Growth, Yield, Quality and Water Use Efficiency of Grafted Tomato Plants Grown in Greenhouse under Different Irrigation Levels

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Abstract: Grafting and proper irrigation managements are becoming valuable practices for optimum growth and yield of vegetables. Tube grafting treatments were applied for 'Faridah' grafted onto 'Unifort'. Irrigation level treatments included 40, 60, 80 and 100% (control treatment) based on crop evapotranspiration (ETc). Grafted plants were more vigorous (taller stem, higher leaf area, heavier vine fresh and dry weights) than un-grafted plants. The total yield was higher by 11.90-12.41% in grafted than un-grafted plants. Fruit quality: vitamin C, titratable acidity and total sugars were better in fruits of grafted than in un-grafted. The highest irrigation level (100% ETc) generated superior vegetative growth with more fruit yield production. On the other hand, water stress treatment (40% ETc) decreased yield production while, it improved fruit quality (vitamin. C, titratable acidity, total soluble solids and total sugars). Grafted plants under lower water level (WL1) enhanced vitamin C and titratable acidity. Water use efficiency increased in grafted plants under lower water level. Grafted plants under a moderate water level (80% ETc) resulted in 16.7% saving in irrigation water, with only slight reduction in yield (0.7-1.3%). Therefore, it can be concluded that grafting is beneficial alternative method for tomato production and conserving water under greenhouse conditions.

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1. Introduction

Growing fruit-bearing vegetables, chiefly tomato, cucumber and watermelon through grafted seedlings became a widespread practice worldwide. Grafting is a valuable technique to avoid soil-borne diseases, provide biotic and abiotic stress tolerance, enhance nutrients uptake, optimize water use, and increase fruit yield and quality. These advantages are due to vigorous root system of rootstocks compared to self-rooted plants (Oztekin et al., 2009 and Schwarz et al., 2010). Therefore, grafting of fruit vegetable crops is receiving progressively important and attention in numerous countries of the world (Echevarria et al., 2012).

Grafting of commercial tomato cultivars onto selected rootstocks could be a promising tool as a rapid alternative to the relatively slow breeding methods intended for increasing tomato fruit quality (Flores et al., 2010). Khah et al. (2006) and Turhan et al. (2011) reported that grafting of tomato plants on suitable rootstocks has positive impacts on cultivation performance, particularly under greenhouse conditions.

Nowadays, water scarcity in arid and semi-arid regions represents a serious problem for agriculture management. Thus, effective irrigation strategies are essential for crop productivity and quality in addition to conserving water (Proietti et al., 2008). A proper irrigation management is essential for improving the quantity and quality of tomato crop grown under greenhouse conditions (Sezen et al., 2010).

Drip irrigation improves WUE by significantly decreasing either run off or crop ETc losses (Patane et al., 2011). The amount of water applied relies mainly on irrigation schedule and ETc rates (Hartz, 1993). Scheduling irrigation application in protected agriculture is very critical. Excessive irrigation reduces yield, while limited irrigation causes water stress and large yield losses, including vital physiological and biochemical changes (Locascio and Smajstrla, 1996 and Proietti et al., 2008).

Little studies are available regarding the relationship between grafting and applied water amounts on growth, yield and quality of fruit-bearing vegetable crops. Therefore, the current study was conducted to examine the impacts of grafting under various irrigation levels on tomato growth, yield, fruit quality and WUE under greenhouse conditions.

2. Materials and methods

The investigation was executed at the Agricultural Research and Experimental Station, College of Food and Agriculture Sciences, King Saud University, Dirab area near Riyadh, Saudi Arabia (latitude: 24° 39 N, longitude: 46° 44 E). A fiberglass greenhouse was selected during 2010/ 2011 and 2011/2012 seasons, with controlled environment: 26 ± 1°C day/19 ± 1°C night temperature and relative humidity was 75 ± 2% to achieve this research study. The soil type was sand with pH 8.01-8.12, EC 1.88-2.37 dSm^{-1}, and N, P and K concentrations: 0.74-0.25, 0.09-0.03 and 1.02-1.46 meq. L^{-1}, in the first and second seasons, respectively.

Plant materials

'Faridah' tomato cultivar (Golden Valley Seed Company, USA) was used as a scion while 'Unifort' (De Ruiter Seed Company, Netherland) was used as rootstock. Both cultivars belong to the *Solanum lycopersicum* Mill., round type tomato group. The choice of rootstock was determined based on indications of the Seed Company that 'Unifort' is characterized by a similar spectrum of resistance/tolerance to biotic stress (Rumbos et al., 2011). Seeds of the scion were sown 3 days earlier than the seeds of the rootstock to ensure optimum stem diameter between both scion and rootstock at grafting time due to the variations in the growth vigor (Khah et al., 2006). The seeds of scion and rootstock were sown on 1^{st} and 4 Sep., respectively in 96 holes trays filled with peat-based substrate. Tube grafting was applied to seedlings, when the scion had 2 true leaves and the rootstock had 2-3 true leaves. 'Unifort' rootstock was cut at a slant and 'Faridah' scion was cut by the same way. Plastic tube was placed onto the cut end of the 'Unifort'. The cut end of 'Faridah' was then inserted into the tube in direct contact, splicing the two cut surfaces together (Marsic and Osvald, 2004). Grafted seedlings were kept for 7 days under controlled conditions (90-95% RH, 24-26°C and 45% shading) to enhance the survival rate. They were shifted to the greenhouse on 14 Sep., 10 days after sowing. Un-grafted seedlings (control plants) were produced at the same nursery under identical conditions and were planted in the greenhouse at the same time.

Experimental design

The experiment lay out was split-plot in a randomized complete block design. Grafting methods were allocated in the main plots and irrigation level treatments were distributed in the sub-plots, with 4 replications. The sub-plot area occupied 8 m^2, which contained 16 plants. The plants were placed in rows 1.0 m apart, and the plant distance was 0.5 m within the rows. The plant trained to one main stem, grown upright in the greenhouse and supported by a high transversal wires system.

Irrigation level treatments

Uniform and optimal irrigation water was supplied through drip irrigation system for 10 days after transplanting to encourage root system establishment. Then, four irrigation water treatments were applied towards the end of experiment based on crop ETc. These treatments were: lower level (WL1 = 40%), medium level (WL2 = 60%), moderate level (WL3 = 80%) and higher water level (WL4 = 100%). The WL4 represents a full irrigation water requirement and considered as a control treatment. The irrigation scheduling scheme was based on pan evaporation because of its simple and easily accessible inside greenhouse (Locascio and Smajstrla, 1996). The total period of the irrigation treatments was 210 days, and the total quantity of water applied was 1440, 2160, 2880 and 3600 m^3 ha^{-1} for irrigation treatments WL1, WL2, WL3 and WL4, respectively.

Agricultural practices

Common agricultural practices like fertilizers application, insects and diseases control were adopted. Harvest-ripe fruits were manually picked and weighed twice a week, started on 3 December and continued until the end of experiment.

Data recorded

At 70 days after transplanting, plant growth traits, namely stem length, leaf area using a Portable Area Meter (LI-COR model 3000A), vine fresh and dry weights were measured. Vine dry weight samples (each about 50 g) were determined by drying at 70ºC until constant weight, using a forced-air oven.

Fruit set (%), fruit number and average fruit weight $plant^{-1}$, early yield (the first five harvests) and the total yield (all the collected fruits) were determined. Samples of 5 ripe fruits (from the third-fourth trusses) representing each sub-plot were picked for analysis of the fruit quality traits; dry weight (g), total soluble solids (TSS, %), vitamin C (mg 100 g^{-1} fw), titratable acidity (TA, %) and total sugars (TS, %). An extract was obtained by blending and filtering flesh of each fruit sample. TSS (%) was deliberated using a digital moveable refractometer (PR-101 model, ATAGO, Japan). For determination TA, 10 g of extracted juice was taken and carefully mixed with 50 ml of distilled water. The mixture was then titrated by 0.1 N NaOH until a pH value reached 8.1. The volume of the sodium hydroxide added to the solution, was multiplied by a correction factor of 0.064 to estimate TA as the percentage of citric acid equivalents in the fruit juice (Turhan and Seniz, 2009). Vitamin C (mg 100 g^{-1} fw, as ascorbic acid) was measured in tomato extract using 2,6 dichlorophenol-indophenol dye (Patane et al., 2011). TS content (%) was also determined following AOAC (1995) methods.

Yield reductions and water saving determination

The reductions in the total fruit yield and water saving was calculated using the following equations as described by Ismail (2010):

Reduction in fruit yield = 100 - (yield of WL1, WL2 or WL3/WL4 x 100)

Water saving = 100 - (water consumption of WL1, WL2 or WL3/WL4 x 100).

Where: WL4 = a full irrigation water requirement (control treatment).

Water-use efficiency (WUE)

WUE values were calculated from total fruit yield (kg ha^{-1}) and total irrigation water applied (m^3 ha^{-1}) as indicated by Lovelli et al. (2007).

Statistical analysis

Analysis of variance (ANOVA) was established to determine any statistically significant differences using a SAS version 8.1 computer program (SAS, 2008). The means were separated through a revised least significant difference (LSD) test at the 0.05 level (Steel and Torrie, 1980).

3. Results and discussions

Vegetative growth traits

'Faridah' plants grafted on 'Unifort' were more vigorous, as shown by the taller stem length, higher leaf area, heavier vine fresh and dry weights compared with un-grafted 'Farida' plants (Table 1). These results are in accordance with the findings of Lee (1994), Khah et al. (2006) and Karaca et al. (2012), who found that grafted plants were taller and more vigorous than un-grafted plants. The effect of grafting on tomato growth traits indicated fitting interaction between scion and rootstock. Grafted 'Farida' onto 'Unifort' plants had a higher accumulation of dry weight in aerial plant parts than un-grafted plants. Romano and Paratore (2001) reported that the dry weight of the aerial organs of grafted tomato plants (‘Rita x Beaufort’) was greater than that of the self-rooted plants.

Significant differences in vegetative growth traits; stem length, leaf area, vine fresh and dry weights were detected among irrigation water levels (Table 1). The superior vegetative growth was obtained with the highest irrigation level (WL4, 100% ETc) followed by moderate water level (WL3, 80% ETc). Meanwhile, the lowest irrigation level (WL1, 40% ETc) recorded the lowest vegetative growth traits. The enhancement in vegetative growth by increasing irrigation level may be attributed to the appropriate balance of moisture content in plant tissues. This moisture balance creates promising conditions for nutrient uptake, photosynthesis and metabolites translocation, which eventually hastened the rate of plant growth (Ezzo et al., 2010). These results are in harmony with El-Zeiny and Ibrahim (2006) who illustrated that tomato plants grown with 80% and 100% ETc provided the vigorous growth compared to lower irrigation level (40% of the calculated water requirement).

Fruit yield and its components

Average fruit weight and number of fruits $plant^{-1}$ in un-grafted tomato plants ('Faridah') were statistically lower than the corresponding values for grafted 'Faridah' plants onto 'Unifort' rootstock (Table 2). Similar results were obtained by Khah et al. (2006), Turhan et al. (2011) and Echevarria et al. (2012), who reported that grafted tomato plants produced bigger fruits and more number of fruits than un-grafted ones. Rouphael et al. (2010) affirmed that average fruit weight and size of Solanaceous fruits are often affected by grafting and it is a fundamental constituent for total fruit yield. The early and total fruit yield was higher by 14.64-20.25% and 11.90-12.41% in grafted tomato than in un-grafted. Grafting 'Faridah' plants onto 'Unifort' hastened fruit formation as a result of increasing early fruit yield (Table 2). Khah (2011) found that the grafted eggplant plants had earlier flowering than un-grafted (control plants), which lead to higher proportion (% flower to fruit) of fruit setting (for the first four sets of flowers) and bigger production during the primary period, under either greenhouse or open field conditions. Fruit earliness is a great advantage for the growers since it increases market profits (Alexopoulos et al., 2007). The lower fruit yield of un-grafted plants was accredited to a reduction in average fruit weight and number of fruit $plant^{-1}$ (Table 2). On the other hand, the highest fruit yield of the tomato 'Faridah' grafted onto 'Unifort' was probably attributed to the vigorous root system of the 'Unifort' rootstock (Rumbos et al., 2011). In general, vigorous root system of the rootstock permits grafted vegetable plants to absorb water and nutrients more efficiently than the scion roots as reported by several authors (e.g., Lee, 1994, Marsic and Osvald, 2004, Oztekin et al., 2009 and Khah, 2011).

It is well established that fruit yield and its components; fruit set, number of fruits, fruit weight, early and total fruit yield decrease with increasing water stress (Table 2). From perspective of fruit set and number of fruits $plant^{-1}$, the highest negative effect was observed when the lowest irrigation level (40% ETc) was applied. Similarly, Losada and Rincon (1994) found that water stress strictly affected fruit set and fruit number. Fruit number $plant^{-1}$ ranged between 30.0 and 49.4 according to the applied irrigation levels (Table 2). The highest fruit number with the highest water level may be derived from the highest produced flower $plant^{-1}$. Kere et al. (2003) indicated that high flowers number obtained with high irrigation level is due to adequate moisture available to the flowers, which reduced flowers abortion. Difference in fruit weight between higher and lower irrigation levels was remarkable, though the treatment WL4 (100% ETc) produced about double weight values (161.0-161.8 g) comparing with fruit weight values (84.2-84.3 g) of WL1 (40% ETc) treatment. This finding is expected since the potential tomato fruit weight relies mainly on the rate of water accumulation because water accounts for 94-95% of the total fruit fresh weight (Turhan and Seniz, 2009). The total fruit yield varied widely from 91.000 to 154.500 t ha^{-1}, in the year 2010/2011 and from 96.750 to 160.000 t ha^{-1}, in the year 2011/2012 with different irrigation water level treatments. The highest yield (154.500-160.000 t ha^{-1}) was recorded in the control treatment (WL4, 100% ETc) followed by (151.000-156.000 t ha^{-1}) of the WL3 (80% ETc) treatment. The highest potential reduction in the fruit yield (39.5-41.1%) was recorded with the lowest water treatment (40% ETc). However, the moderate water level (80% ETc) resulted in the lowest reduction (2.3-2.5%) in the fruit yield compared with control treatment (100% ETc). These results indicated that the moderate irrigation level saved about 16.7% of water supplied with slight reduction in fruit yield. This low percentage of yield reduction detected under WL3 treatment is acceptable for the farmer since it was accompanied with saving roughly 20% of applied irrigation water. This finding can support the viewpoint of Patane et al. (2011) that under water shortage in arid and semi-arid areas, maximizing water use is considered more valuable to the farmer than maximizing crop yield.

Table 1. Influence of grafting and irrigation level treatments on vegetative growth traits of tomato plants during 2010/2011 and 2011/2012 growing seasons

Treatments	Stem length (cm)		Leaf area (cm²)		Vine fresh weight (g)		Vine dry weight (g)	
	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012
(a) Grafted tomato plants								
Grafted	203.3 a	199.3 a	8284.7 a	8192.1 a	1450.5 a	1440.4 a	191.5 a	190.1 a
Un-grafted	197.0 b	194.2 b	7923.8 b	7476.8 b	1408.2 b	1398.9 b	181.7 b	179.1 b
(b) Irrigation water levels								
WL1 (40% ETc)	184.6 d	182.0 d	6087.9 d	6021.1 d	1327.1 d	1318.1 d	152.6 d	153.0 d
WL2 (60% ETc)	197.5 c	192.9 c	7515.0 c	7412.3 c	1410.6 c	1399.5 c	176.3 c	173.5 c
WL3 (80% ETc)	207.9 b	204.8 b	9310.1 b	8657.6 b	1483.8 b	1472.4 b	203.2 b	200.2 b
WL4 (100% ETc)	210.5 a	207.3 a	9504.0 a	9446.8 a	1495.9 a	1488.6 a	216.8 a	215.8 a

Means in each column for each treatment followed by different letters are significantly different using revised LSD at 0.05 level.

Table 2. Influence of grafting and irrigation level treatments on yield and its components of tomato plants during 2010/2011 and 2011/2012 growing seasons

Treatments	Fruit set (%)		Fruit number		Fruit weight (g)		Early yield (ton ha^{-1})		Total yield (ton ha^{-1})	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
(a) Grafted tomato plants										
Grafted	89.8 a	78.8 b	44.5 a	46.1 a	156.8 a	157.4 a	33.039 a	36.349 a	140.375 a	145.750 a
Un-grafted	89.2 a	87.6 b	39.9 b	41.4 b	155.9 b	156.6 b	27.474 b	31.707 b	124.875 b	130.250 b
(b) Irrigation water levels										
WL1 (40% ETc)	53.1 d	80.6 d	30.0 c	31.7 c	151.4 d	152.4 d	23.441 c	26.348 d	91.000 d	96.750 d
WL2 (60% ETc)	63.0 c	86.3 c	43.3 b	44.9 b	154.5 c	155.0 c	28.863 b	32.571 c	134.000 c	139.250 c
WL3 (80% ETc)	74.5 b	92.5 b	47.5 a	49.0 a	158.6 b	158.9 b	34.303 a	38.046 b	151.000 b	156.000 b
WL4 (100% ETc)	85.0 a	94.2 a	48.0 a	49.4 a	161.0 a	161.8 a	34.419 a	39.148 a	154.500 a	160.000 a

Means in each column for each treatment followed by different letters are significantly different using revised LSD at 0.05 level.

Fruit quality

Fruits of tomato 'Faridah' grafted onto 'Unifort' tended to have higher values of vit. C, TA and TS compared with 'Faridah' fruits. Dry weight and TSS were insignificantly different (Table 3). Compared with un-grafted fruits, grafted fruits accumulated higher vit. C content. This finding agrees with Balliu et al. (2008) who recorded higher vit. C in grafted fruits compared to un-grafted. The highest vit. C content was found in the 'Faridah' grafted onto 'Unifort' fruits (25.0-24.9 mg 100 g^{-1} fw) and the lowest values were found in 'Faridah' fruits (23.4-23.1 mg 100 g^{-1} fw). The vit. C values detected in this study were higher than that recorded by Turhan et al. (2011). They found that the highest vit. C content (17.81 mg 100 g^{-1} fw) was found in the tomato 'Yeni Talya' fruits, and the lowest value (7.84 mg 100 g^{-1} fw) was found in 'Beril' grafted onto 'Arnold' fruits. Generally, the average vit. C content in tomato fruits is 8-119 mg 100 g^{-1} fw, and it may fluctuate among tomato cultivars and species (Atherton and Rudich, 1986). Both TA and TS contents were also significantly affected by grafting. The highest TA value was detected in grafted tomato fruits. The TA values ranged from 0.56-0.57% (Table 3). Lower values (0.22-0.40%) were recorded in fruits of 33 different tomato genotypes (Turhan and Seniz, 2009). The obtained results agree with those reported by Flores et al. (2010) and Turhan et al. (2011). Their results revealed that rootstock improved the TA of grafted tomato fruits.

Lower water level treatment (WL1, 40% ETc) reduced fruit dry weight, but it improved other fruit quality traits; vit. C, TA, TSS and TS (Table 3). These results might be explained on the basis that the reduction of fruit size under water stress (WL1) was attributed to the reduction of water content rather than to the reduction of assimilates introduced to the fruit (Ho, 1996). This observation might explains why fruit chemical composition under water stress treatment (WL1) is high than higher water level treatments. The heaviest fruit dry weight (> 10 g) was derived from the plants of WL4 (100% ETc), while other water treatments reduced fruit dry weight. The means of vit. C and TA in the fruit ranged from 21.0-27.8 mg 100 g^{-1} fw and 0.52 to 0.63%, in that order. Differences in vit. C and TA were significantly higher with water stress treatment (WL1, 40% ETc) as compared to WL4 (100% ETc) treatment (Table 3). Similar results were obtained by Patane et al. (2011) who reported that vit. C and TA contents augmented with limited irrigation level (50% ETc) as compared with full water level (100% ETc). Favati et al. (2009) indicated that water shortage positively affect vit. C content in processing tomato. The largest the tomato fruit, the lowest the vit. C content. The higher TSS content under stress water treatment is vital for processing industry, since it is recognized how tomato with high TSS content improves processing efficiency through it needs less energy to evaporate water from fruit (Johnstone et al., 2005 and Favati et al., 2009).

Interaction effects

Vine fresh weight, fruit fresh weight, total yield and fruit quality (vit. C and TA) were significantly affected by grafting and irrigation level combination, with clear significant grafted tomato plants x irrigation level interaction (Table 4). In both grafted and un-grafted plants, vine fresh weight, fruit fresh weight, total yield, vit. C and TA increased with response to an increase in water level. The lowest yield values (84.000-89.500 t ha^{-1}) were detected with un-grafted tomato 'Faridah' plants under water stress treatment (WL1, 40% ETc). Nevertheless, grafted 'Faridah' plants onto 'Unifort' under the control water level (WL4, 100% ETc) gave the highest fruit yield (166.000-171.000 t ha^{-1}) in both seasons. Tomato grafted plants under higher water level (WL4) exhibited a 97.6% increase in total yield compared to un-grafted plants under lower water level (40% ETc) in the first season, and a 91.1% increase for the second season as a result of increasing fruit weight and number of fruits $plant^{-1}$ (Table 2). Similar finding was attained by Fernandez-Garcia et al. (2004) who reported that tomato fruit yield increased in grafted plants under well-watered and this increase was primarily associated with increasing mean fruit weight and number of fruits $plant^{-1}$. On the other hand, the lowest fruit yield obtained in un-grafted plants under lower water level was probably attributed to that the potential water deficiency produced smaller fruit size with lighter weight as a result of formed small and poor root system (Lee, 1994). Thus, the results of the influence of grafting tomato plants signified that grafting improved vigorous root system, chiefly under available water irrigation, which in turn enhances growth promotion and increases yield.

The interaction effect between grafting and water levels on vit. C and TA contents showed maximum values with grafting tomato fruits under water stress treatment (WL1, 40% ETc), followed by un-grafted tomato fruits with the same treatment (WL1). On the other hand, the minimum value of vit. C content was detected with un-grafted plants under the highest water level (WL4, 100% ETc), followed by grafted plants under the same WL4 treatment (Table 4). This result could be attributed to the maximum foliar growth resulted in grafted and un-grafted plants that received full water (100% ETc) may cause a suitable cover and shading for fruits (Patane et al., 2011). In this respect, Gautier et al. (2009) exhibited reduction in vit. C for shaded tomato fruits through ripening, since vit. C synthesis depends on exposure to the light (Venter, 1977). Likewise, Abdel-Razzak et al.

(2013) found a positive relationship between fruit quality in terms of vit. C of cherry tomato plants pruned to one-branch under the water stress level (40% ETc) compared to the plants pruned to double branches with the same water level.

Yield enhancement and water saving

According to the interaction data, there were clear combinations between grafting and irrigation levels, resulting in yield enhancement. Grafted 'Faridah' plants onto 'Unifort' + the highest water level (WL4, 100% ETc) gave the maximum yield (14.8-16.1%) higher than control treatment (un-grafted 'Faridah' plants + the highest water level) (Table 5). However, un-grafted 'Faridah' plants + water stress treatment (WL1, 40% ETc) led to the maximum reduction (39.9-41.3%) in yield. This result was not the case of Proietti et al. (2008) who found a lack of interaction between grafting and irrigation rate on yield of mini-watermelon. In general, the decrease in water amount applied throughout the growing season has an adverse influence on yield. The greatest reduction in yield arises when there is a continuous water lack until the date of the first pick (Sezen et al., 2006 and Ismail, 2010). On the other hand, grafted 'Faridah' plants onto 'Unifort' + the moderate water level (80% ETc) led to 10.7-11.9% increase in yield. However, un-grafted 'Faridah' plants under the same water level led to yield reduction (Table 5). Thus, grafting + moderate water level might have a positive impact on tomato production under greenhouse conditions.

Water use efficiency (WUE)

The WUE is the relative of the total yield to the total irrigation water amount applied (Lovelli et al., 2007). The WUE values related to the grafting, water irrigation levels and their combination treatments are presented in Figures 1, 2 and 3.

Table 3. Influence of grafting and irrigation level treatments on fruit quality of tomato plants during 2010/2011 and 2011/2012 growing seasons

Treatments	Dry weight (g)		Vit. C (mg 100 g^{-1} fw)		TA (%)		TSS (%)		TS (%)	
	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012
(a) Grafted tomato plants										
Grafted	9.36 a	9.44 a	25.0 a	24.9 a	0.569 a	0.571 a	5.9 a	6.0 a	3.72 a	3.80 a
Un-grafted	9.33 a	9.39 a	23.3 b	23.1 b	0.562 b	0.566 b	5.8 a	5.9 a	3.68 b	3.71 b
(b) Irrigation water levels										
WL1 (40% ETc)	8.50 d	8.42 d	27.8 a	27.3 a	0.622 a	0.635 a	6.6 a	6.5 a	3.92 a	4.12 a
WL2 (60% ETc)	9.04 c	8.83 c	25.8 b	25.6 b	0.566 b	0.567 b	6.1 b	6.1 b	3.74 b	3.80 b
WL3 (80% ETc)	9.82 b	9.71 b	24.1 c	23.6 c	0.557 c	0.555 c	5.6 c	5.5 c	3.60 c	3.61 c
WL4 (100% ETc)	10.60 a	10.54 a	21.0 d	21.5 d	0.539 d	0.523 d	5.3 d	5.1 d	3.49 d	3.50 d

Means in each column for each treatment followed by different letters are significantly different using revised LSD at 0.05 level.

Table 4. Interaction effects between grafting and irrigation water level treatments on vine fresh weight, fruit fresh weight, total yield and fruit quality (vit. C and TA) traits of tomato plants during 2010/2011 and 2011/2012 growing seasons

Grafted treatments	Irrigation level treatments	Vine fresh weight (g)		Fruit weight $plant^{-1}$ (g)		Total yield (ton ha^{-1})		Vit. C (mg 100 g^{-1} fw)		TA (%)	
		2010/2011	2011/2012	2010/2011	2011/2012	2010/2011	2011/2012	2010/2011	2011/2012	2010/2011	2011/2012
Grafted (Faridah + Unifort)	WL1 (40% ETc)	1344.8 e	1335.8 f	152.0 e	153.0 e	98.000 f	104.000 g	27.8 a	27.5 a	0.627 a	0.636 a
	WL2 (60% ETc)	1428.3 c	1416.0 d	155.8 c	155.3 d	137.500 d	143.000 e	26.5 b	26.8 a	0.566 b	0.571 b
	WL3 (80% ETc)	1510.5 a	1499.0 a	158.8 b	159.8 b	160.000 b	165.000 b	24.3 c	23.8 bc	0.544 c	0.552 c
	WL4 (100% ETc)	1518.5 a	1510.8 a	161.5 a	162.8 a	166.000 a	171.000 a	21.5 d	22.0 d	0.536 cd	0.540 d
Un-grafted (Faridah)	WL1 (40% ETc)	1309.0 f	1300.5 g	150.8 e	151.8 e	84.000 g	89.500 h	27.6 a	27.0 a	0.625 a	0.629 a
	WL2 (60% ETc)	1393.0 d	1383.0 e	153.3 d	154.8 d	130.500 e	135.000 f	26.0 b	24.5 b	0.561 b	0.562 b
	WL3 (80% ETc)	1457.0 b	1445.8 c	157.5 b	158.0 c	142.000 c	147.000 d	24.0 c	23.5 c	0.533 d	0.544 cd
	WL4 (100% ETc)	1473.3 b	1466.5 b	161.0 a	160.8 b	143.000 c	149.000 c	20.5 d	21.0 d	0.501 e	0.511 e

Means in each column for each treatment followed by different letters are significantly different using revised LSD at 0.05 level.

(a) Influence of grafting

The WUE in the grafted tomato plants increased by 12.29% and 11.85% in the first and second seasons, respectively compared with those of un-grafted ones (Figure 1), even though grafted and un-grafted treatments were supplied with the same amounts of water. Thus, it is possible to improve the WUE using grafting technique in tomato production. This result supports the finding of Schwarz et al. (2010) who indicated that to reduce losses in production and to improve WUE under water shortage conditions in high-yielding genotypes like tomato would be grafting them onto suitable rootstocks able for reducing the effect of water stress on the plant shoots.

(b) Influence of water irrigation levels

Linear regression equations relating WUE with applied irrigation levels were tested, and a strong relationship (R^2 = 0.90-0.94) between the WUE and irrigation level treatments was detected (Figure 2). In general, when the lower the level of irrigation water applied the lower tomato production with the higher the water use efficiency was happened. Total yield significantly reduced with the decreases in irrigation water level, which resulted in increased WUE. The WUE increased with the lowest irrigation water level (40% ETc) by 30.1% and 30.5% more than control treatment (100% ETc) in the first and second seasons, respectively. The results achieved in this study are parallel with those of Abdel-Razzak et al. (2013) in the cherry tomato plants.

(c) Combined effect of grafting and irrigation levels

There was clear interaction between grafting and irrigation water level treatments for WUE (Figure 3). The WUE value ranged from 39.71 kg m^{-3} to 59.58 kg m^{-3} depending on the interaction treatments. The highest WUE value of 57.26-59.58 kg m^{-3} was recorded in grafted tomato plants under water stress treatment (WL1, 40% ETc). However, the lowest WUE value of 39.71-41.38 kg m^{-3} was recorded in un-grafted plants under the highest water level WL4 (control treatment, 100% ETc) in the first and second seasons, respectively. Generally, WUE of the various irrigation level treatments tended to increase with grafted tomato plants under low level of irrigation water applied (Figure 3). Un-grafted treatment had the lowest WUE value due to the high irrigation water levels applied, and also due to the lower total yield (Table 2).

Conclusions

The positive effect of the 'Unifort' rootstock on plant growth and productivity in addition to increase WUE allows more consideration on the feasibility of grafting technique as a helpful alternative method for production tomato cultivars grown under greenhouse conditions. It is possible to increase tomato production, improve the WUE with saving water irrigation throughout grafting technique. It is recommended that grafted tomato plants under a moderate irrigation level (80% ETc) can conserve about 20% of irrigation water applied, but accepted with slight reduction in the total yield (0.7-1.3%) under greenhouse conditions. In conclusion, grafting method resulted in a net benefit (saving about 20% of water applied) and this aspect is chiefly vital in arid areas, where water scarcity is an increasing concern and water costs are continually raising.

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Table 5. Potential tomato yield reduction (%) and water saving (%) due to the interaction between grafting and irrigation water level treatments during 2010/2011 and 2011/2012 growing seasons

Treatments	First season 2010/2011					Second season 2011/2012		
	Total yield ($t\ ha^{-1}$)	Yield ratio to control treatment (%)	Yield increase reduction (%)	Water saving (%)	Total yield ($t\ ha^{-1}$)	Yield ratio to control treatment (%)	Yield increase reduction (%)	Water saving (%)
Grafted x WL1	98.000	68.53	- 31.47	50	104.000	69.80	- 30.20	50
Grafted x WL2	137.000	96.15	- 3.85	33.33	143.000	95.97	- 4.03	33.33
Grafted x WL3	160.000	111.89	+ 11.89	16.67	165.000	110.74	+ 10.74	16.67
Grafted x WL4	166.000	116.08	+ 16.08	0	171.000	114.76	+ 14.76	0
Un-grafted x WL1	84.000	58.74	-41.26	50	89.500	60.07	-39.93	50
Un-grafted x WL2	130.500	91.26	- 8.74	33.33	135.500	90.95	- 9.06	33.33
Un-grafted x WL3	142.000	99.30	- 0.70	16.67	147.000	98.66	- 1.34	16.67
Un-grafted x WL4	143.000	100	0	0	149.000	100	0	0

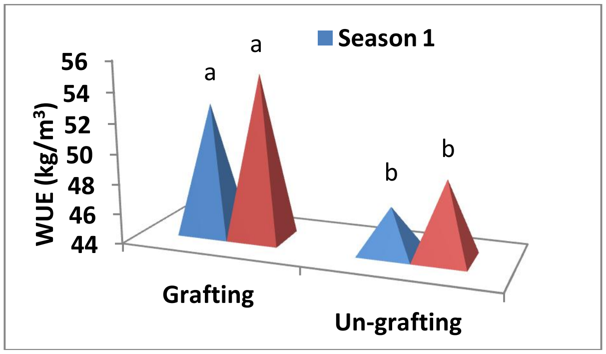

Figure 1. Influence of tomato grafting methods on WUE during seasons of 2010/2011 and 2011/2012.

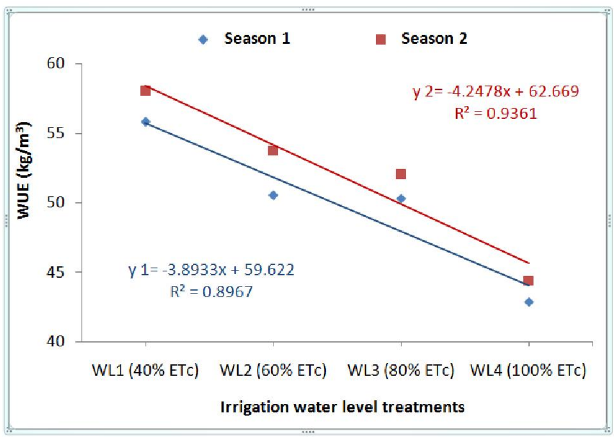

Figure 2. Influence of irrigation water level treatments on WUE during seasons of 2010/2011 and 2011/2012.

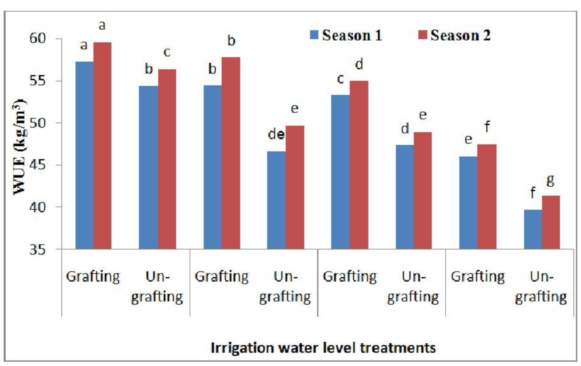

Figure 3. Influence of combinations between grafting methods and irrigation water level treatments on WUE during seasons of 2010/2011 and 2011/2012.

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