Assessing Tomato Yield and Water Saving under Deficit Irrigation in Jordan Valley

Rami A. Al-Qerem1, Ayman A. Suleiman2, Mohammed R. Shatanawi2

ABSTRACT

An open-field tomato crop experiment was conducted in 2007 in Jordan Valley to assess the impact of regulated deficit irrigation (RDI) practice on tomato yield and quality, and crop evapotranspiration. The experiment included three treatments, in which the first treatment received 100% of the crop water requirement during the entire season (T1) which was 125 days. The second and third treatments (T2 and T3) received similar irrigation amounts to that of T1 for the first 55 days of the growing season starting from transplanting until the end of the flowering stage, after which T2 and T3 received 80% and 60% of T1, respectively, until the end of the growing season. The root zone depletion analyses for T3 showed that tomato was under water stress after 75 days of planting, while water stress took place after 85 days for T2, and there was no significant water stress on T1. Total yield of tomato was 88.4, 85.6 and 74.3 ton ha\(^{-1}\) for T1, T2 and T3, respectively. There were no significant differences \((p \leq 0.05)\) between T1 and T2 treatments in yield quantities but T3 was significantly lower than T1. Regarding fruit quality, there was small difference among treatments in fruit size and weight and dry matter among treatments. Fruit total soluble solids were significantly different among treatments and was highest for T3. From these results, it can be concluded that T2 with 80% RDI is a good practice because it will save water while sustaining yield and quality.

Keywords: Crop Evapotranspiration, Crop Water Use Efficiency, Deficit Irrigation, Soil Water, Tomato.

INTRODUCTION

Jordan is one of the ten poorest countries in the world in water resources. Due to limited water resources and relatively high population growth rate (2.5% in 2004), the annual per capita share is expected to decrease from 160 m\(^{3}\) in current years to less than 90 m\(^{3}\) by 2025 (Shatanawi et al., 2007). The irrigation share of the total water usage demonstrates a significant decrease during the period from 1985 to 2005 (78% in 1985 to 62% in the year 2005). In absolute figures, irrigation water use has also been reduced from its peak of 726 million cubic meters (MCM) in 1993 to 511 MCM in the year 2003 (MWI-GTZ, 2004). Therefore, any efforts to save water in Jordan are highly appreciated.

The scope for further irrigation development to meet food requirements in the future is severely constrained by the decreasing water resources and the growing competition among the different sectors for water. Therefore, reducing irrigation water without significantly affecting crop production will result in releasing resources for other uses or expanding the irrigated area. In the context of improving water productivity, there is a growing interest concerning deficit irrigation (DI). Deficit irrigation is practice

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whereby water supply is reduced below maximum levels, and mild water stress is allowed with minimal effects on yield. The principles underlying DI can be viewed as an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction (English, 1990). Under conditions of scarce water supply and drought, the DI can lead to great economic gains, in addition to maximize yield per unit of water for a given crop (FAO, 2002). Conventional DI can be divided into two types; first one is sustained DI where DI is practiced during the entire crop cycle, while the second is regulated DI (RDI) where DI is practiced in the non-critical phenological crop stages (Shatanawi et al., 2007).

Deficit irrigation practices in some cases may improve crop productivity and quality more than that of traditional irrigation schemes. In central India, Smout and Gorantiwar (2006) found that onion, wheat, groundnut and sunflower productivity and quality were better for deficit irrigation than for full irrigation. Sarwar and Perry (2002), in a DI study in Pakistan on wheat and rice, reported that supplying the crops with 80% of the crop evapotranspiration showed no significant differences on yield or even salt accumulation in soil profile, but 60% deficit did. In Jordan, Shatanawi et al. (2007) tested DI on lemon trees in the Jordan valley for two years. They found that applying 75% of crop water requirements was generally more efficient than that of full irrigation treatment, and there were no significant alteration on either yield or fruit quality.

Tomato (*Lycopersicon esculentum*) occupies the largest planting area among vegetables in the world (Zegbe et al., 2006). In Jordan, tomato is one of the most important cash crops and has been planted in large areas. In 2007, the total planted area for open field and greenhouse tomato were 10,540 hectares, out of 33,440 hectares of total vegetables planted area in Jordan during the same year (Ministry of Agriculture, 2008). Tomato has relatively high water requirements of 400-600 mm that varies depending on climate (Doorenbos and Kassam, 1979).

Many studies have been conducted to investigate the impact of DI on tomato yield, quality and other parameters, using different irrigation methods (Sammis and Wu, 1986; Guichard et al., 2001; Nakajima et al., 2004; Warner et al., 2004; Topcu et al., 2007). Most researches showed that there was a good potential to save water with only small reduction in total yield (Sammis and Wu, 1986; Obreza et al., 1996). However total solids amount and marketable yield percentage could be altered with DI practices (Warner et al., 2004). The objective of this study was to determine the impact of mild regulated DI on tomato yield, quality and water use efficiency in the Jordan Valley, Jordan.

**2. MATERIALS AND METHODS**

**2.1. Experimental location, design, treatments and management practices**

The experiment was conducted at the University of Jordan Agricultural Research Station in the central Jordan Valley (32° 10' N latitude and 35° 37' E longitude), and altitude of -230 m (below mean sea level) in 2007. The source of irrigation water for the experiments was from King Abdullah’s canal, the average seasonal EC was 2 dS m⁻¹. There were three irrigation levels namely; 100%, 80% and 60% representing T₁, T₂ and T₃, respectively, of crop water requirements (ETc).

Irrigation was applied three times per week unless ETc value was very small; the irrigation event was postponed. Irrigation was added to compensate the estimated ETc in the previous days after the last irrigation with addition of leaching requirements and system efficiency. Deficit irrigation started approximately at the end of flowering stage on 16th of
April because of tomato’s reproductive stage considered as a critical stage for water stress (Wudiri and Henderson, 1985). For the deficit treatments the total amount of calculated full irrigation water requirement treatment was multiplied by 0.8 for T2 and by 0.6 for T3. Irrigation events started manually at the same time for all treatments with different durations by observing installed flow meters reading. The total amount of rainfall during the growing season was approximately 83 mm. The rainfall was mostly concentrated during April with high intensity.

About 31 mm of water was applied before and after transplanting to ensure a suitable environment for the seedling growth. For the first-three weeks after transplanting, tomato was not irrigated to insure good root system establishment. Also transparent plastic tunnels with 60 cm width and 70 cm height were used in the first-two weeks after transplanting to protect the small seedlings from freeze and wind. Tomato crop was fertigated 16 times during the season (out of 34 irrigation events). The total amounts of fertilizers applied for the site were 4.72 kg (157.2 kg ha⁻¹) of nitrogen, 3.06 kg (102 kg ha⁻¹) of P₂O₅, 5 kg (166.7 kg ha⁻¹) of K₂O and 0.02 kg of iron.

A Randomized Complete Block Design (RCBD) was used including three RDI treatments and four replicates. Each plot was 5×5 m, while the area of each block was 75 m². The total planted area was 300 m² with 2 m buffer zone around the four sides of each block and between plots, which made a 690 m² of total experimental area. Tomato seedlings of RS589956 variety were transplanted into the open field on the 21st of January, 2007. This variety has determinate growth habit. A drip irrigation system was used with laterals of 16 mm and pressure compensating drippers with a flow rate of 2.3 liter hr⁻¹ and spacing of 40 cm. The laterals were mulched with 80 cm wide black plastic and 10 cm from each side of the mulch was covered with soil. Row spacing was 125 cm, while the plant spacing was 40 cm. A single row of plants was grown in the middle of the plastic mulch with a single lateral for each row, which made plant density of 17,600 plants ha⁻¹ with 11 plants per row and 44 plants per plot, thus the total number of plants where 528 for the whole experiment.

2.2. Tomato yield and quality parameters
Tomato yield was harvested at three different dates during the growing season; 29th of May and 11th and 25th of June. The total yield weight was recorded for each plot in the field at harvest. A sample of twenty five fruits was randomly picked from each plot at each harvesting time. The fresh and dry weights for the ripe fruits were determined. The dry weight samples were measured as described by Heuvelink (1995) and was only determined for the first harvest samples. The total soluble solids (TSS) was measured as described by Zegbe et al., (2006) using a hand-held 0-50% sugar refractometer instrument (Bellingham and Stanley LTD Tuabaridge wells). Finally, the size of ten fruits was determined for each plot using a graduated cylinder.

2.3. Crop water requirements and irrigation
The reference ET (ET₀) was calculated using the FAO-56 Penman-Monteith equation (Allen et al., 1998). An average value for ET₀ was calculated from two automated metrological stations. The first station was in Der-Alla, which is approximately 10 km north of the experimental location, while the second one was in Al-Karamah, which is 14 km south of the experimental location. The average ET₀ was used to calculate crop evapotranspiration (ETₜ). The two stations supply hourly and daily values of ET₀, using FAO-56 Penman-Monteith equation, which described as follows:

\[
ETₜ = \left(0.408Δ(R_n - G) + \frac{Y(900)}{(1 + 273)(e₁ - e₂)}\right) \left(\frac{1}{(1 + 0.34υ₂)}\right)
\]
where ET₀ is reference evapotranspiration (mm day⁻¹), Rₙ is net radiation at the crop surface (MJ m⁻² day⁻¹), G is soil heat flux density (MJ m⁻² day⁻¹), T is mean daily air temperature at 2 m height (°C), u₂ is wind speed at 2 m height (m s⁻¹), eₛ is saturation vapour pressure (kPa), eₜ is actual vapour pressure (kPa), eₛ - eₜ is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa °C⁻¹), and γ psychrometric constant (kPa °C⁻¹).

The single crop coefficient (Kc) was used to calculate ETc, by multiplying ETc by ET₀. Allen et al. (1998) described in the following equation (described by Allen et al., 1998):

\[ \text{ET}_{c,\text{adj}} = K_c \times K_s \times \text{ET}_0 \]  

where \( K_s \) is a dimensionless transpiration reduction factor depends on available soil water and ranges from 0 (severe stress) to 1 (no stress), and \( \text{ET}_{c,\text{adj}} \) is actual crop evapotranspiration (mm day⁻¹) when crop is under water stress. The \( K_s \) was determined for the three treatments during the growing season and was calculated by the procedure described in Allen et al. (1998) for each day. The \( K_s \) was calculated as:

\[ K_s = (\text{TAW} - D_{r}) / (\text{TAW} - \text{RAW}) = (\text{TAW} - D_{r}) / ((1 - P) \text{TAW}) \]  

where \( D_r \) is root zone depletion (mm), TAW is total available soil water in the root zone (mm), RAW readily available soil water in the root zone (mm), and \( P \) is average fraction of TAW that can be depleted from the root zone before water stress (reduction in ET) occurs.

Root zone depletion was calculated as:

\[ D_{r,i} = D_{r,i-1} - (P R_i - R O_i) - I_i - C R_i + \text{ET}_{c,i} + D P_i \]  

where \( D_{r,i} \) is root zone depletion at the end of day \( i \) (mm), \( D_{r,i-1} \) is water content in the root zone at the end of the previous day, \( i-1 \) (mm), \( P R_i \) is precipitation on day \( i \) (mm), \( R O_i \) is run-off from the soil surface on day \( i \) (mm), \( I_i \) is net irrigation depth on day \( i \) that infiltrates the soil (mm), \( C R_i \) is capillary rise from the groundwater table on day \( i \) (mm), \( \text{ET}_{c,i} \) is crop evapotranspiration on day \( i \) (mm), and \( D P_i \) is water loss out of the root zone by deep percolation on day \( i \) (mm). Both \( R O_i \) and \( C R_i \) were neglected.

Deep percolation was calculated as:

\[ D P_i = (P R_i - R O_i) + I_i - \text{ET}_{c,i} - D_{r,i-1} \geq 0 \]  

The low-quarter distribution uniformity test was done. The distribution uniformity was approximately 95%. The low-quarter distribution uniformity (DU₁₂) was calculated as:

\[ DU_{1q} = \left( \frac{q_n}{q_a} \right) \times 100 \]  

where \( q_n \) is average flow from the lowest one quarter of the emitter, and \( q_a \) is average flow from all emitter.

Potential application efficiency for low-quarter (PAE₁₂) was used to estimate the gross irrigation depth to apply as described by Burt et al. (1997):

\[ \text{PAE}_{1q} = DU_{1q} \times (100 - % \text{ surface losses}) \]  

where the surface losses are applied water losses due runoff and evaporation. These losses were assumed to be zero.

Leaching requirements were calculated according to USDA-National Engineering Handbook (USDA-NRCS,
1987) for localized irrigation (drip irrigation) equation 9 to calculate leaching fraction (LF), where \( EC_i \) is the irrigation water electrical conductivity in dS m\(^{-1} \) and \( EC_{dw} \) is the electrical conductivity of the drainage effluent or the maximum water salinity that tomato can tolerate, which equal to 12.5 dS m\(^{-1} \) as reported in USDA-NRCS (1987), that makes LF approximately equal to 15%.

\[
LF = \frac{EC_i}{EC_{dw}}
\]  

(8)

Irrigation requirements were calculated using equation 9.

\[
IR = \sum_{i=1}^{n} \frac{ET_{dl}}{[(1 - LF) \times PAE_{eq}]}
\]  

(9)

where IR is irrigation requirements (mm), and \( n \) number of days after the last irrigation.

The crop water use efficiency (WUE) was calculated as described by Shatanawi et al. (2007). The total yield of fresh weight is divided by the seasonal irrigation and the total rainfall during the season.

### 2.4. Soil physical properties and soil water content measurements

Three soil profiles were randomly made in the study area to measure soil properties. Soil texture was determined using the pipette method (Gee and Bauder, 1986) at 12.5, 27.5, 42.5, 57.5, 72.5 cm and 92.5 cm depths for each of the three soil profiles. Bulk density was determined by core method (Blake and Hartage, 1986) for each depth in the three profiles. Soil water content at pressures of 0.3 and 15.0 bars were determined for disturbed samples from the same pervious locations using ceramic plate extractor. Field capacity and permanent wilting points were considered at 0.3 and 15.0 bars, respectively (Klute, 1986). The soil basic infiltration rate was determined in the field using double ring infiltrometer method in two separate sites in the experimental area as described by Bouwer (1986) (Table 1).

<table>
<thead>
<tr>
<th>Soil layer (cm)</th>
<th>Bulk density (g cm(^{-3} ))</th>
<th>( FC^a ) (cm(^3) cm(^{-3} ))</th>
<th>( FC^b ) (cm(^3) cm(^{-3} ))</th>
<th>PWP (cm(^3) cm(^{-3} ))</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Soil texture class</th>
<th>IR (mm hr(^{-1} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-20</td>
<td>1.74</td>
<td>0.195</td>
<td>0.177</td>
<td>0.126</td>
<td>76.4</td>
<td>11.8</td>
<td>11.8</td>
<td>Sandy loam</td>
<td>67.7</td>
</tr>
<tr>
<td>20-35</td>
<td>1.70</td>
<td>0.187</td>
<td>0.191</td>
<td>0.120</td>
<td>78.1</td>
<td>12.6</td>
<td>9.3</td>
<td>Sandy loam</td>
<td>-</td>
</tr>
<tr>
<td>35-50</td>
<td>1.62</td>
<td>0.180</td>
<td>0.186</td>
<td>0.110</td>
<td>77.3</td>
<td>14.3</td>
<td>8.4</td>
<td>Sandy loam</td>
<td>-</td>
</tr>
<tr>
<td>50-65</td>
<td>1.60</td>
<td>0.175</td>
<td>0.183</td>
<td>0.110</td>
<td>73.9</td>
<td>19.4</td>
<td>6.7</td>
<td>Sandy loam</td>
<td>-</td>
</tr>
<tr>
<td>65-80</td>
<td>1.66</td>
<td>0.121</td>
<td>0.177</td>
<td>0.085</td>
<td>80.7</td>
<td>12.6</td>
<td>6.7</td>
<td>Loamy sand</td>
<td>-</td>
</tr>
<tr>
<td>80-100</td>
<td>1.71</td>
<td>0.105</td>
<td>0.126</td>
<td>0.071</td>
<td>86.5</td>
<td>8.4</td>
<td>5.1</td>
<td>Loamy sand</td>
<td>-</td>
</tr>
</tbody>
</table>

\( ^a \) Field capacity measured in laboratory (ceramic plate extractor).

\( ^b \) Field capacity estimated from field observations

Soil water content was determined with nuclear hydro-probe (Campbell Pacific, model 503). Soil water
content readings were taken at 16 different dates during the crop cycle at 12.5, 27.5, 42.5, 57.5, 72.5 and 92.5 cm soil depths in three plots, one from each treatment. The plots contained three steel access tubes that were installed at 0, 30 and 60 cm from the row center horizontally. The access tubes were 120 cm in length, 5 cm inner diameter and 0.5 cm wall thickness.

2.6. Statistical analysis

Statistical analysis of treatment effects on yield quantities, fruits volume, fruits number and fruit total soluble solids was performed using SAS repeated measures Mixed Model procedure. The repeated measures Mixed Model procedure is used when you have data from a running time (period of a growing season), but WUE and fruit dry matter were analyzed by general linear model procedure which was based on total yield data (SAS, 1998). The means were separated using the least significant difference (LSD) mean separation test at $\alpha = 0.05$.

3. RESULTS AND DISCUSSION

3.1. Tomato crop under full and deficit irrigation

The seasonal FAO-56 ET$_0$ for the experimental site was 605 mm and the crop ET (ET$_c$) for optimal full growth tomato was 405 mm, calculated based on the estimated crop coefficient (K$_c$) assuming no effect of soil water stress on the crop ET (Table 2). Table 2 illustrates also the seasonal applied irrigation and actual monthly applied irrigation for the different treatments. The seasonal percentage of irrigation water saving was 19.1% and 35.4% for T$_2$ and T$_3$, respectively.

<table>
<thead>
<tr>
<th>Month</th>
<th>T$_1$</th>
<th>T$_2$</th>
<th>T$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>February (mm)</td>
<td>31.0</td>
<td>31.0</td>
<td>31.0</td>
</tr>
<tr>
<td>(pre-transplanting)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>March (mm)</td>
<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>April (mm)</td>
<td>93.6</td>
<td>82.7</td>
<td>64.1</td>
</tr>
<tr>
<td>May (mm)</td>
<td>196.6</td>
<td>143.1</td>
<td>107.7</td>
</tr>
<tr>
<td>June (mm)</td>
<td>120.9</td>
<td>96.1</td>
<td>74.1</td>
</tr>
<tr>
<td>Seasonal irrigation (mm)</td>
<td>467.0</td>
<td>377.9</td>
<td>301.9</td>
</tr>
<tr>
<td>WS (%)</td>
<td>0.0</td>
<td>19.1</td>
<td>35.4</td>
</tr>
<tr>
<td>Seasonal adjusted ET$_c$ (mm)</td>
<td>400.4</td>
<td>353.4</td>
<td>240.7</td>
</tr>
</tbody>
</table>

The stress coefficient (K$_s$) indicated that there was no significant water stress on the tomato crop during the
first 75 days after transplanting for all treatments since they got the same amount of irrigation for the first 55 days after transplanting (Figure 1). After approximately 75 days of transplanting water stress started to appear in T3 treatment and approximately after 85 days water stress started to appear in T2 treatment. For T1 some water stress was observed only at the end of the season. Withholding irrigation in the first-three weeks after transplanting did not indicate a serious water stress in tomato because ETc was relatively low due to low evaporation of the partially mulched soil and low transpiration due small leaf area index. That is why only slight drop in Ks values were observed during that period. For T3 the Ks values in many days reached zero, which indicated a sever water stress and the plants could not extract any quantity of water from the soil. For T3, the average Ks values during DI practiced were approximately 0.6 thus affecting crop ET dramatically. The Ks value did not exceed 0.7 when mild water stress on T1 treatment occurred at the end of the season. This was expected since most of the fruits were already mature or harvested at the end of the late season stage.

![Figure 1. Water stress coefficient (Ks) for the different treatments.](image)

Table 2 shows the total values of the adjusted crop ET based on the Ks calculations. Comparing these values with optimal calculated crop ET for tomato at the same period makes it obvious that total crop ET for T3 was heavily affected. T2 was moderately altered while T1 had only very small alteration. Figure 2 presented a 10-day adjusted ET values (actual ET) for all treatments and for reference ET. The full irrigated treatment had ET close to ETc which indicates that tomato crop was growing normally with a minimum reduction of crop transpiration. On the other hand, T2 and T3 had poor relation with ETc after RDI was practiced indicating that transpiration was lower than ET0 especially T3.
Total fresh yield weight for T1, T2 and T3 was 88.42, 84.58 and 74.30 ton ha$^{-1}$, respectively (Table 3). There was a significant difference ($p \leq 0.05$) between T1 and T3 in total yield. The tomato yield obtained is higher than those locally obtained in Jordan. Deek et al. (1997) reported a yield between 51.4 and 35.3 ton ha$^{-1}$, which was obtained under three irrigations events per week with 504 mm total water supply, and under irrigation once a week with 353 mm total water supply, respectively, for open field tomato in the Jordan Valley. The experimental tomato yield was lower than that reported for other regions. Tei et al. (2002) observed total yield between 100 and 180 ton ha$^{-1}$, in central Italy. It is well-known that tomato yield may differ for varied cultivars. Also yield varies from year to year depending on the season climatological condition and many other factors such as soil fertility.

The least water use efficiency (WUE) was for T1 with a value of 160.7 kg ha$^{-1}$ mm$^{-1}$, while the values for T2 and T3 were 185.6 and 193.0 kg ha$^{-1}$ mm$^{-1}$, respectively (Table 3). T1 WUE was significantly lower ($p \leq 0.05$) than both of T2 and T3 treatments. Shrivastava et al. (1994) investigated WUE for field grown tomato grown under plastic mulch in India for three irrigation levels (0.4, 0.6 and 0.8 fractions of the pan evaporation). The highest WUE value of 190 kg ha$^{-1}$ mm$^{-1}$ was obtained for the lowest irrigated treatment with 0.4 of the pan evaporation and. The WUE for the two irrigation levels were 95 and 76 kg ha$^{-1}$ mm$^{-1}$ for 0.6 and 0.8 of the pan evaporation fraction levels, respectively. These results were in agreement with the findings of this study. Furthermore, the irrigation amounts were the main factor for the differences between the treatments because the effective rainfall amounts were minimal.
Table 3. Tomato total yield, fruit average fresh weight (FFW), fruit average volume (FAV), total soluble solids (TSS), average fruit dry matter (FDM) and water use efficiency (WUE), for full irrigated treatment (T1) and the two treatments under regulated deficit irrigation (T2 and T3).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Yield (ton ha(^{-1}))</th>
<th>FFW (g)</th>
<th>FAV (cm(^3))</th>
<th>TSS (%)</th>
<th>FDM (%)</th>
<th>WUE (kg ha(^{-1}) mm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>88.41a</td>
<td>105.13</td>
<td>108.6</td>
<td>4.09a</td>
<td>4.73</td>
<td>160.6a</td>
</tr>
<tr>
<td>T2</td>
<td>85.58ab</td>
<td>108.39</td>
<td>107.5</td>
<td>4.45b</td>
<td>5.00</td>
<td>185.6b</td>
</tr>
<tr>
<td>T3</td>
<td>74.30b</td>
<td>95.94</td>
<td>96.1</td>
<td>4.96c</td>
<td>5.34</td>
<td>193.0b</td>
</tr>
</tbody>
</table>

Significance (P) 0.0366 0.0812 0.1494 < 0.0001 0.0670 0.0162

Data in columns followed with different letters (a, b and c) are significantly different (p ≤ 0.05) based on LSD mean separation test at α = 0.05 rejection level.

The fruits quality parameters are important for tomato crop marketing. The fruits average volume and total dissolved solids (TSS) were 108.6, 107.5 and 96.1 cm\(^3\) and 4.09, 4.45% and 4.96% for T1, T2 and T3, respectively. The fruit dry matter and fruit average fresh weight were 4.73, 5.00% and 5.34 % and 105.13, 108.39 and 95.94 grams for T1, T2 and T3, respectively. The fruit dry matter and fruit average fresh weight were 4.73, 5.00% and 5.34 % and 105.13, 108.39 and 95.94 grams for T1, T2 and T3, respectively (Table 3). There were significant differences (p ≤ 0.05) between T1 and T2 and T2 and T3 treatments for TSS. Although there were no significances differences for average fruit weight, volume and dry matter percentage among all treatments, there was a noticeable trend in these results. Topcu et al. (2007) found that the full irrigated treatment and conventional DI treatment with 50% less irrigation water did not have significant differences in fruit average volume, fruit dry matter or TSS values. Therefore, the fruit quality results were in normal range.

### 3.2. Soil water contents

During the period when deficit irrigation was practiced (after 55 days of transplanting) varying amounts of irrigation water for different treatments were applied. Figure 3 shows the soil water content for three layers in the soil profile at 0-35, 35-65 and 65-100cm (each layer is an average value of two readings from two sub-layers). Soil water content readings started after 80 days of planting until the end of the season. Soil water contents for T1 and T2 were approximately the same in the first 35 cm of soil profile, while T3 soil water content was much lower. Generally, in the next two layers, there were noticeable differences in soil water content among the three treatments. In first soil layer (0-35 cm) a rapid change in soil water was observed as a result of irrigation, deep percolation, water uptake and evaporation. In the second soil layer (35-65 cm) soil water content changes became steadier but there were evidence of absorption by roots in these layers. Finally, in the third soil layer (65-100 cm), it was noticeable that the soil water content readings were even steadier. This indicated that roots were less in this soil layer.
Soil water content data may help in explaining the severity of water stress among treatments. Figure 4 illustrates soil water content for the root zone along with field capacity (FC), saturated soil water content, permanent wilting point (PWP) and readily available water (RAW). Soil water contents were near FC for all treatments before the RDI was practiced, but after RDI implementation, the T3 soil water content was near PWP. The soil water content of T2 was near the RAW line without any serious water stress. The soil water content of T1 was always higher than RAW. These soil water content readings were in agreement with the crop stress coefficient values, which were very low in the final 30 days of the season for T3, almost zero in some days. These results indicate that using only 60% of ETc for tomato production will result in a very severe water stress, poor quality of lower quantity of yield and may shorten the plant life.
Conclusions and Recommendations
The 80% ETc seems to be the best deficit irrigation strategy with reasonable water saving without serious yield reduction. The 100% ETc treatment had approximately the same yield as the 80% ETc treatment with non significant differences in quality except for the total soluble solid which was higher for the 80% ETc. Also, the WUE for T2 was higher than T1 treatment. The 60% ETc RDI treatment had high water stress and had a significantly lower yield than other two treatments. It can be concluded that the supplemental of only 80% of crop water requirements as a part of RDI practices on tomato crop, is very effective and can save water, which is very critical in Jordan Valley, without any serious drawback on growers’ income.

REFERENCES
Assessing Tomato… Rami A. Al-Qerem, Ayman A. Suleiman, Mohammed R. Shatanawi

363-375), Madison Wisconsin USA, American society of agronomy, Inc. and soil science society of America, Inc.


solids and yield. American society of agricultural and biological engineering, ASAE Annual Meeting Paper No.042094. USA.


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