficit irrigation and partial root-zone drying irrigation practices under the water deficit of 50% caused less number of tomato fruit compared to full irrigation practice, the fruit numbers in deficit irrigation and partial root-zone drying irrigation practices were statistically similar.

Water–yield relationships and water productivity

Decreasing irrigation quantities and water use caused lower yields. The linear relationship equations obtained from the data of two trial years for total marketable yield-seasonal irrigation quantity and total marketable yield-seasonal evapotranspiration showed that total marketable yield significantly increased ($P < 0.01$) with increasing of the seasonal irrigation quantity ($r^2 = 0.845$) and the evapotranspiration ($r^2 = 0.818$). The linear relationship equations were important at the level of 0.01 in both water types. Zheng et al. (2013) reported significant linear water use–tomato crop yield relationships.

Treated wastewater application supported obtaining of high WUE and IWUE values (Figs. 5 and 6). The averages of treatments in trial years' data showed that the TWW provided 23.6% higher IWUE and 24.7% higher WUE values compared to the FW. The TWW applications provided 21.1% higher marketable yield values than FW applications considering 2-year averages (Fig. 3). However, the yield difference between the ET values of TWW and FW applications was 1.1% (Fig. 1), and irrigation amounts given to the applications were same. Therefore, it could be said that higher yield values obtained in the TWW applications caused by significant increases in the IWUE and WUE. The obtaining of higher water productivity values under treated wastewater application conditions comparing with freshwater application conditions are compatible with findings of some studies conducted on tomato (Li et al. 2012; Najafi 2006).

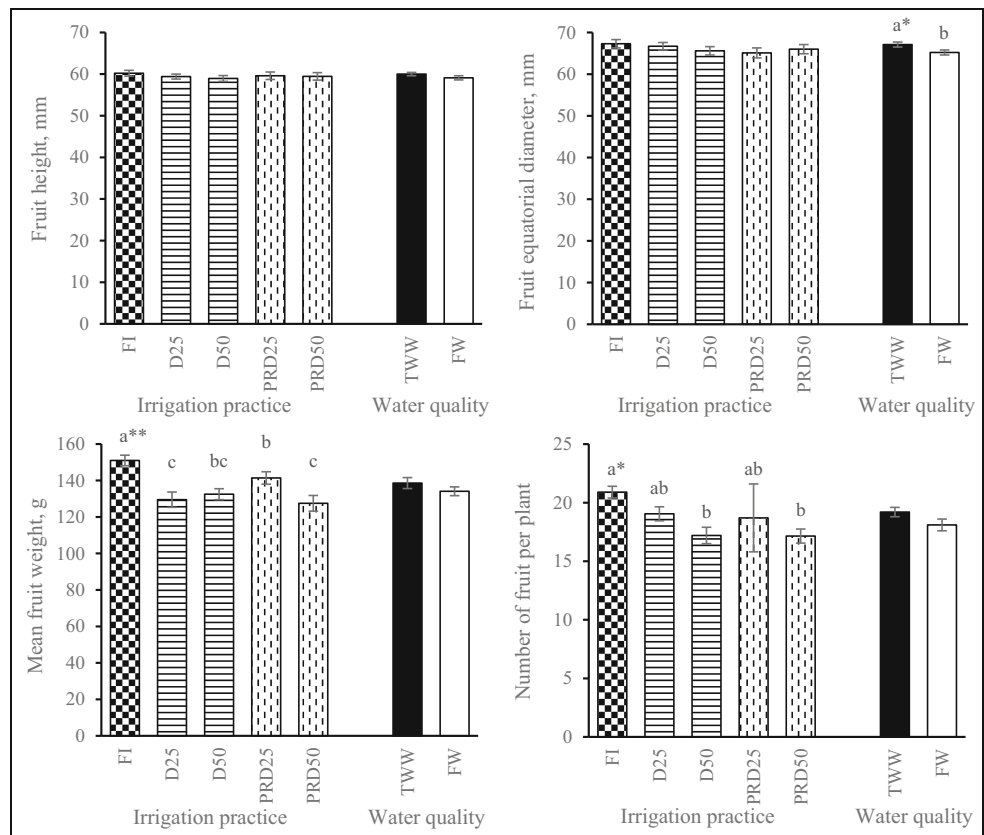
Different irrigation practices significantly affected the WUE and IWUE values (Figs. 5 and 6). Although the D50 and PRD50 practices improved the IWUE values compared to the FI practice, the D25 and PRD25 practices had statistically similar WUE and IWUE values with the FI practice. There were non-significant differences in the WUE and IWUE values obtained from the DI and PRD practices for both two water-deficit conditions. Considering 2-year average values, the IWUE value was improved 31.5% in the D50 practice and 34.7% in the PRD50 treatment compared to FI practice (Fig. 6). Total marketable yield values were significantly lower in the PRD and D practices compared to the FI practice (Fig. 3). Therefore, it could be said that lesser irrigation quantities applied for PRD and D practices promoted the obtaining of higher WUE and IWUE values compared to FI practice. Likewise, Sadras (2009) expressed that partial root-zone drying irrigation improves water productivity, but similar benefits are often achieved with conventional deficit irrigation practice. Numerous studies conducted on tomato have shown that partial root-zone drying and deficit irrigation practices enhance WUE and IWUE values. Giuliani et al. (2016) reported positive effects of regulated deficit irrigation on WUE in the processing tomato. Kirda et al. (2004) determined that partial root-zone drying irrigation and deficit irrigation practices, irrigated with 50% lesser irrigation quantity, gave significantly higher IWUE values compared to the full irrigation practice. IWUE values in the partial root-zone drying irrigation and deficit irrigation practices were also statistically similar. Affi et al. (2012), Nardella et al. (2012), and Psarras et al. (2014) observed no statistically significant difference between WUE values of partial root-zone drying irrigation and deficit irrigation practices. However, these treatments significantly increased WUE value compared to full irrigation practice. Affi et al. (2012), Akhtar et al. (2014), Stikic et al. (2003), Zegbe et al. (2004), and Wang et al. (2010a) expressed that tomato WUE value was the highest in partial root-zone drying irrigation practice.

Leaf dry matter and water contents

Leaf dry matter contents (DMCs) changed between 9.2 and 13.3% in experimental years. Although DMC values in the irrigation practices were similar, irrigation applications with different quality waters had important effect on DMC value (Fig. 7). Considering 2-year average values, TWW applications significantly decreased the DMC value by 10.1% compared to the FW application. A negative linear relationship ($r^2 = 0.170$) was determined between DMC value and tomato marketable yield. Similarly, Ismail et al. (2007) determined that increasing leaf dry weights led to a decrease in tomato yield.

Water qualities had no statistical effect on leaf relative water content (RWC). However, RWC values were affected largely by irrigation practices (Fig. 7). Decreasing irrigation

Fig. 4 Tomato fruit height, equatorial diameter, mean weight, and number in different irrigation practices and water qualities. The mean values marked with *same letters* in columns are not significantly different (** $P < 0.01$ or * $P < 0.05$). Explanations of abbreviations are as in Fig. 1



quantities reduced RWC values. Therefore, lower values were obtained from PRD50 (77.7%) and D50 (79.4%) practices, and greater response was observed from FI practices (90.1%) considering 2-year average values. These results were in line with that of Akhtar et al. (2014) who reported that RWC value was the highest in full-irrigated tomato. It was also reported that PRD practice was better than DI practice in terms of observing higher RWC value. According to our study

results, between seasonal evapotranspiration and RWC values, a significant a linear relationship ($r^2 = 0.950$; $P < 0.01$) was determined. Moreover, the linear relationship between seasonal irrigation quantity and RWC values was also significant ($r^2 = 0.970$, $P < 0.01$). Similarly, Thompson et al. (2007) indicated that relationship between relative leaf water potential in tomato crop and soil water content was linear.

Fig. 5 Water use efficiencies in different irrigation practices and water qualities. The mean values marked with *same letters* in columns in each trial year are not significantly different (** $P < 0.01$ or * $P < 0.05$). Explanations of abbreviations are as in Fig. 1

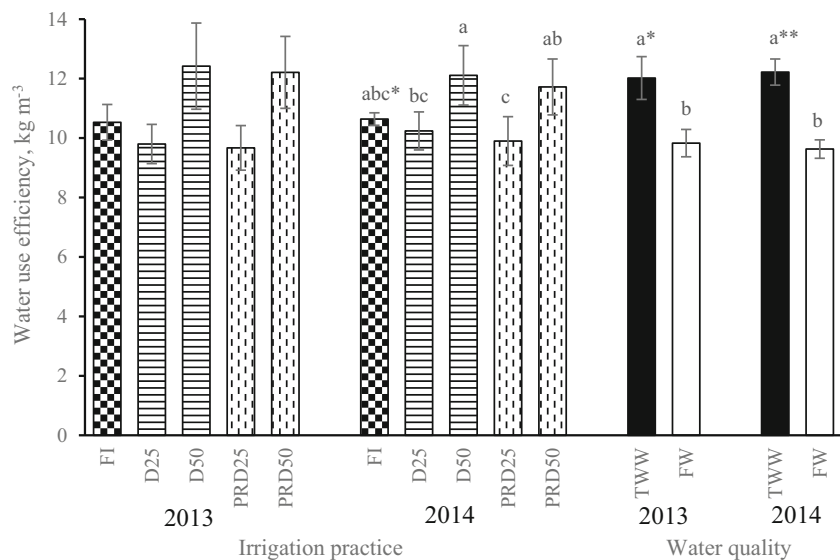
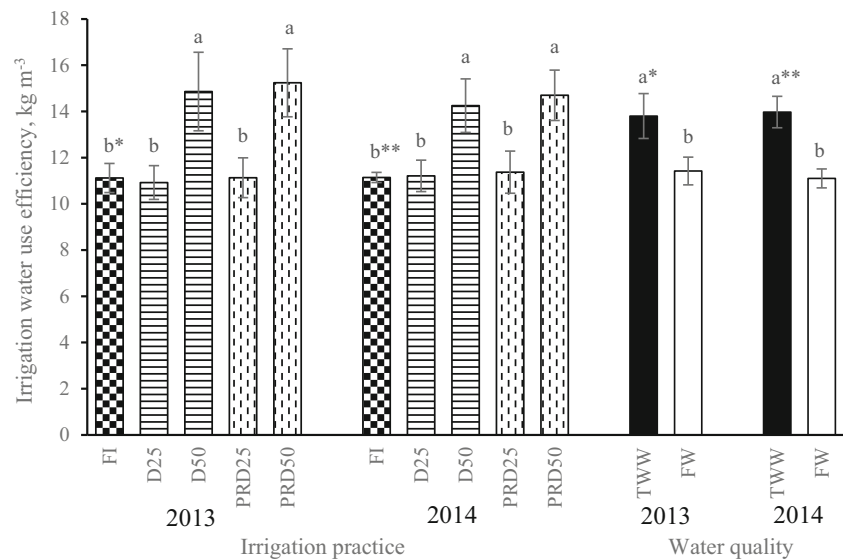


Fig. 6 The irrigation water use efficiencies in different irrigation practices and water qualities. The mean values marked with *same letters* in columns in each trial year are not significantly different (** $P < 0.01$ or * $P < 0.05$). Explanations of abbreviations are as in Fig. 1



Fruit quality

Fruit firmness is an important quality parameter for fresh market tomato. Fruit firmness values ranged from 0.77 to 1.43 kg cm⁻² in trial years. Considering 2-year average values, TWW application decreased by 8.1% fruit firmness compared to FW application (Fig. 8). PRD and DI practices also caused less firmness values. The lowest values were observed from the lowest irrigated conditions. However, the changes for fruit firmness under the different irrigation water types and irrigation practices were not statistically significant. Al-Lahham et al. (2003) observed significantly lower tomato fruit firmness under the wastewater application conditions. Ünlü and Padem (2009) expressed that increased N efficiency may decrease tomato firmness. Total N content of wastewater plots and treated wastewater compared to freshwater plots and freshwater was higher (Tables 4 and 5). However, significant reduction for fruit firmness under wastewater application conditions was not observed in our study. In line with this, Warner et al. (2004) determined insignificant effects on tomato fruit firmness of different N fertilization rates. Although the fruit firmness values in the PRD and DI practices in our study were similar, Sun et al. (2014) expressed that PRD practice leads to greater tomato fruit firmness compared to D practice.

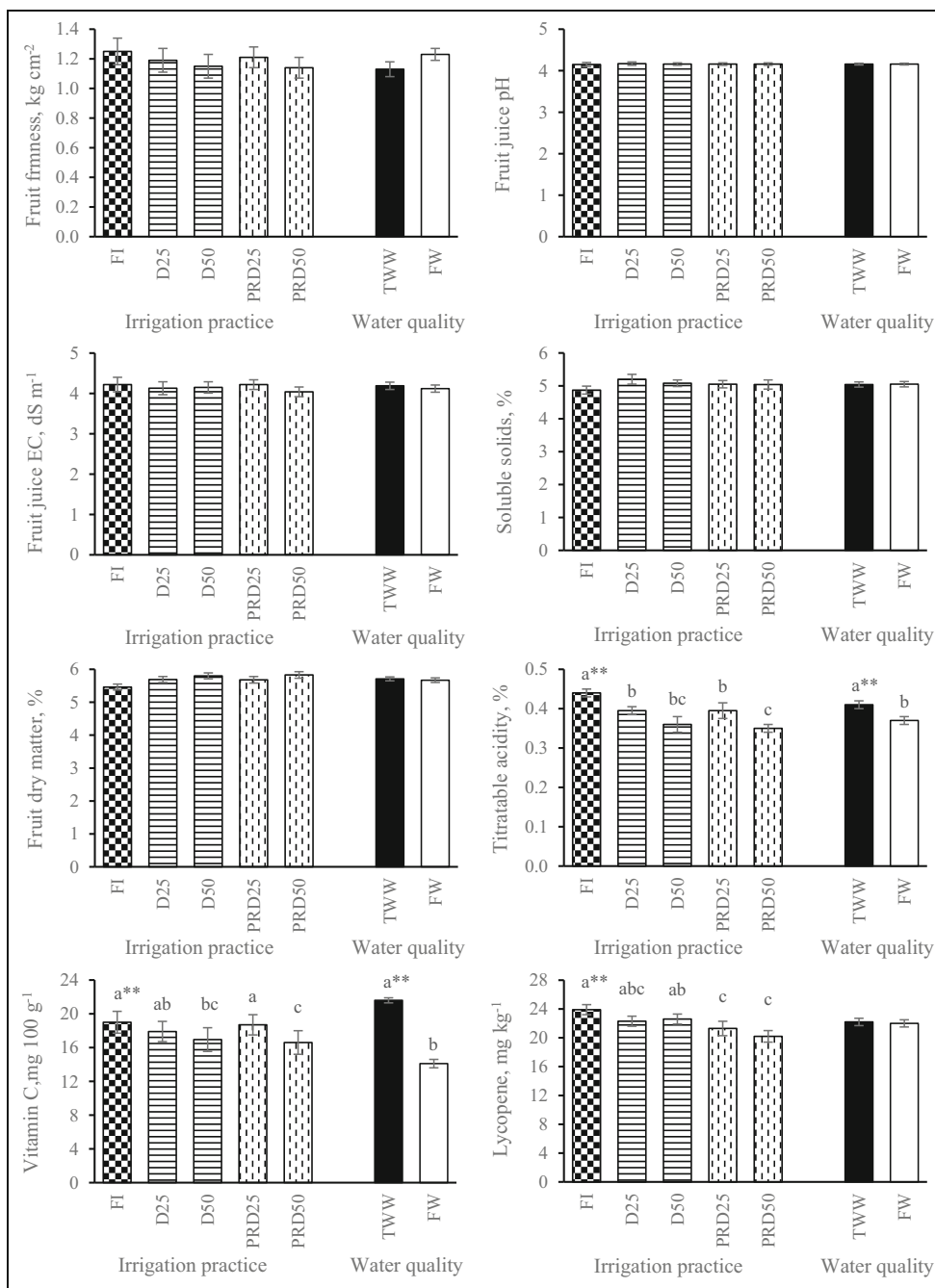
Results of this study showed that increasing fruit size decreased fruit firmness. A negative linear relationship between fruit firmness and fruit size was found ($r^2 = 0.370$; $P < 0.01$). This finding is agreed with that of Al-Lahham et al. (2003) as they said that there was an inverse correlation between firmness and fruit size.

Tomato fruit juice pH, electrical conductivity, and soluble solid and fruit dry matter contents changed between 4.0 and 4.31, and 3.71 and 4.74 dS m⁻¹, and 4.47 and 5.54, and 5.17–6.0%, respectively. However, irrigation water types and

irrigation practices did not significantly affect these values. On the contrary, the fruit titratable acidity, vitamin C, and lycopene contents were significantly affected (Fig. 8). Considering 2-year average values, TWW application increased the titratable acidity and vitamin C contents by 10.8 and 53.2% compared to FW application values, respectively. Less irrigation quantities applied with different irrigation practices also created lower titratable acidity, vitamin C, and lycopene contents. According to 2-year averages, the lowest titratable acidity, vitamin C, and lycopene contents were measured in the PRD50 practice as 0.35%, 16.6 mg 100 g⁻¹, and 20.2 mg kg⁻¹, respectively. The titratable acidity, vitamin C, and lycopene contents in FI practice at the highest values, respectively, were 25.7, 14.5, and 18.3% higher than the contents in PRD50 practice.

In general, the data obtained from our experiment showed that the values for fruit quality parameters (i.e., pH, electrical conductivity, titratable acidity, vitamin C, lycopene, soluble solids, and fruit dry matter contents) under TWW application were similar or even increased compared to FW application. Nevertheless, PRD and DI practices decreased quality parameter values except pH, soluble solids, and dry matter contents compared to FI practice data. pH did not change, and soluble solids and total dry matter contents increased under PRD and DI practice conditions. High soluble solids and dry matter contents may provide positive implications for the food processing industry (Gatta et al. 2015). Below 4.5 pH values are desirable for both industrial and fresh tomato. Moreover, titratable acidity value greater than 0.35 is suggested for processing (Giordano et al. 2000). Lycopene constitutes approximately 80–90% of the total carotenoid content. Therefore, it is a preventative agent for cancers as an efficient antioxidant (Shi and Le Maguer 2000). Quality parameters that characterize the tomato fruit are in agreement with results in the many

Fig. 8 Fruit quality values in different irrigation practices and water qualities. The mean values marked with *same letters* in columns are not significantly different (** $P < 0.01$). Explanations of abbreviations are as in Fig. 1



literatures. Turhan and Şeniz (2009) indicated that tomato fruit dry matter content ranged from 3.83 to 7.0%, soluble solid content ranged from 3.4 to 5.5%, titratable acidity ranged from 0.22 to 0.40%, and pH ranged from 3.78 to 5.25 for 33 different tomato genotypes collected from different parts of Turkey. George et al. (2004) also reported that the titratable acidity varied from 0.26 to 0.70%, the soluble solid content varied from 5 to 7%, the vitamin C varied from 8.40 to 32.4 mg 100 g⁻¹, and the lycopene content varied from 2.04 to 6.94 mg 100 g⁻¹ for 12 different tomato genotypes. Changes for these parameter values depend on several factors

such as cultivars, cultural practices, irrigation practices, water quality, stages of maturity, and growing conditions. Therefore, similar or different results with our results were obtained in many studies. Gatta et al. (2015) found that while titratable acidity, soluble solids, and dry matter contents in tomato fruits were not different between the treated agro-industrial wastewater and groundwater applications, pH significantly decreased in the wastewater irrigation conditions. Disciglio et al. (2015) also determined that soluble solids and dry matter contents were similar in the groundwater and wastewater irrigations, and pH values significantly lower in

the wastewater application. Cirelli et al. (2012) expressed that use of treated wastewater and freshwater did not affect the soluble solids, titratable acidity, and dry matter in tomato fruits significantly. Al-Lahham et al. (2003) reported that while tomato soluble solid content was significantly lower in treated wastewater-irrigated plots in relation to potable water, pH was similar. Psarras et al. (2014) showed that fruit soluble solids and titratable acidity in tomato were not significantly affected by water sources (freshwater and secondary-treated wastewater) and the irrigation practices (full, deficit, and partial root-zone drying irrigations). Deficit and partial root-zone drying irrigations improved tomato fruit quality (soluble solids, titratable acidity, and vitamin C) compared to full irrigation practice (Akhtar et al. 2014). The soluble solid content in tomato fruits was significantly higher in deficit and partial root-zone drying irrigations than in full irrigation (Zegbe-Domínguez et al. 2003). Titratable acidity and soluble solids did not show significant differences between deficit and full-irrigated tomato fruits. Even quality increased under deficit irrigation conditions (Savic et al. 2011). Moreover, Sepaskhah and Ahmadi (2010) and Sun et al. (2014) indicated that the fruit quality in the partial root-zone drying irrigation was higher than in the deficit irrigation.

Soil macro, micro, and trace mineral contents

Macro minerals are the important component of soil fertility as the crop main nutrient source. Macro mineral (total N, P₂O₅, K₂O, Ca, Mg, and Na) contents in topsoil layer of 30 cm after trials in 2013 and 2014 are shown in Table 5. Irrigation with TWW increased the macro mineral contents with respect to FW. Freshwater with less macro mineral content led to a lower loading of nutrients in the soil (Table 4). However, the analysis results showed that the macro mineral contents in surface soil (with exception of Na) were not affected with the TWW applications significantly. The findings of some researches uncovered that obtaining important increases in nutrient contents of cultivated soils irrigated with reclaimed wastewaters generally required long-term applications (Areola et al. 2011; Rusan et al. 2007). On the contrary, results of some studies with short periods showed that soil fertility increased in the wastewater irrigation conditions (Alrajhi et al. 2015; Disciglio et al. 2015; Singh and Agrawal 2012). It could be said that the nutrient accumulation process due to increased water percolation during wet season based on annual rainfall of about 1000 mm in this study site may require further time. Although there were no significant increases for soil fertility in wastewater-irrigated plots, we obtained higher tomato yields under wastewater irrigation conditions compared to FW irrigation (Fig. 3). Obtaining of higher yield with TWW might be realized with direct use of additional nutrients added to soil with wastewater applications considering wastewater's extra nutrient contents (Table 4). Similarly, Disciglio et al.

(2015) concluded that irrigation with agro-industrial effluents could supply readily biodegradable organic compounds and absorbable nutrients (N, P) to the soil.

The greater increases for macro mineral contents in the soil were observed under FI practice (Table 5). Total N, P₂O₅, and K₂O contents in full-irrigated plots with TWW were increased by 25, 2.5, and 18.5%, respectively, compared with FW-irrigated plots considering 2-year average. However, increase rates with TWW did not reach statistically significant levels. Macro mineral contents in PRD and DI practices were decreased with the decrease in irrigation quantities applied. While PRD25 and D25 practices provided similar total N values compared with FI practice, PRD50 and D50 practices significantly reduced total N, P₂O₅, and K₂O contents in the soil. However, PRD and DI practice plots had statistically similar macro mineral contents. Less soil nutrient contents in PRD and DI practices could be explained with soil–water content effects to the nutrient distribution, solubility, and leaching (Alrajhi et al. 2015). In accordance with this, Wang et al. (2010b) expressed that partial root-zone drying irrigation practice facilitated soil organic N mineralization, and so, N nutrition in tomato was improved.

The significant variations were determined in surface soil micro and trace mineral contents (B, Fe, Zn, Cu, Mn, Cd, Ni, and Pb) for different irrigation water types and practices (Table 5). Irrigation with TWW led to significant increases in Fe, Zn, Cu, Cd, and Ni contents in the surface soil layer of 30 cm considering 2-year average values. In comparison to the FW application, the Fe, Zn, Cu, Cd, and Ni contents increased by 23.5, 15.5, 19.2, 8.8, and 26.1%, respectively. Moreover, these values were higher by 26.9, 11.7, 55, 85, and 16.8% than values in prior to the experiments, respectively (Table 3). The Cd content in plots irrigated with FW was also high considering initial soil Cd content. Reason of high Cd content in freshwater-irrigated plots can be fertilizer applications in prior to the experiments. Wuana and Okieimen (2011) reported that the compounds of N, P, and K fertilizers contain trace amounts of heavy metals (e.g., Cd and Pb). While nitrogen and potash fertilizers have relatively low heavy metal content, phosphoric fertilizers usually include toxic heavy metals at the considerable levels (Su et al. 2014). The irrigation with TWW and FW provided statistically similar Mn and Pb contents. Moreover, Mn and Pb contents were close to the initial values given in Table 3. The positive linear correlative relationships between Cu, Mn, Cd, and Ni contents in irrigation waters and Cu, Mn, Cd, and Ni contents of the soils after irrigation were observed ($r = 0.590$ for Cu, $r = 0.993$ for Mn, $r = 0.486$ for Cd, and $r = 0.445$ for Ni). Therefore, it could be said that high micro and trace mineral contents in wastewater plots are due to their relatively high contents in wastewaters used (Table 4). Increase of micro and trace mineral contents in wastewater-irrigated soils has been reported also in different studies. Khaskhoussy et al. (2015)

expressed that the treated wastewater irrigation increased significantly the Cu, Cd, and Ni contents in soil and had no significant effect on the Zn and Pb content. Rusan et al. (2007) indicated that wastewater irrigation had no significant effect on soil Pb content. Areola et al. (2011) expressed that Cd, Ni, and Cu concentrations in wastewater-irrigated soils were higher than the recommended values for crop production. Singh et al. (2012) determined higher Fe, Mn, Zn, Cu, Pb, and Ni contents after harvest in sewage water-irrigated soil cultivated with different crops compared to well water-irrigated soil.

The B, Fe, Cu, Cd, Ni, and Pb contents were greater in the FI practice with respect to the PRD and DI practices. The contents decreased with decrease of irrigation quantities. Therefore, the lowest values were determined in PRD50 and D50 practices (Table 5). The application of low irrigation quantities in the PRD and DI practices could decrease the micro and trace mineral supplement into the soil, and mineral accumulation could be decreased with low soil–water interaction. Similar to our findings, Oliveira et al. (2015) determined that the Fe, Cu, Cd, and Ni contents in topsoil layer of 10 cm were high in the full irrigation practice in comparison to the deficit irrigation practice.

This study results displayed that the accumulation of heavy metals in soils processed with different irrigation water types and irrigation practices was lower than the maximum permissible limits reported by Pescod (1992) and Khan et al. (2013) (300 mg kg⁻¹ for Zn, 135 mg kg⁻¹ for Cu, 3 mg kg⁻¹ for Cd, 75 mg kg⁻¹ for Ni, 300 mg kg⁻¹ for Pb). Moreover, heavy metal values were in safe limits according to the regulation on use in soil of domestic and urban sewage sludge in Turkey (The Official Gazette 2010).

Fruit macro, micro, and trace mineral contents

Macro (total N, K, Ca, Mg, and Na), micro, and trace (B, Fe, Zn, Cu, Mn, Cd, Ni, Pb, Co, Cr) mineral contents detected in tomato fruits are given in Table 6. Although all macro mineral contents in TWW application were higher than the values in FW application considering 2-year averages, only K, Na, and Ca showed significant differences with respect to irrigation water qualities. Fruit K, Na, and Ca contents in the TWW application were higher by 2.9, 16.7, and 14.7% than in the FW application. Significant increase in especially Na content is probably a result of the relatively higher level of this mineral in treated wastewater and wastewater-irrigated soil (Tables 4 and 5). This opinion could be also supported with the positive linear correlative relationships determined for fruit Na content–soil Na content ($r = 0.994$) and fruit Na content–irrigation water Na content ($r = 0.316$). Higher macro mineral contents obtained under the wastewater irrigation conditions in the present study are in agreement with the data in tomato fruits reported by Al-Momany et al. (2014) and Emongor et al.

(2012). Gatta et al. (2015) also determined that Na content in tomato fruits under treated wastewater irrigation was significantly higher than groundwater irrigation. Moreover, Zavadil (2009) noticed that primary-treated wastewater irrigation led to a significant increase in the Na content in the consumable parts of vegetables (e.g., lettuce salad, radish, carrot, early potatoes, and sugar beet).

Macro mineral contents in the tomato fruits were significantly higher for FI than for PRD and DI practice plants (Table 6). Macro mineral contents were affected with reduced irrigation quantities. Therefore, the lowest values were determined for PRD and DI practices with water deficit of 50%. However, there were no statistical differences between PRD and DI practices under irrigations with less water of 25 and 50%. Contrarily, Sun et al. (2014) determined that partial root-zone drying irrigation significantly increased the fruit K and Mg contents compared to deficit irrigation. Lower values with PRD and DI practices were obtained for both water qualities as well. Considering 2-year average values, N, K, Na, Ca, and Mg contents in PRD50 practice with the lowest fruit macro mineral contents were lower by 28.7, 6.9, 26.7, 25.5, and 46.7% than the values observed in FI practice, respectively. It could be said that lower irrigation quantities in PRD and DI practices provided less fruit nutrient contents because nutrient uptake by plants is generally lower under less soil water conditions. Nahar and Gretzmacher (2002) also expressed that the uptake of N, K, Na, Ca, Mg, and S in tomato plants was significantly reduced by water stress.

Higher contents of micro and trace minerals (B, Fe, Zn, Cu, Mn, Cd, Ni, Pb, Co, Cr) in the fruits of tomato plants irrigated with treated wastewater were determined in both experimental years (Table 6). According to the 2-year combined data, all micro and trace mineral contents in the TWW application except Zn were significantly higher than in the FW application contents. The TWW increased contents of B, Fe, Cu, Mn, Cd, Ni, Pb, Co, and Cr by 22.3, 15.1, 8.4, 45.8, 44.2, 22.7, 42.9, 37.5, and 50% in response to the FW application, respectively. These significant variations may be a result of high levels of micro and trace minerals present in the wastewater-irrigated soil as well as in the treated wastewater (Tables 4 and 5). Previous studies conducted by Al-Lahham et al. (2007), Al-Momany et al. (2014), and Khan et al. (2011) reported that the fruits in tomato plants irrigated with treated wastewater had higher micro and trace mineral contents compared to freshwater-irrigated plants.

Partial root-zone drying irrigation and deficit irrigation practices significantly reduced fruit micro and trace mineral contents compared to the FI practice in both trial years (Table 6). The lowest values were generally measured in fruits grown under PRD50 and D50 practices. Moreover, fruit micro and trace mineral contents measured in the PRD and DI practices were statistically similar under both water-deficit conditions of 25 and 50%. Mineral ions in soil solution could be

Table 6 Macro, micro, and trace mineral contents (mean \pm SEM) in the fruits of tomato irrigated with different quality waters under different irrigation practices in 2013 and 2014

Year	Parameter	FI		D25		D50		PRD25		PRD50	
		TWW	FW	TWW	FW	TWW	FW	TWW	FW	TWW	FW
2013	Total N (%)	2.38 \pm 0.05	2.48 \pm 0.08	2.12 \pm 0.12	2.32 \pm 0.09	2.10 \pm 0.05	2.01 \pm 0.20	2.28 \pm 0.07	1.91 \pm 0.11	2.15 \pm 0.19	
	K (%)	2.66 \pm 0.02	2.44 \pm 0.12	2.47 \pm 0.09	2.40 \pm 0.01	2.47 \pm 0.04	2.35 \pm 0.04	2.47 \pm 0.03	2.32 \pm 0.04	2.45 \pm 0.06	
	Na (%)	0.017 \pm 0.001	0.017 \pm 0.001	0.017 \pm 0.000	0.013 \pm 0.001	0.016 \pm 0.000	0.015 \pm 0.000	0.015 \pm 0.001	0.016 \pm 0.000	0.016 \pm 0.001	
	Ca (%)	2.13 \pm 0.04	2.02 \pm 0.03	1.85 \pm 0.06	1.73 \pm 0.08	1.46 \pm 0.06	1.41 \pm 0.08	2.01 \pm 0.16	1.45 \pm 0.02	1.45 \pm 0.02	1.56 \pm 0.02
	Mg (%)	0.34 \pm 0.06	0.25 \pm 0.01	0.15 \pm 0.01	0.21 \pm 0.04	0.24 \pm 0.04	0.18 \pm 0.01	0.17 \pm 0.01	0.18 \pm 0.02	0.18 \pm 0.02	0.17 \pm 0.02
	B (mg kg ⁻¹)	5.01 \pm 0.21	4.64 \pm 0.07	3.68 \pm 0.61	2.79 \pm 0.31	3.04 \pm 0.36	2.14 \pm 0.21	3.06 \pm 0.11	2.59 \pm 0.24	2.59 \pm 0.24	2.73 \pm 0.35
	Fe (mg kg ⁻¹)	109.5 \pm 11.8	90.0 \pm 11.7	99.8 \pm 3.8	83.1 \pm 5.2	99.3 \pm 4.8	82.5 \pm 6.7	78.5 \pm 0.6	55.4 \pm 3.3	55.4 \pm 3.3	76.1 \pm 10.0
	Zn (mg kg ⁻¹)	32.5 \pm 1.3	31.7 \pm 2.6	30.2 \pm 0.5	30.5 \pm 0.7	28.2 \pm 2.5	27.6 \pm 2.1	28.9 \pm 1.6	30.0 \pm 2.1	30.0 \pm 2.1	25.4 \pm 0.5
	Cu (mg kg ⁻¹)	11.6 \pm 0.3	10.3 \pm 0.3	9.2 \pm 0.3	9.7 \pm 1.7	9.3 \pm 1.1	7.1 \pm 0.2	9.9 \pm 1.1	8.9 \pm 1.9	8.9 \pm 1.9	8.0 \pm 0.2
	Mn (mg kg ⁻¹)	32.7 \pm 3.1	24.5 \pm 0.9	31.6 \pm 3.0	19.3 \pm 1.3	23.3 \pm 0.8	17.6 \pm 1.5	30.4 \pm 0.4	22.2 \pm 1.8	22.2 \pm 1.8	30.0 \pm 1.3
	Cd (mg kg ⁻¹)	0.076 \pm 0.002	0.050 \pm 0.001	0.066 \pm 0.002	0.034 \pm 0.002	0.036 \pm 0.002	0.017 \pm 0.001	0.063 \pm 0.002	0.043 \pm 0.004	0.043 \pm 0.004	0.023 \pm 0.002
	Ni (mg kg ⁻¹)	0.28 \pm 0.01	0.20 \pm 0.02	0.21 \pm 0.004	0.17 \pm 0.01	0.22 \pm 0.01	0.15 \pm 0.03	0.21 \pm 0.005	0.20 \pm 0.01	0.20 \pm 0.01	0.19 \pm 0.05
	Pb (mg kg ⁻¹)	0.26 \pm 0.01	0.16 \pm 0.01	0.22 \pm 0.02	0.14 \pm 0.01	0.20 \pm 0.01	0.11 \pm 0.01	0.25 \pm 0.01	0.16 \pm 0.02	0.16 \pm 0.02	0.21 \pm 0.01
	Co (mg kg ⁻¹)	0.21 \pm 0.01	0.17 \pm 0.005	0.21 \pm 0.02	0.11 \pm 0.004	0.11 \pm 0.02	0.09 \pm 0.003	0.18 \pm 0.001	0.13 \pm 0.03	0.13 \pm 0.03	0.18 \pm 0.004
	Cr (mg kg ⁻¹)	0.41 \pm 0.04	0.25 \pm 0.02	0.26 \pm 0.02	0.15 \pm 0.03	0.26 \pm 0.01	0.18 \pm 0.01	0.25 \pm 0.02	0.18 \pm 0.01	0.18 \pm 0.01	0.17 \pm 0.02
	Total N (%)	3.75 \pm 0.10	3.51 \pm 0.69	2.71 \pm 0.07	2.36 \pm 0.10	2.43 \pm 0.17	2.29 \pm 0.10	2.51 \pm 0.16	2.35 \pm 0.04	2.35 \pm 0.04	2.46 \pm 0.05
2014	K (%)	2.70 \pm 0.01	2.54 \pm 0.06	2.27 \pm 0.09	2.56 \pm 0.05	2.58 \pm 0.01	2.53 \pm 0.04	2.66 \pm 0.05	2.63 \pm 0.001	2.50 \pm 0.11	
	Na (%)	0.016 \pm 0.001	0.012 \pm 0.001	0.013 \pm 0.001	0.011 \pm 0.000	0.010 \pm 0.001	0.008 \pm 0.001	0.011 \pm 0.001	0.011 \pm 0.000	0.010 \pm 0.001	
	Ca (%)	1.27 \pm 0.02	1.03 \pm 0.07	1.21 \pm 0.12	1.11 \pm 0.08	0.93 \pm 0.03	1.01 \pm 0.07	1.19 \pm 0.07	1.09 \pm 0.06	1.17 \pm 0.09	
	Mg (%)	0.34 \pm 0.02	0.28 \pm 0.01	0.24 \pm 0.03	0.23 \pm 0.01	0.15 \pm 0.01	0.19 \pm 0.08	0.22 \pm 0.02	0.20 \pm 0.02	0.19 \pm 0.02	
	B (mg kg ⁻¹)	5.35 \pm 0.15	4.09 \pm 0.02	4.76 \pm 0.22	3.76 \pm 0.21	4.55 \pm 0.24	3.43 \pm 0.27	4.59 \pm 0.14	3.83 \pm 0.10	3.85 \pm 0.09	
	Fe (mg kg ⁻¹)	85.5 \pm 0.9	80.9 \pm 2.2	69.3 \pm 4.6	78.2 \pm 5.4	76.7 \pm 3.7	72.7 \pm 1.0	62.6 \pm 5.8	62.1 \pm 1.5	66.5 \pm 2.0	
	Zn (mg kg ⁻¹)	25.0 \pm 0.7	23.2 \pm 0.6	18.5 \pm 1.5	21.2 \pm 3.0	21.8 \pm 1.4	21.4 \pm 1.7	21.5 \pm 0.9	21.7 \pm 0.9	19.8 \pm 1.4	
	Cu (mg kg ⁻¹)	9.2 \pm 0.7	9.8 \pm 0.1	9.0 \pm 0.5	8.9 \pm 0.1	8.6 \pm 0.1	8.3 \pm 0.3	9.7 \pm 0.3	7.8 \pm 0.4	8.6 \pm 0.2	
	Mn (mg kg ⁻¹)	34.6 \pm 1.5	32.4 \pm 1.0	31.0 \pm 1.0	20.5 \pm 1.2	26.6 \pm 0.7	19.0 \pm 7.5	28.2 \pm 1.9	23.3 \pm 0.3	27.7 \pm 1.1	
	Cd (mg kg ⁻¹)	0.095 \pm 0.003	0.093 \pm 0.007	0.090 \pm 0.037	0.068 \pm 0.003	0.057 \pm 0.004	0.036 \pm 0.004	0.076 \pm 0.003	0.053 \pm 0.003	0.039 \pm 0.003	
	Ni (mg kg ⁻¹)	0.33 \pm 0.02	0.32 \pm 0.02	0.32 \pm 0.01	0.27 \pm 0.01	0.30 \pm 0.01	0.26 \pm 0.01	0.33 \pm 0.004	0.27 \pm 0.01	0.27 \pm 0.01	
	Pb (mg kg ⁻¹)	0.22 \pm 0.02	0.15 \pm 0.01	0.17 \pm 0.01	0.13 \pm 0.02	0.13 \pm 0.003	0.11 \pm 0.01	0.20 \pm 0.02	0.12 \pm 0.01	0.14 \pm 0.02	
	Co (mg kg ⁻¹)	0.35 \pm 0.01	0.24 \pm 0.03	0.21 \pm 0.05	0.23 \pm 0.01	0.14 \pm 0.003	0.15 \pm 0.03	0.30 \pm 0.003	0.22 \pm 0.01	0.25 \pm 0.01	
	Cr (mg kg ⁻¹)	0.44 \pm 0.02	0.26 \pm 0.01	0.25 \pm 0.02	0.13 \pm 0.01	0.25 \pm 0.02	0.17 \pm 0.01	0.25 \pm 0.02	0.16 \pm 0.02	0.18 \pm 0.01	
	Total N (%)	3.06 \pm 0.31	3.00 \pm 0.39	2.41 \pm 0.15	2.34 \pm 0.06	2.27 \pm 0.11	2.15 \pm 0.12	2.40 \pm 0.10	2.13 \pm 0.11	2.31 \pm 0.11	
	K (%)	2.68 \pm 0.01	2.49 \pm 0.06	2.37 \pm 0.07	2.48 \pm 0.04	2.52 \pm 0.03	2.44 \pm 0.05	2.57 \pm 0.05	2.48 \pm 0.07	2.47 \pm 0.06	
Na (%)	0.016 \pm 0.001	0.014 \pm 0.001	0.015 \pm 0.001	0.012 \pm 0.001	0.013 \pm 0.001	0.011 \pm 0.002	0.013 \pm 0.001	0.013 \pm 0.001	0.013 \pm 0.002		
Ca (%)	1.70 \pm 0.19	1.52 \pm 0.22	1.53 \pm 0.15	1.42 \pm 0.15	1.20 \pm 0.12	1.21 \pm 0.10	1.60 \pm 0.20	1.27 \pm 0.09	1.27 \pm 0.09		
Mg (%)	0.34 \pm 0.03	0.26 \pm 0.01	0.20 \pm 0.03	0.22 \pm 0.02	0.19 \pm 0.03	0.19 \pm 0.04	0.19 \pm 0.02	0.19 \pm 0.02	0.18 \pm 0.01		
B (mg kg ⁻¹)	5.18 \pm 0.14	4.36 \pm 0.13	4.22 \pm 0.38	3.28 \pm 0.27	3.80 \pm 0.39	2.79 \pm 0.33	3.83 \pm 0.35	3.21 \pm 0.30	3.29 \pm 0.30		
Fe (mg kg ⁻¹)	97.5 \pm 7.5	85.5 \pm 5.7	84.6 \pm 7.3	80.7 \pm 3.5	88.0 \pm 5.7	77.6 \pm 3.7	70.6 \pm 4.4	58.7 \pm 2.2	71.3 \pm 5.0		
Zn (mg kg ⁻¹)	28.7 \pm 1.8	27.5 \pm 2.3	24.3 \pm 2.7	25.8 \pm 2.5	25.0 \pm 1.9	24.5 \pm 1.8	25.2 \pm 1.8	25.9 \pm 2.1	22.6 \pm 1.4		
Cu (mg kg ⁻¹)	10.4 \pm 0.6	10.0 \pm 0.2	9.1 \pm 0.3	9.3 \pm 0.8	8.9 \pm 0.5	7.7 \pm 0.3	9.8 \pm 0.5	8.4 \pm 0.9	8.3 \pm 0.2		
Mn (mg kg ⁻¹)	33.6 \pm 1.6	28.5 \pm 1.9	31.3 \pm 1.4	19.9 \pm 0.8	25.0 \pm 0.9	18.3 \pm 3.4	29.3 \pm 1.0	22.7 \pm 0.8	28.8 \pm 0.9		
Cd (mg kg ⁻¹)	0.086 \pm 0.005	0.072 \pm 0.010	0.078 \pm 0.017	0.051 \pm 0.008	0.046 \pm 0.005	0.027 \pm 0.004	0.069 \pm 0.004	0.048 \pm 0.003	0.031 \pm 0.004		
Ni (mg kg ⁻¹)	0.30 \pm 0.01	0.26 \pm 0.03	0.27 \pm 0.03	0.22 \pm 0.02	0.26 \pm 0.02	0.20 \pm 0.03	0.27 \pm 0.03	0.24 \pm 0.02	0.23 \pm 0.03		
Pb (mg kg ⁻¹)	0.24 \pm 0.01	0.16 \pm 0.01	0.20 \pm 0.01	0.14 \pm 0.01	0.17 \pm 0.02	0.11 \pm 0.01	0.22 \pm 0.01	0.14 \pm 0.01	0.17 \pm 0.02		

Table 6 (continued)

Year	Parameter	FI		D25		D50		PRD25		PRD50	
		TWW	FW	TWW	FW	TWW	FW	TWW	FW	TWW	FW
	Co (mg kg ⁻¹)	0.28 ± 0.03	0.21 ± 0.02	0.21 ± 0.02	0.17 ± 0.03	0.13 ± 0.01	0.12 ± 0.02	0.24 ± 0.03	0.18 ± 0.03	0.22 ± 0.01	0.18 ± 0.01
	Cr (mg kg ⁻¹)	0.42 ± 0.02	0.25 ± 0.01	0.25 ± 0.01	0.14 ± 0.01	0.26 ± 0.01	0.18 ± 0.01	0.25 ± 0.01	0.17 ± 0.01	0.18 ± 0.01	0.18 ± 0.01
	Mean										
	PRD50										
	FW		TWW	FW	FI	D25	D50	PRD25	PRD50		
2013	1.74 ± 0.05	2.21	2.09	2.43a**	2.22ab	2.06bc	2.09bc	2.09bc	1.95c		
	2.34 ± 0.03	2.50a**	2.37b	2.55	2.43	2.41	2.40	2.40	2.40		
	0.012 ± 0.001	0.016a**	0.014b	0.017a**	0.015bc	0.015b	0.015b	0.015b	0.014c		
	1.22 ± 0.10	1.80a**	1.56b	2.07a**	1.79b	1.44c	1.73b	1.73b	1.39c		
	0.13 ± 0.01	0.21	0.19	0.29a**	0.18bc	0.21b	0.18bc	0.18bc	0.15c		
	2.34 ± 0.25	3.50a**	2.90b	4.82a**	3.23b	2.59bc	2.83bc	2.83bc	2.53c		
	50.0 ± 3.0	92.7a**	72.2b	99.8a**	91.5a	90.9a	67.0b	67.0b	63.1b		
	27.0 ± 0.9	29.0	29.4	32.1a*	30.3ab	27.9bc	29.5abc	29.5abc	26.2c		
	6.9 ± 0.7	9.61	8.59	11.0a*	9.5ab	8.2b	9.4ab	9.4ab	7.5b		
	12.0 ± 0.9	29.6a**	19.1b	28.6a**	25.4a	20.4b	26.3a	26.3a	21.0b		
	0.020 ± 0.002	0.053a**	0.033b	0.063a**	0.050b	0.027c	0.053b	0.053b	0.022d		
	0.16 ± 0.01	0.22a**	0.18b	0.24a*	0.19b	0.19b	0.20ab	0.20ab	0.18b		
	0.12 ± 0.01	0.23a**	0.14b	0.21a**	0.18ab	0.16b	0.20a	0.20a	0.17b		
0.06 ± 0.01	0.18a**	0.11b	0.19a**	0.16ab	0.10c	0.16b	0.16b	0.12c			
0.15 ± 0.01	0.27a**	0.18b	0.33a**	0.20b	0.22b	0.22b	0.22b	0.16c			
2014	2.31 ± 0.06	2.77	2.57	3.63a**	2.54b	2.36b	2.43b	2.43b	2.38b		
	2.37 ± 0.05	2.54	2.52	2.62a**	2.41c	2.55ab	2.65a	2.65a	2.43bc		
	0.008 ± 0.001	0.012a**	0.010b	0.014a**	0.012ab	0.009 cd	0.011bc	0.011bc	0.009d		
	0.84 ± 0.05	1.16a**	1.01b	1.15a*	1.16a	0.97b	1.14a	1.14a	1.01ab		
	0.14 ± 0.10	0.23	0.21	0.31	0.24	0.17	0.21	0.21	0.17		
	3.56 ± 0.22	4.62a**	3.74b	4.72a**	4.26b	3.99bc	4.21b	4.21b	3.71c		
	60.8 ± 14.5	72.1	70.9	83.2a**	73.7ab	74.7ab	62.4b	62.4b	63.6b		
	22.2 ± 0.8	21.3	21.9	24.1	19.9	21.6	21.6	21.6	21.0		
	8.4 ± 0.1	9.04	8.64	9.5a*	9.0ab	8.5b	8.8ab	8.8ab	8.5bb		
	12.1 ± 2.0	29.6a**	21.5b	33.5a**	25.8b	22.8b	25.8b	25.8b	19.9		
	0.019 ± 0.004	0.071a*	0.054b	0.094a**	0.079ab	0.046 cd	0.065bc	0.065bc	0.029d		
	0.22 ± 0.01	0.31a**	0.27b	0.32a**	0.30b	0.28b	0.30ab	0.30ab	0.25c		
	0.14 ± 0.02	0.17a**	0.13b	0.19a**	0.15b	0.12c	0.16ab	0.16ab	0.14bc		
0.16 ± 0.01	0.25a**	0.20b	0.30a**	0.22b	0.15c	0.26a	0.26a	0.21b			
0.14 ± 0.01	0.28a**	0.17b	0.35a**	0.19bc	0.21b	0.20b	0.20b	0.16c			
2013–2014	2.02 ± 0.13	2.49	2.33	3.03a**	2.38b	2.21b	2.26b	2.26b	2.16b		
	2.36 ± 0.03	2.52a**	2.45b	2.59a**	2.42c	2.48bc	2.52ab	2.52ab	2.41c		
	0.010 ± 0.001	0.014a**	0.012b	0.015a**	0.014b	0.012bc	0.013b	0.013b	0.011c		
	1.03 ± 0.10	1.48a**	1.29b	1.61a**	1.47b	1.20c	1.44b	1.44b	1.20c		
	0.14 ± 0.05	0.22	0.20	0.30a**	0.21b	0.19b	0.19b	0.19b	0.16b		

Table 6 (continued)

Year	PRD50		Mean						
	FW	FW	TWW	FW	FI	D25	D50	PRD25	PRD50
	2.95 ± 0.31		4.06a**	3.32b	4.77a**	3.75b	3.29 cd	3.52bc	3.12d
	55.4 ± 7.0		82.4a*	71.6b	91.5a**	82.6a	82.8a	64.7b	63.3b
	24.6 ± 1.2		25.2	25.7	28.1a**	25.1b	24.7b	25.6b	23.6c
	7.7 ± 0.5		9.33a*	8.61b	10.2a**	9.2ab	8.3bc	9.1bc	8.0c
	12.1 ± 1.0		29.6a**	20.3b	31.0a**	25.6b	21.6c	26.0b	20.4c
	0.019 ± 0.002		0.062a**	0.043b	0.079a**	0.064b	0.036c	0.059b	0.025c
	0.19 ± 0.02		0.27a**	0.22b	0.28a**	0.24b	0.23bc	0.25b	0.21c
	0.13 ± 0.01		0.20a**	0.14b	0.20a**	0.17bc	0.14d	0.18ab	0.15 cd
	0.11 ± 0.02		0.22a**	0.16b	0.24a**	0.19b	0.12d	0.21b	0.16c
	0.14 ± 0.01		0.27a**	0.18b	0.34a**	0.20b	0.22b	0.21b	0.16c

The values marked with the same letters for water qualities or irrigation practices in each line of the “Mean” column of each trial year are not significantly different TWW treated wastewater, FW freshwater, FI full irrigation, D25 and D50 25 and 50% deficit irrigation, PRD25 and PRD50 25 and 50% deficit irrigation with PRD

** $P < 0.01$; * $P < 0.05$

decreased with the reduced irrigation quantity. Therefore, less fruit mineral contents in PRD and DI practices may be attributed to reduction of the rate of absorption by the plant roots under less soil–water conditions. Similarly, Agbemafle et al. (2015) observed significant decreases in the contents of Fe, Cu, and Zn minerals in tomato under 30% lesser irrigation application conditions.

The accumulation of heavy metals in fruits of tomato plants full irrigated with TWW was in the order of $Fe > Mn > Zn > Cu > Cr > Ni > Co > Pb > Cd$ considering 2-year average values. The trend of metal accumulation in wastewater-irrigated D25, PRD25, and PRD50 practices was in the following order: $Fe > Mn > Zn > Cu > Ni > Cr > Co > Pb > Cd$. The order in the D50 practice also was $Fe > Mn > Zn > Cu > Ni > Cr > Pb > Co > Cd$. Metal pollution index (MPI) values calculated with 2-year average data were 1.65 $mg\ kg^{-1}$ in TWW application and 1.27 $mg\ kg^{-1}$ in FW application. MPI values for FI, D25, PRD25, D50, and PRD50 practices under the TWW application, respectively, were determined as 2.05, 1.66, 1.70, 1.45, and 1.36 $mg\ kg^{-1}$. The values for FI, D25, PRD25, D50, and PRD50 practices under the FW application were 1.65, 1.31, 1.32, 1.12, and 0.97 $mg\ kg^{-1}$, respectively. Higher chemical content of the treated wastewater used in the experiment resulted in higher heavy metal pollution in tomato fruits under full-irrigated conditions. Higher MPI values suggested that treated wastewater application might cause more health risk for humans compared to freshwater application. It is apparent for Cd and Pb that concentrations in tomato fruits exceeded standard limits given by FAO/WHO (425.5 $mg\ kg^{-1}$ for Fe, 60 $mg\ kg^{-1}$ for Zn, 40 $mg\ kg^{-1}$ for Cu, 500 $mg\ kg^{-1}$ for Mn, 0.05 $mg\ kg^{-1}$ for Cd, 67.9 $mg\ kg^{-1}$ for Ni, 0.10 $mg\ kg^{-1}$ for Pb, and 2.30 $mg\ kg^{-1}$ for Cr) (Codex Alimentarius Commission 2001, 2011; Lente et al. 2014). The risk for Cd and Pb was also observed in both water qualities. Moreover, Cd, Co, and Cr contents of irrigation waters used in the experiments were higher than the maximum concentrations (0.01 $mg\ l^{-1}$ for Cd, 0.05 $mg\ l^{-1}$ for Co, and 0.10 $mg\ l^{-1}$ for Cr) recommended by FAO (Pescod 1992). It could be said that high Cd content in irrigation waters provided high Cd accumulation in tomato fruits. As a supportive argument to this claim, Gharaibeh et al. (2015) reported that Cd accumulation in fruits of tomato plant increased with the increase of Cd concentration in irrigation water.

Conclusions

Our results clearly showed that the impact of treated wastewater irrigation on soil nutrient content was not apparent, but tomato marketable yield was strongly influenced with direct use of current nutrients in wastewater. Therefore, water

productivity was greater under wastewater irrigation conditions. Decreasing irrigation quantities supported obtaining of higher water productivity values. Fruit quality was improved under full-irrigated tomato with treated wastewater. Although soil mineral contents were below permissible limits, wastewater irrigation increased fruit metal pollution. Fruit Cd and Pb contents were above safe limits. Partial root-zone drying irrigation caused in similar yield, fruit quality, water use, and mineral contents with deficit irrigation practice under same irrigation quantities. Treated wastewater application under the full irrigation conditions has greater potential to increase available heavy metal risk. Therefore, partial root-zone drying and deficit irrigation practices in the hot-dry regions under conditions where irrigation water resources are limited could be a feasible strategy for improvement of water use efficiency and reduce the metal pollution in wastewater-irrigated tomato fruits.

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