Effect Of Saline Water On Tomato Under Subsurface Drip Irrigation: Yield And Fruit Quality

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Abstract: In scope of salinity tolerance and management of crops, an experiment was carried out on three tomato cultivars (Solanum lycopersicum, cvs. Rio Tinto, Rio Grande and Nemador) tested for drip irrigation (DI) and subsurface drip irrigation (SDI) to investigate the response on fruit yield and fruit quality. This experiment was set in a silty clay soil, using saline water (6.57 dS.m⁻¹) and applying three irrigation regimes: 100%, 85% and 70% of tomato water requirement. Results show an increase of soil salinity in the case of deficit regime (70% of crop water requirement) and with DI. Tomato was more affected by saline water under deficit regime (70%), DI and the combination of two treatments (deficit irrigation and DI), exhibiting a decrease of the number of flowers, fruits number, fruit size and yield. The significant decrease of these parameters was higher in Rio Tinto and Nemador cultivars compared to Rio Grande cultivar. The adaptive yield response of Rio Grande was more significant in SDI treatment. Additionally a significant increase of the number of fruits affected by blossom-end rot was observed. We also observed an increase of titratable acidity, total soluble solid content and a decrease of pH of fruits in the three cultivars under deficit regime and DI system. Rio Grande appears more adapted to the water deficit and SDI under local conditions of Tunisia.

Keywords: Tomato; saline stress, cultivar, subsurface drip irrigation, Tunisia.

INTRODUCTION

Soil salinity is a major limiting factor that affects about 20% of the irrigated area in the World (FAO, 2005) and about 30% of Tunisian irrigated areas (Hachicha, 2007). In the arid context, salt stress inhibits crops growth and yields. The negative impact of salt excess on plant growth is induced by the combination of three abiotic factors (i) low osmotic potential of the soil solution (water stress) which reduces the availability of water uptake for the plants, (ii) disruption of nutritional balance (iii) and effect on specific ions (salt stress), (Ashraf et al., 1994; Marschner, 1995).

Several works have been carried out to determine the negative impact of salinity on crops growth and yield. Studies in tomato have shown that the increase of salinity in the irrigation water can induce a decrease on both weight of fresh fruits (Sonneveled and Welles, 1988; Li et al., 2001; Mégan et al., 2008) and fruits size (Eltez et al., 2002; Navarro et al., 2002; Mégan et al., 2008); also an increase of blossom-end rot (Tadesse et al., 1999; Rubio et al., 2009; Mégan et al., 2008). Although yield response to salinity is not a unique pattern and it depends on levels of salinity in the irrigation water, varieties, time of exposure to the salt condition and environmental condition. This way, Franco et al. (1993) and Navarro et al. (1999) observed that the decrease of mean weight of fruits was the first parameter of yield decrease rather than the fruit number reduction under the effects of salinity. In spite of these negative aspects, the increase of salinity improves the total soluble solids (TSS), titratable acidity and decreases the pH of fruit juices, as various authors have observed in tomato among others crops (Tuzel et al., 2001; Yurtseven et al., 2005; Mégan et al., 2008) and pepper (Rubio et al., 2009).

There is a general demand to improve crops tolerance to salinity in order to maintain yield levels and plant growth, even under increasing levels of soil salinity. DeMalach and Pasternak (1993) and Claudivan et al. (2005) recommend the selection of tolerant varieties and species to water stress and salt stress. So, Meiri et al. (1992) and Botia et al. (2005) have shown that salt tolerance of melon varies widely and depends on the cultivar and the type of cultivation. In order to reduce salinity effect on crops by hydraulic approaches, several authors have recommended a better management of irrigation water by leaching salts from the root zone (Oron et al., 2002; Shani and Dudley, 2001; Garcia –Sanchez et al., 2003). An inefficient water use induces crop yield decreasing (Antony and Singand hupe, 2004). According to Jaimez et al. (2000), water stress between flowering and fructification generated a reduction of pepper yield. Localized irrigation systems can also reduce evaporation but...
increase the accumulation of salts in the root zone (Al-Omran et al., 2005; Ouled Ahmad et al., 2007). Among these systems, drip irrigation (DI) is more adapted to saline water (Meiri et al., 1992; Dagdelen et al., 2008).

Indeed, it permits an uniform and frequent application of water (Oron and Bilgel, 2002) and direct feeding to the plant at the root level, inducing an increase of yield and saving of water (Bozkurt et al., 2006; Sezen et al., 2008). However, this system can create an accumulation of salts in the soil surface (Pasternak and DeMalach, 1986b; DeMalach and Pasternak, 1993; Osorio and Césped, 2000; Oron et al., 2002; Hachicha et al., 2006). As an alternative to reduce these negative aspects and improve water use efficiency, subsurface drip irrigation (SDI) has been developed (Oron et al., 2002; Romero et al., 2004; Al-Omran et al., 2005). This system, in comparison with DI used with saline water, allowed better yield of squash, according to Al-Omran et al. (2005). The improvement of yield and fruit quality by the use of SDI has also been observed in tomato (Ayars et al., 2001), onion (Enciso et al., 2007), cotton (Detar, 2007), potato (Patel and Rajput, 2007) and bean (Gençoglan et al., 2006).

Tomato is moderately tolerant to salinity (1.3 dS. m⁻¹ < electrical conductivity of saturated soil extract (ECe) < 6 dS. m⁻¹) and is typically cultivated in regions exposed to soil salinization (Maggio et al., 2004). Salts–induced yield reduction, in tomato as well as other typical spring–summer crops of Mediterranean zones, is generally caused by additional environmental constraints beyond salinity, including high temperatures and low relative humidity, which also may contribute to inhibit fruit growth and enlargement (Johnson et al., 1992; Maggio et al., 2004). Besides soil, climatic conditions and technical itineraries, the choice of appropriate cultivars is one of the most important factors of success for the cultivation of processing tomatoes. In Tunisia, as in the other Mediterranean countries, tomato crop is economically the most important vegetable. In 2008, the Tunisian cultivated area of tomato was about 27270 ha. This crop is generally irrigated by drip irrigation. It has become more and more widespread since the beginning of the nineties. Recently, research has been focusing on irrigation techniques like SDI. This work is a part of a series of experiments. In the first step, SDI and DI were used with three water qualities (EC=2.3 dS.m⁻¹ used as a control treatment, EC=4.3 dS.m⁻¹, EC=6.57 dS.m⁻¹) for one tomato cultivar (Heinz-2274) (Kahlaoui et al., in press). In the second step, we have retained only saline water (6.57 dS.m⁻¹) with two systems of irrigation (DI and SDI) for three cultivars of tomato (Rio Grande, Rio Tinto and Nemador) (Kahlaoui et al., 2011). In this paper, the aim was to investigate the response of three tomato cultivars to subsurface drip irrigation and drip irrigation on fruit yield and fruit quality under three different irrigation regimes, using saline water of 6.57 dS. m⁻¹.

MATERIALS AND METHODS

Plant Material:

The experiment was carried out during spring-summer period (from May to August, 2007). Three cultivars of tomato (Lycopersicon esculentum Mill.) were used: Rio Grande, Rio Tinto and Nemador. Seeds were provided by the Laboratory of Seeds and Plant Control of the General Direction of Protection and Control of the Agricultural Production and Quality, Tunisia.

Experimental Design:

The experiment was located at the Cherfech Agricultural Experimental Station, 25 km north of Tunis in the Low Valley of Mejerda River. Climate of the region is Mediterranean with an annual rainfall close to 470 mm and an average yearly evapotranspiration of 1370 mm (Penman method). The soil is silty clay with about 40% of clay, 50% of silt and 10% of sand. The organic matter is about 1% and total CaCO₃ is about 40%. The soil pH is around 7-8 and no fertilizer was used in our experiment. The parcel was divided in three areas corresponding to 3 regimes of irrigation water. Within each parcel, plants were distributed in six rows, three by treatment; each line included 30 plants. Lines 1, 3 and 5 corresponded to the DI treatment, whereas lines 2, 4 and 6 corresponded to the SDI treatment. The experiment was set using emitters with filters and buried at 30 cm depth for SDI. Transplanting date was 2/05/2007 in single lines, using seedlings at the 5 - 7 leaves stage. Tomato plants were spaced 1m between rows and 0.40 m between plants.

Irrigation Water:

Irrigation water came from a well. Its pH is 7.45; electrical conductivity (EC) is about 6.57 dS. m⁻¹ and the sodium adsorption ratio (SAR) equals to 14. It is rich in NaCl (Na⁺ = 35.65 me. L⁻¹, Cl⁻ = 34.21 me. L⁻¹), while K⁺ = 3.96, Ca²⁺ = 7.73 and Mg²⁺ = 4.83 me. L⁻¹. Three regimes of water were applied: 100%, 85% and 70% of crop water requirement, according to climatic data (about 1434 mm). Plants were irrigated each two days and for the first month, the dose was the same for the three regimes. After that, we applicated three different water regimes. These doses were about 40 mm, 34 mm, 20 mm for each water treatment, respectively. As well known there is an effect on soil and crop, according the concentration of NaCl in water. The EC of the well water is the half of the range for the tomato crop, meaning that tomato would be over the tolerance threshold and probably affected up to 49% of yield reduction (Mass and Hoffman, 1977).

Crop Measures And Analyses:

Soil Analyses:

Soil salinity was determined before installation and at the end of the crop cycle at the roots level and every 20 cm up to 40 cm depth. The soil/water ratio was 1/5. A significant linear relationship permitted to convert the electrical conductivity EC (1/5) to the electrical conductivity of the saturated paste extract (ECe) (Jammazi and Hachicha, 2002):

\[ ECe = 5.853 \times EC (1/5) - 0.262 \]

\[ (n = 134 \text{ and } R^2 = 0.91) \]

with \( 1.2 < ECe < 8.3 \text{ dS. m}^{-1} \) and \( 0.2 < EC (1/5) < 1.4 \text{ dS. m}^{-1} \)

Determination Of Flowers, Fruits Number And Fruit Size:

The flowers number was determined by counting the number of flowers each day at flowering stage. Similarly for fruit number at the stage of fructification. In this paper, we used only the number of fruits for the assessment of yield by plant. At the same time seven fruit-grade classes were adopted for determining the fruit size: \( C1 < 30 \text{ mm} \); \( 30 \text{ mm} < C1 < 35 \text{ mm} \); \( 35 \text{ mm} < C2 < 40 \text{ mm} \); \( 40 \text{ mm} < C3 < 45 \text{ mm} \); \( 45 \text{ mm} < C4 < 50 \text{ mm} \); \( 50 \text{ mm} < C5 < 55 \text{ mm} \); \( 55 \text{ mm} < C6 < \text{ mm} \).

Determination Of Fruit Quality Parameters:

Titratable acidity was measured by titration of 10 ml of juice with NaOH 0.1N until pH = 8.2. It is expressed by % of citric acid:

\[ \% \text{ Acidity} = \frac{V_{\text{NaOH}} \times 0.064}{V_{\text{juice}}} \times 100 \]

The total soluble solid content (TSS) was measured by a refractometer (SOPELEM 3841) and expressed in % (Brix), while pH was measured with a digital pH meter (WTW).

Data Analyses:

The experiment was carried out according to randomized design with three factors (cultivar, irrigation regime and irrigation system) and three replications per treatment. In each treatment, three plants/replications were used in statistical analysis. Statistical processing was achieved by the software STATISTICA, Version 5 (Statsoft France, 1997) and the parameters recorded were subjected to analysis of variance with two and three ways. Means comparison were carried out as needed by the LSD test at the significant level of 0.05.

RESULTS AND DISCUSSION

Effects On Soil:

As reported in a previous publication, soil salinity varied according the irrigation regime. ECe was generally higher for the 70% water regime than the control treatment (100% water requirement). This increase was highly significant \( (P \leq 0.05) \) in the case of Rio Tinto cultivar. The irrigation system had a significant effect on the soil salinity: ECe was significantly \( (P \leq 0.05) \) higher in DI than in SDI, particularly in the case of Rio Tinto. In addition, ECe was significantly higher at the 0-20 cm layer than at 20-40 cm depth. Our study exposed several effects concerning the tested treatments in a Tunisian soil (Kahlaoui et al., 2011). Similar results have been obtained by Mendlinger et al. (1994), Oron et al. (2002), and

Effects On Fruit Yield Parameters:

Effect On The Flowers Number:

We observed a significant \( (P \leq 0.05) \) decrease of the flowers number in the three cultivars with the deficit regime (70% of water requirement) (Figure 1a). Compared to the control treatment, this decrease was 28%, 38% and 41% for Rio Grande, Rio Tinto and Nemador, respectively. The irrigation system treatment affected significantly \( (P \leq 0.05) \) the flowers number in all cultivars, being greater in SDI than DI for all cultivars in all the three regimes (Figure 1b). As regards in the Figure 1c, irrigation regime versus irrigation system interaction, in the three cultivars, had a significant \( (P \leq 0.05) \) effect on the number of flowers. At 70% of water requirement, the number of flowers was greater in Rio Grande cultivar compared to the other cultivars and DI. The decrease of flowers, in our investigations, is due to the increase of abortion of flowers. These results are in accord with previous work obtained by Bertin (1995) and Kahlaoui et al. (2011) on tomato.
Effect On Fruits Number:

As observed in Figure 1a’, results show a higher fruits number in Rio Grande than the other cultivars for the regime 100% and a significant decrease ($P \leq 0.05$) in Nemador for the regime 70%. The treatment belonging irrigation system had a significant ($P \leq 0.05$) effect on the fruits number of the tomato cultivars. A highly significant increase of fruits number was observed in SDI in comparison to DI for all cultivars. The highest increase regarding this parameter was found in Rio Grande (Figure 1b’). When looking for the combination of both treatments (irrigation regime and irrigation system) on the three cultivars, it was observed that the fruits number was increased in Rio Grande in the three regimes of irrigation (100%, 85% and 70% of water requirement) with both systems of irrigation (SDI and DI) compared to the other cultivars (Rio Grande and Rio Tinto) (Figure 1c’). At the lower amount of water applied, the interaction of both treatments showed higher fruits number in SDI than DI for the three cultivars. Thus, a significant relative increase was found in Rio Grande regarding the other cultivars. Likewise in the flowers parameters, a decrease of the fruits number occurred for the three cultivars with the deficit regime (70% of water requirement), results that are in agreement with those of Showemimo et al., (2007) who obtained a decrease of 75% of the tomato fruits number under water stress. Conversely, Fernandez et al., (2005) reported that water deficit did not affect fruit number in pepper. In Figures 1b’ and 1c’, the significant reduction observed is due to the higher accumulation of salts in DI than SDI. This accumulation of salts has been attributed to the increase of evaporation rate near the soil surface in the case of DI (Hachicha et al., 2006, Kahlaoui et al., 2011). So, we can deduct that the reduction in fruit number observed in the present study appears to be related to a decrease of the average number of flowers induced by saline water and water stress. This is consistent with the hypothesis of Cuartero and Fernandez-Munoz (1999) that stress restricts the number of flowers per truss.

Blossom-end Rot (BER):

The results in Figure 5a show a significant increase of fruits BER number in all cultivars of tomato with the reduction of the amount of water applied. This increase occurred more in Nemador than in the other cultivars.
(Rio Grande and Rio Tinto) at 70% of water requirement. Rio Grande was less affected by BER incidence. The irrigation system treatment had a significant effect on the three cultivars. The fruits BER number was increased in the three cultivars with DI and, in general, was higher in Nemador than in the other cultivars (Rio Grande and Rio Tinto) (Figure 5b). For the combination of the two treatments studied previously, the fruits BER trend to increase with the reduced amounts of water applied for the three cultivars of tomato. In the regime 70% of water requirement, the fruits BER number was greater in Nemador with DI than in the other cultivars (Figure 5c). So, Nemador was more sensitive to blossom-end rot. BER is often associated with local Ca deficiency in fruits (Marcelis and Ho, 1999; Saure, 2001; Adams, 2002; Silber et al., 2005), but the direct cause of this physiological disorder remains obscure and, in spite of numerous studies, the causative mechanism of BER has not been identified (Saure, 2001). According to our previous work (Kahlouei et al., 2011), the irrigation with saline water (6.57 dS.m\(^{-1}\)) induced a great accumulation of salts, being higher in DI than SDI. So the salt stress lead to the increase in the number of fruits affected by BER, which is in agreement with the hypothesis of Ho and White (2005) who indicated that blossom-end rot could be caused by a reduction of Ca\(^{2+}\) translocation to the fruit tip in the period of rapid fruit expansion. The contribution of salinity to the reduction of Ca\(^{2+}\) in the fruit tip could be related to the decrease in the xylem water import caused by a decrease in water uptake by the roots and the reduction of xylem development in fruits (Ho et al., 1987; Belda and Ho, 1993). In our results, the significant increase of BER was higher in Nemador cultivar and lower in Rio Grande irrigated with saline water. There is a notable difference in susceptibility to BER between the three cultivars used in the present work, being Nemador more sensitive than Rio Tinto and Rio Grande, respectively (Figure 7). This cultivar differences in susceptibility to BER have been related to: (i) the fruit growth rate (Ho et al., 1993), (ii) the efficiency of calcium (Ca) uptake and subsequent translocation of Ca to fruit (Adams and Ho, 1995), and (iii) Ca transport within the fruit (Adams and Ho, 1995). Likewise of our results, a number of studies have reported cultivar differences in the susceptibility to BER under saline conditions (Adams and Ho, 1992; Ho et al., 1995; Cuartero and Fernandez-Munoz, 1999). The increase of blossom-end rot incidence has previously been shown in many crops including tomato (Van Ieperen, 1996, Tuzel et al., 2001; Magan et al., 2008; Liebisch et al., 2009), cucumber (Frost and Kretchman, 1989) and pepper (Tadesse et al., 2001; Rubio et al., 2009).

**Fig. 2:** Effect of irrigation regimes on fruits size of three tomato cultivars irrigated with saline water (6.57 dS. m\(^{-1}\)). All values are the mean of three replications (n = 3). (a: 100% of water requirement; b: 85% of water requirement; c: 70% of water requirement).

**Effect On Fruit Size:**

The results of different grade categories of fruit size for the three tomato cultivars are presented in the Figure 2. The C4 and C5 classes are abundant for the three cultivars, being greater in Rio Grande at 100% of
water requirement. The size decreased with the reduction of the amount of water applied. C0 and C1 frequencies were greater in Nemador than Rio Tinto and Rio Grande. According to irrigation system treatment, C4 and C5 frequencies were higher in Rio Grande compared to the other cultivars and DI (Figure 3). As observed in the Figure 4, the combination of the two treatments (regime and system of irrigation) on the three cultivars shows that the C0 and C1 frequencies were greater in Nemador, Rio Tinto and Rio Grande, respectively and C4 and C5 frequencies decreased in the three cultivars with the more deficit water regime (70%) and DI. According to our data, the decrease of fruit size was higher in Rio Tinto and Nemador than in Rio Grande. This observation is corroborated by Johnson et al., (1992) study and by Bhattarai et al., (2006) on tomato. Such reductions in fruit size are related to lowered water potential that constrained the rate of fruit expansion. The reduction in fruit size due to salinity is variety specific.

Fig. 3: Effect of irrigation systems on fruits size of three tomato cultivars irrigated with saline water (6.57 dS. m⁻¹). All values are the mean of three replications (n = 3). (a: Subsurface drip irrigation (SDI); b: Drip irrigation (DI)).

**Fruit Yield:**

The present study shows a significant decrease (≤ 0.05) of fruit yield with the reduction of the amount of water applied for irrigation with saline water (6.57 ds.m⁻¹) in the three cultivars of tomato. This decrease was enhanced in the more deficit regime (70% of water requirement) compared to the control treatment (100% of water requirement) (Figure 6a). It involved particularly Rio Tinto and Nemador cultivars. Therefore, Rio Grande appears more adaptive to water stress. These results were in agreement with the finding by Della Costa and Gianquinto (2002) in pepper and Iqbal et al. (2008) in sunflower. Therefore, Iqbal et al. (2008) reported that the best yield is for “Suncrosss” compared with «Gulshan-98» cultivar under water stress conditions. It is generally accepted that water deficit reduces yield in pepper (Jaimez et al., 2000; Delta Costa and Gianquinto, 2002; Sezen et al., 2006). Fernandez et al. (2005) reported that water deficit did not affect fruit number. Reduction in pepper fruit size appears as the controlling factor for fruit yield. There are inconsistencies in the literature regarding the contribution of fruit number to induced reductions in tomato fruit yield. Sonnvele and welles (1988), Li et al. (2001) and Eltez et al., (2002) reported that the number of fruits is unaffected by moderate salinity, and that reduced yield is entirely due to smaller fruits. Our results are consistent with Adam and Ho (1989) and Van Ieperen (1996) who observed that the number of harvested fruits per plant decrease with salinity and water stress and is a contributing factor to reduced fruit yield. In addition, the increase of fruits showing blossom end rot, as documented in our data, also contribute to yield reduction. The relatively low blossom end rot in fruits found for Rio Grande cultivar suggest that this cultivar is close the “less sensitive cultivar to blossom end rot”, according to Cuartero and Fernandez –Munoz (1999).

For the future, the use of SDI under saline condition in some areas of Tunisia and others countries can contribute to improve the water use efficiency and increase the yield. Indeed, our data show a positive response of fruit yield for the three cultivars of tomato with SDI and irrigated with saline water (6.57 dS.m⁻¹). The most adaptive yield response to SDI was found in Rio Grande cultivar (Figure 6b). Similar results were obtained when analyzing both factors (SDI and deficit water) and saline water (6.57 dS.m⁻¹) (Figure 6c). This is consistent with reports on agricultural and horticultural crops, including onion (Enciso et al., 2007), tomato (Ayars et al., 2001), squash (Al-Omran et al., 2005) and potato (Patel and Rajput, 2007). Indeed, Al-Omran et al. (2005) reported that the response of squash yield is different between the two irrigation systems. It appears that SDI creates more suitable conditions in the root zone for plant growth and production and proves that the advantages of SDI were related to the relative decrease in salt accumulation in the root zone where the plant roots were active and the water content was relatively higher.
Fruits Quality:

As shown in Table 1, the titratable acidity percentage increased significantly (P ≤ 0.05) for the three cultivars with the regime 70%. The irrigation system treatment has a significant effect (P ≤ 0.01) on titratable acidity percentage (Table 2). This quality parameter is greater in DI compared to SDI system for the three cultivars. The higher significant increase was found in Nemador. Considering the combination of irrigation regimes and irrigation systems treatments, our data shows a significant (P ≤ 0.05) increase of the titratable acidity percentage for the three cultivars of tomato at 70% of water requirement with DI. This increase is noticed in Rio Tinto and Nemador cultivars (Table 3). As to the total soluble solid content (TSS), the effect of irrigation regimes on TSS content is presented in Table 1. This quality parameter increased significantly (P ≤ 0.01) in the more deficit (70%) regime compared to the control treatment (100% of water requirement) for the three cultivars. This increase of TSS content involved mainly the Nemador cultivar. As shown in Table 2, the irrigation system treatment had a significant effect (P ≤ 0.01) on TSS content. The TSS content was greater in DI than SDI for the three tomato cultivars. The combination of both treatments affected significantly (P ≤ 0.01) the TSS content. It was increased in the three cultivars with the higher water deficit and DI (Table 3). Considering the pH of the juice, we observed a significant (P ≤ 0.05) reduction in the three cultivars for the regime 70% (Table 1). As regards of Table 2, the juice pH of tomato increased significantly (P ≤ 0.05) more in SDI than in DI for Rio Grande and Nemador. Similarly, a significant increase of pH was found in the combination of both treatments (irrigation system and irrigation regime). It increases in the more deficit water (70% of water requirement) with DI for the three cultivars.

Table 1: Effect of three irrigation regimes (100%, 85% and 70% of water requirement) on fruit quality of three tomato cultivars irrigated with saline water (6.57 dS. m⁻¹).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Acidity (%)</th>
<th>TSS (brix%)</th>
<th>pH</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Rio Grande</td>
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<td></td>
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<tr>
<td>100%</td>
<td>5.17 ± 0.01b</td>
<td>6.45 ± 0.96a</td>
<td>4.38 ± 0.15a</td>
</tr>
<tr>
<td>85%</td>
<td>5.24 ± 0.089b</td>
<td>10.85 ± 1.06b</td>
<td>4.06 ± 0.06c</td>
</tr>
<tr>
<td>70%</td>
<td>5.48 ± 0.12d</td>
<td>11.29 ± 0.14bc</td>
<td>3.73 ± 0.13f</td>
</tr>
<tr>
<td>Rio Tinto</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>100%</td>
<td>5.03 ± 0.11a</td>
<td>8.64 ± 0.59ab</td>
<td>4.18 ± 0.01b</td>
</tr>
<tr>
<td>85%</td>
<td>5.08 ± 0.20a</td>
<td>10.61 ± 1.74b</td>
<td>4.00 ± 0.02cd</td>
</tr>
<tr>
<td>70%</td>
<td>5.35 ± 0.12c</td>
<td>11.36 ± 0.19bc</td>
<td>3.88 ± 0.03e</td>
</tr>
<tr>
<td>Nemador</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>5.36 ± 0.122c</td>
<td>8.33 ± 0.37ab</td>
<td>4.15 ± 0.16b</td>
</tr>
<tr>
<td>85%</td>
<td>5.74 ± 0.29e</td>
<td>10.98 ± 1.74b</td>
<td>3.95 ± 0.08d</td>
</tr>
<tr>
<td>70%</td>
<td>5.78 ± 0.15e</td>
<td>14.21 ± 0.34c</td>
<td>3.86 ± 0.16e</td>
</tr>
</tbody>
</table>

Analysis of variance
Effect of cultivar (C) * ** ns
Effect of regime (R) * ** *
Interaction (C)x(R) * ** *

All values are the mean of three replications (n = 3) of three cultivars of tomato (Rio Grande, Rio Tinto and Nemador) irrigated by different regimes. Mean ± SE with different letters are significantly different at P ≤ 0.05 according to LSD test. Different letters indicate significant differences at P ≤ 0.05.

** indicate significant differences at P ≤ 0.05 and P ≤ 0.01, respectively, according to the analysis of variance.

TTS: total soluble solid content

Table 2: Effect of subsurface drip irrigation (SDI) and drip irrigation (DI) on fruit quality of three tomato cultivars irrigated with saline water (6.57 dS. m⁻¹).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Acidity (%)</th>
<th>TSS (brix%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>SDI</td>
<td></td>
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</tr>
<tr>
<td>Rio Grande</td>
<td>5.19 ± 0.12b</td>
<td>8.83 ± 0.12ab</td>
<td>4.23 ± 0.11c</td>
</tr>
<tr>
<td>Rio Tinto</td>
<td>4.69 ± 0.23a</td>
<td>9.50 ± 0.35b</td>
<td>4.02 ± 0.04b</td>
</tr>
<tr>
<td>Nemador</td>
<td>5.18 ± 0.11b</td>
<td>5.18 ± 0.11a</td>
<td>3.98 ± 0.07b</td>
</tr>
<tr>
<td>DI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rio Grande</td>
<td>5.40 ± 0.21c</td>
<td>9.83 ± 1.12b</td>
<td>3.10 ± 0.06a</td>
</tr>
<tr>
<td>Rio Tinto</td>
<td>5.62 ± 0.05d</td>
<td>11.02 ± 0.28bc</td>
<td>4.01 ± 0.04b</td>
</tr>
<tr>
<td>Nemador</td>
<td>6.07 ± 0.26e</td>
<td>13.4 ± 1.40c</td>
<td>3.65 ± 0.02ab</td>
</tr>
</tbody>
</table>

Analysis of variance
Effect of cultivar (C) * ** ns
Effect of system (S) ** **
Interaction (C)x(S) * ** *

All values are the mean of three replication (n = 3) of three cultivars of tomato irrigated by drip irrigation (DI) and subsurface drip irrigation (SDI). Mean ± SE with different letters are significantly different at P ≤ 0.05 according to LSD test. ns,*,** indicate non significant or significant differences at P ≤ 0.05 and P ≤ 0.01, respectively, according to the analysis of variance.

TTS: total soluble solid content

As regards to these parameters, are important quality factors for both fresh-market and processing tomatoes (Carvajal et al., 2000). It is well known that the total soluble solids content, the most important criterion for tomato paste processing, increases with salinity, although yield reduction is also expected (Saranga et al., 1991; Carvajal et al., 2000). The present study is in agreement with results found on eggplants by Savvas and Lenz.
(1996), on melon by Feigin et al. (1987), on tomato by Tuzel et al. (2001), Maggio et al. (2004), Yurtseven et al. (2005), Mégan et al. (2008), on pepper by Rubio et al. (2009) in saline conditions and on citrus by Pérez-Pérez et al. (2009) in the case of water deficit. The increase in quality of tomato fruits was also highlighted by Goykovic and Saavedra (2007) in their review. Therefore, the increase of titratable acidity and TSS improves the flavor of juice (De Pascale et al., 2001; Maggio et al., 2004; Mégan et al., 2008). Regarding the use of irrigation systems, the increase of these two parameters of fruits (titratable acidity and TSS) is observed in the three cultivars with DI treatment.

![Fig. 4](image)

**Fig. 4:** Effect of the combination of irrigation regimes and irrigation systems on fruits size of three tomato cultivars irrigated with saline water (6.57 dS m⁻¹). All values are the mean of three replications (n = 3). (a: combination of SDI and 100% of water requirement; a': combination of DI and 100% of water requirement; b: combination of SDI + 85% of water requirement; b': combination of DI and 85% of water requirement; c: combination of SDI + 70% of water requirement; c': combination of DI and 70% of water requirement).

**Conclusion:**

The study carried out with saline water put in evidence the effects of the system and regime of irrigation. These effects differ significantly according the three tomato cultivars experimented in the field (Rio Grande, Rio Tinto and Nemador). Under the global evaluation of the cultivars, Rio Grande distinguishes for dual–purpose cultivation in Tunisia. It appears more adapted to water deficit in terms of fruit production (flowers number, fruits number, fruit size and fruit yield) and incidence of blossom –end rot, compared to the other cultivars (Rio Tinto and Nemador). Concerning the irrigation system, Rio Grande has higher yield with SDI, technical aspect
being relevant for production under Tunisian conditions with saline water. In opposition to its negative aspect, the use of saline water with water deficit (70%) and DI system improved fruits quality; notably titratable acidity, total soluble solid contents (TSS) and a significant decrease of the pH juice.

Table 3: Effect of subsurface drip irrigation (SDI) and drip irrigation (DI) under three irrigation regimes on fruit quality of three tomato cultivars irrigated with saline water (6.57 dS m⁻¹).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Acidity (%)</th>
<th>TSS (brix%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SDI</td>
<td>DI</td>
<td>SDI</td>
</tr>
<tr>
<td>Rio Grande</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>5.13 ± 0.022c</td>
<td>5.21 ± 0.042d</td>
<td>5.46 ± 0.086a</td>
</tr>
<tr>
<td>85%</td>
<td>5.26 ± 0.047d</td>
<td>5.42 ± 0.032e</td>
<td>10.00 ± 0.088c</td>
</tr>
<tr>
<td>70%</td>
<td>5.49 ± 0.087de</td>
<td>5.67 ± 0.038ef</td>
<td>11.05 ± 0.104cd</td>
</tr>
<tr>
<td>Rio Tinto</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>4.61 ± 0.098a</td>
<td>5.30 ± 0.041de</td>
<td>8.61 ± 0.273b</td>
</tr>
<tr>
<td>85%</td>
<td>4.87 ± 0.087b</td>
<td>5.45 ± 0.079de</td>
<td>10.04 ± 0.220c</td>
</tr>
<tr>
<td>70%</td>
<td>5.20 ± 0.102b</td>
<td>6.32 ± 0.045ef</td>
<td>11.48 ± 0.176cd</td>
</tr>
<tr>
<td>Nemador</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>4.87 ± 0.053bc</td>
<td>5.52 ± 0.054e</td>
<td>8.05 ± 0.080b</td>
</tr>
<tr>
<td>85%</td>
<td>5.20 ± 0.056d</td>
<td>6.07 ± 0.087c</td>
<td>9.04 ± 0.075c</td>
</tr>
<tr>
<td>70%</td>
<td>5.41 ± 0.045de</td>
<td>6.62 ± 0.035g</td>
<td>9.87 ± 0.053c</td>
</tr>
</tbody>
</table>

All values are the mean ± SE of three replications (n = 3) of three cultivars of tomato irrigated by drip irrigation (DI) and subsurface drip irrigation (SDI) with three regimes (100%, 85% and 70% of water requirement). Mean ± SE with different letters are significantly different at P ≤ 0.05 according to LSD test.

***,*** indicate significant differences at P ≤ 0.05 and P ≤ 0.01, respectively, according to the analysis of variance.

TSS: total soluble solid content

Fig. 5: Effect of (a) irrigation regimes, (b) irrigation systems and (c) combination of irrigation regimes and irrigation systems on fruits BER number of three tomato cultivars irrigated with saline water (6.57 dS. m⁻¹). All values are the mean ± SE of three replications (n = 3) and bars with different letters are significantly different at (P ≤ 0.05) according to LSD test.
Fig. 6: Effect of (a) irrigation regimes, (b) irrigation systems and (c) combination of irrigation regimes and irrigation systems on fruit yield of three tomato cultivars irrigated with saline water (6.57 dS. m⁻¹). All values are the mean ± SE of three replications (n = 3) and bars with different letters are significantly different at (P ≤ 0.05) according to LSD test.

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REFERENCES


