Effects of Low Salinity Stress on Growth, Yield and Water Use Efficiency of Tomato under Soilless Cultivation

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Abstract

This study was conducted to investigate the effects of low salinity stress on growth, yield, water use efficiency (WUE), and fruit quality of cherry tomatoes cultivated under a soilless condition. The experiment was conducted using Hydroponic Power’s Pot under six salinity levels (electrical conductivity (EC): 0.78, 0.91, 1.10, 1.26, 1.41, and 1.58 dS m$^{-1}$), with three pots (six plants) in a completely randomized design in each treatment. The results showed that plant fresh weight, soil-plant analysis development (SPAD) value (leaf chlorophyll), and dry weight were significantly affected by salinity stress at EC = 1.58 dS m$^{-1}$. Tomato yield was significantly affected by salinity stress when EC reached 1.41 dS m$^{-1}$, and was more sensitive than growth variables. Fruit quality was improved with increasing salinity. Evapotranspiration was also significantly affected by salinity stress at EC = 1.58 dS m$^{-1}$.

However, WUE for yield (fresh fruit) and biomass were not significantly different among salinity levels. The SPAD value (leaf chlorophyll) was the most sensitive indicator for salinity stress. The salinity threshold of the tomatoes was 1.41 dS m$^{-1}$ to achieve higher fruit quality and yield by using Vegetable Life A nutrient solution.

Key Words: Tomato, Low salinity stress, Sugar content, Acidity, Water requirement, Water use efficiency

1. INTRODUCTION

The tomato is one of the most popular vegetables worldwide. Global production is estimated at 138.7 million metric tons, with China and India the leading producers during 2012 (Faostat, 2015). The tomato is the most common crop plant produced by hydroponic culture in greenhouses due to uniform products and improved control under those growing conditions. Among tomato cultivars, the cherry tomato is a widespread variety of table tomato, grown in China, United States, and other countries.

The harmful effects of salinity stress on tomatoes have been found to cause a reduction in growth (Kamrani et al., 2013), fruit size, and fruit yield (Bustomi Rosadi et al., 2014; Magan et al., 2008). The summary by Gama et al. (2007) listed three mechanism by which plants are compromised by salinity stress: 1) water deficit due to reduced water potential in the root zone; 2) a toxic effect due to the high concentration of Na$^+$ and Cl$^-$; and; 3) nutrient imbalance by depression of uptake and/or shoot transport. Tester and Davenport (2003) also reported that high concentrations of Na$^+$ could cause a range of osmotic and metabolic problems within plant shoots. On the other hand, it is widely considered that the quality of fruits of tomato plants grown under saline conditions is higher than those grown under non-saline conditions (Cornish, 1992; Magan et al., 2008). Auerswald et al. (1999) also reported that sugar and acid contents of fruits were enhanced with increasing electric conductivity (EC) levels of the nutrient solution. Azarmi et al. (2010) found that growth variables and yield were reduced with increasing salinity; however, qualitative properties of fruit were improved by salinity at EC levels between 2.5–6 dS m$^{-1}$ under a hydroponics system.

Previous studies have mostly focused on higher salinity levels (EC > 2.0 dS m$^{-1}$) when considering salinity stress in soilless cultivation, (Del Amor et al., 2001; Azarmi et al., 2010; Maggio et al., 2007; Reina-Sanchez et al., 2005) because a nutrient solution is generally highly saline. In accordance with soil cultivation, it was also found that tomato yield is reduced and fruit quality is improved by adding salt to a nutrient solution in soilless cultivation (Del Amor et al., 2001; Azarmi et al., 2010). However, very little information on the effects of low salinity levels (EC < 1.6 dS m$^{-1}$) is

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available, and the threshold salinity value for the cultivation of tomatoes under a soilless condition remains vague.

According to the above description, a higher salinity concentration causes a reduction of growth and fruit yield, but improves fruit quality. Under the condition of a low salinity concentration, it is important to determine a threshold salinity value which minimizes the reduction in fruit yield, but improves fruit quality.

The present study was conducted to achieve the following objectives:

1: To investigate the effects of low salinity concentration (EC < 1.6 dS m$^{-1}$) of a nutrient solution on plant growth, yield, and fruit quality of tomatoes cultivated under a soilless condition.

2: To calculate the evapotranspiration ($ET$) and water use efficiency ($WUE$) for tomatoes cultivated under a soilless condition through the gravimetric method.

3: To evaluate the salinity threshold of a nutrient solution for maintaining the yield of tomatoes while also improving fruit quality.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted in a plastic covered house with open surrounding sides, located at the Experimental Farm of Gifu University, Gifu Prefecture, Japan (35º27´51˝N, 136º44´14˝E), over a period of 8 weeks from May to July, 2014. The house was 11 m in length and 5 m in width with an area of 55 m$^2$. Daily temperatures and relative humidity inside the house are shown in Fig. 1. The average temperature during the day and night was 31.5°C and 20.8°C, respectively, whereas the average relative humidity was 52.8% and 88.9%, respectively during the experiment duration.

2.2 Experimental Design and Treatments

Cherry tomato (Lycopersicon esculentum Miller) “Pepe” was cultivated using a commercial hydroponic kit (Power’s Pot MNEC-3000, manufactured by MINORU kasei Co., Japan) (Fig. 2). The pot can be separated into a nutrient solution bucket, plant table, and plant bowl. A standard nutrient solution (Vegetable Life A, manufactured by Otsuka Chemical Co. Ltd., Tokyo, Japan. N, P, K, Mg, Mn, and B of 1.3%, 0.6%, 1.9%, 0.32%, 0.008%, and 0.008%, respectively), diluted 200 times by tap water as a solution, which had an EC of 0.8 dS m$^{-1}$, was used to cultivate the tomatoes. Sodium chloride (NaCl) was added to the solution to impose salinity stress on tomato plants.

Seedlings were transplanted in a randomized complete block design with six plants per treatment at the approximately 20 cm height stage. A total of 36 plants were cultivated in 18 pots (two plants per pot). Six salinity levels, namely the control (CT) (0.8 dS m$^{-1}$; recommend by the manufacturer), ST1 (0.95 dS m$^{-1}$), ST2 (1.10 dS m$^{-1}$), ST3 (1.25 dS m$^{-1}$), ST4 (1.40 dS m$^{-1}$), and ST5 (1.55 dS m$^{-1}$) were prepared as treatments. For example, the ST2 treatment was exposed nutrient solution with an EC maintained at approximate 1.10 dS m$^{-1}$ by the addition of salt throughout the experiment duration. The EC of each pot was measured daily after irrigation, and salt was added to maintain the EC levels of each treatment. The average measured EC ($n = 168$; three pots × 56 days) was used as the actual EC of each treatment (Table 1).

Lateral buds were pruned during sprouting. The top bud was pruned by the fifth week (from 29 to 35 days
after transplantation) when the plant was in the four flower trusses stage.

2.3 Measurements

2.3.1 Evapotranspiration

Daily $ET$ (g d$^{-1}$) per pot was measured by the gravimetric method, calculated as follows:

$$ET_i = W_i - W_{i+1}$$

where $ET_i$ is the evapotranspiration at day $i$ (g), $W_i$ is the weight of the whole bucket (including 13 L of nutrient solution) after irrigation at day $i$ (g), and $W_{i+1}$ is the weight of the whole bucket before irrigation at day $i+1$ (g). Irrigation was conducted by adding nutrient solution. The amount of irrigation was taken to be the same as $ET_i$. The total $ET$ per pot (two plants) during the test was divided between each plant based on the final plant biomass. The total $ET$ per plant was defined as the actual $ET$.

2.3.2 Plant Growth Variables

The weight of a fresh plant (g plant$^{-1}$) was measured by weighing the plant and plant bowl together, which were taken out from the Power’s Pot once a week. Leaf chlorophyll was measured by a soil-plant analysis development (SPAD) chlorophyll meter (SPAD-502 meter, manufactured by Konica Minolta, Tokyo, Japan) once a week. Yadava (1986) reported that SPAD values have a direct linear relationship with extracted leaf chlorophyll. Therefore, the SPAD value was used to describe leaf chlorophyll in the present study. After the cultivation test, the weight of the aboveground biomass and root biomass were measured after drying at 105°C for 30 min, and then at 70°C until a constant weight was achieved in a ventilated oven (Chen et al., 2012).

2.3.3 Yield and WUE

Fruit yield (g plant$^{-1}$), individual fruit weight, and fruit number of all plants were measured during the harvest seasons (from week 6 to 8).

Water availability for plants is one of the most limiting factors affecting agriculture (Araus, 2004). $WUE$, described as the amount of water used per unit of yield, can be used to monitor and compare the different plant growth systems (Meric et al., 2011).

$WUE$ was calculated in total yield ($WUE_{t}$, g/kg, gram of fresh fruit produced per kg of water) and in biomass ($WUE_{b}$, g/kg, gram of biomass produced per kg of water) per pot.

2.3.4 Fruit Quality Variables

Tomato fruits were harvested nearly twice a week during the fully mature fruit stage. The fruits of similar size and no appearance of defects were chosen at harvesting day for fruit quality measurements. Eight fruits (two per truss) per plant were chosen during the harvest seasons. Each fruit was then juiced by small juicer. Fruit sugar content (%) was measured by a hand refractometer (N-1E, manufactured by ATAGO, Japan). Prepared juice was diluted 50 times with Quinone Reagent Solution (RE-99432, manufactured by ATAGO, Japan), which was then used to measure fruit acid content (%) by the Pocket acid meter (PAL-AC1, manufactured by ATAGO, Japan).

2.4 Data Analysis

Statistical analysis was conducted using one-way ANOVA, and measurement results were compared by Duncan’s test at the 5% level using the SPSS program. One plant in the ST3 treatment was not used because of abnormally high biomass (> 150%) compared with the average of the other plants under the same treatment.

3. RESULTS AND DISCUSSION

3.1 Plant Growth

The effects of salinity stress on plant growth indicators are shown in Tables 2–4. Table 2 shows that the lowest fresh weight was recorded in the ST5 treatment from day 35. The ST5 treatment showed significant differences in fresh weight compared to the CT from day 49. Table 3 shows that the SPAD value (leaf chlorophyll) experienced stress at day 28 under ST4, and followed from day 35 under ST5, but recovered later under ST4. Dry weight, dry root weight, and dry aboveground organ weight also showed significant difference under ST5 (Table 4).

Based on the above phenomena, plant fresh weight and SPAD value (leaf chlorophyll) were significantly affected by salinity stress from day 49 and 35, respectively under the ST5 treatment. It was indicated that the SPAD value (leaf chlorophyll) was more sensitive as a plant growth indicator than plant fresh weight under salinity stress. Besides, tracing the plant fresh weight is difficult under traditional agricultural production. Therefore, based on timeliness and simplicity of the SPAD value (leaf chlorophyll), this method may be very useful for detection of various stresses, and especially management of salinity in tomato cultivation under salinity conditions.

Plant growth indicators showed significant differences under the ST5 treatment. Meanwhile, the values of growth variables under ST4 (e.g., fresh weight from day 28, SPAD value from day 14, dry weight, dry root weight, dry aboveground biomass weight; fruit number, and weight of one fruit) were obviously lower than that of the other treatments. This indicated that the growth variables also suffered slight stress under the ST4 treatment, although no significant difference was observed. According to this result, the threshold value of tomato growth could be estimated as between 1.41 dS m$^{-1}$ (ST4) and 1.58 dS m$^{-1}$ (ST5). The decrease in fresh weight could be caused by the inhibition of leaf expansion related to salt-induced destruction of the water balance (Huang and Redmann, 1995), inhibition of cell division (Wignarajah et al., 1975), and inhibition of leaf photosynthesis (Parida and Das, 2005). The SPAD value (leaf chlorophyll) was significantly reduced from day 35 under the ST5 treatment. This could be attributed to salt-induced
### Table 2: Effects of salinity stress on plant fresh weight (g) (Data are the means ± SD of six plants except ST3 treatment of five plants. Values in the same column that are followed by different lower-case letters (a–b) are significantly different (Duncan’s test, \( p < 0.05 \)).)

<table>
<thead>
<tr>
<th>ST level</th>
<th>CT</th>
<th>ST1</th>
<th>ST2</th>
<th>ST3</th>
<th>ST4</th>
<th>ST5</th>
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<tbody>
<tr>
<td></td>
<td>Day 7</td>
<td>Day 14</td>
<td>Day 21</td>
<td>Day 28</td>
<td>Day 35</td>
<td>Day 42</td>
</tr>
<tr>
<td>CT</td>
<td>295 ± 14</td>
<td>364 ± 12</td>
<td>504 ± 41</td>
<td>728 ± 84</td>
<td>1,241 ± 168</td>
<td>1,469 ± 191</td>
</tr>
<tr>
<td>ST1</td>
<td>275 ± 38</td>
<td>334 ± 61</td>
<td>515 ± 50</td>
<td>741 ± 72</td>
<td>1,247 ± 104</td>
<td>1,521 ± 127</td>
</tr>
<tr>
<td>ST2</td>
<td>320 ± 17</td>
<td>396 ± 21</td>
<td>570 ± 33</td>
<td>805 ± 63</td>
<td>1,286 ± 185</td>
<td>1,519 ± 253</td>
</tr>
<tr>
<td>ST3</td>
<td>308 ± 10</td>
<td>373 ± 11</td>
<td>527 ± 25</td>
<td>754 ± 72</td>
<td>1,027 ± 107</td>
<td>1,291 ± 143</td>
</tr>
<tr>
<td>ST4</td>
<td>299 ± 29</td>
<td>366 ± 50</td>
<td>520 ± 78</td>
<td>710 ± 96</td>
<td>1,064 ± 135</td>
<td>1,158 ± 177</td>
</tr>
<tr>
<td>ST5</td>
<td>300 ± 24</td>
<td>366 ± 50</td>
<td>520 ± 78</td>
<td>710 ± 96</td>
<td>1,064 ± 135</td>
<td>1,158 ± 177</td>
</tr>
</tbody>
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### Table 3: Effects of salinity stress on SPAD value (leaf chlorophyll) (Data are means ± SD of six plants except ST3 treatment of five plants. Values in the same column that are followed by different lower-case letters (a–c) are significantly different (Duncan’s test, \( p < 0.05 \)).)

<table>
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<tr>
<td>CT</td>
<td>261.59 ± 41.79</td>
<td>21.81 ± 1.60</td>
<td>239.78 ± 41.15</td>
<td>516.97 ± 146.85</td>
<td>48.50 ± 12.16</td>
<td>10.74 ± 1.67</td>
</tr>
<tr>
<td>ST1</td>
<td>276.82 ± 35.96</td>
<td>23.82 ± 1.34</td>
<td>253.00 ± 34.71</td>
<td>469.78 ± 36.43</td>
<td>50.67 ± 12.42</td>
<td>9.76 ± 2.43</td>
</tr>
<tr>
<td>ST2</td>
<td>353.98 ± 44.79</td>
<td>22.87 ± 2.28</td>
<td>253.00 ± 34.71</td>
<td>469.78 ± 36.43</td>
<td>50.67 ± 12.42</td>
<td>9.76 ± 2.43</td>
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<td>ST3</td>
<td>229.59 ± 32.42</td>
<td>20.20 ± 3.16</td>
<td>209.38 ± 30.09</td>
<td>363.20 ± 141.72</td>
<td>40.17 ± 11.14</td>
<td>8.82 ± 1.60</td>
</tr>
<tr>
<td>ST4</td>
<td>173.46 ± 26.65</td>
<td>14.76 ± 1.78</td>
<td>158.69 ± 24.71</td>
<td>315.32 ± 85.60</td>
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### Table 4: Effects of salinity stress on the dry weight, yield, and WUE (Data of dry weight and yield are means ± SD of six plants except ST3 treatment of five plants. Data of WUE for yield and biomass are means ± SD of three pots except ST3 treatment of two pots. Values in the same column that are followed by different lower-case letters (a–c) are significantly different (Duncan’s test, \( p < 0.05 \)).)

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3.2 Yield

In the present study, the average actual yield ($Y_a; n = 6$) of the CT (0.78 dS m$^{-1}$) is defined as the reference yield ($Y_o$) for tomato growth with no salinity stress effects. The relationship between relative yield ($Y_r/Y_o$) and salinity levels showed that the relative yield was significantly decreased by exposure to salinity in the ST4 and ST5 treatments (Fig. 3). Table 4 shows that tomato yield experienced stress under the ST4 and ST5 treatments. The fruit number was reduced by the salinity of the ST5 treatment.

Based on the above explanation, the EC at ST4 (EC = 1.41 dS m$^{-1}$) can be regarded as the yield threshold salinity under a soilless cultivation condition. Many other studies have reported the EC threshold of tomato to range between 2.5 and 4 dS m$^{-1}$ under soilless cultivation (Azarmi et al., 2010; Bustomi Rosadi et al., 2014; Magan et al., 2008). These discrepancies may relate to interactions between the cultivar, environmental factors, and cultural practices (Dorais et al., 2001). For example, Reina-Sanchez et al. (2005) estimated threshold values ranging from 0 to 3.4 dS m$^{-1}$ for four tomato cultivars (Lycopersicon esculentum Mill.: L; threshold value: $L9 < L1 < Floradade < L5$) under a common cultivation condition. Magan et al. (2008) also obtained three different threshold values (3.6, 3.1, and 2.9 dS m$^{-1}$) through three soilless experiments, based on different growth season, cultivar, or cultivation density between every two experiments.

The above explanation indicates that the salinity threshold of tomato yield estimated from this experiment was effective under the suitable conditions without the stress of environmental factors and using Vegetable Life A nutrient solution.

The plant growth variables showed significantly affected by salinity under ST5 treatment (1.58 dS m$^{-1}$), but yield decreased significantly under ST4 treatment (1.41 dS m$^{-1}$). This difference indicated that tomato yield was more sensitive than growth variables under salinity stress. This finding supports that of Shabani et al. (2012), who showed that cherry tomato growth variables and yield are significantly different compared to non-salt treatment (1.9 dS m$^{-1}$) when salinity was higher than 5.8 dS m$^{-1}$ and 5.0 dS m$^{-1}$, respectively. In another trial, we also found that the yield of tomato under salinity stress at the flowering, fruiting, or between the flowering and fruiting stage was significantly different compared to no salinity condition, but there are no differences for growth variables (fresh weight, height, leaf chlorophyll and dry weight) (Zhang et al., 2016).

3.3 Water Use Efficiency (WUE)

In the present study, the average actual $ET_a$ ($ET_o; n = 6$) of the CT (0.78 dS m$^{-1}$) is defined as reference crop $ET$ ($ET_o$) for tomato growth with no salinity stress effects (Allen et al., 1998; Doorenbos and Pruitt, 1977). The average ratio of total fresh weight to actual $ET_a$ was approximate 3.56%, which showed that the fresh weight of a plant could be neglected in estimating actual $ET_a$ in the present study.

Fig. 4 shows the relationship between $ET_a/ET_o$ and salinity levels. The $ET_a/ET_o$ of the ST5 treatment was significantly different compared with the CT, indicating that salinity stress effects water uptake of tomatoes. This result is in agreement with the conclusions of Reina-Sanchez et al. (2005) and Romero-Aranda et al. (2001), who also observed that water uptake was decreased with increasing salinity. This phenomenon may be caused by an osmotic and toxic effect. Salt induction disrupts the plant osmotic balance and results in decreasing plant water uptake and closing stomatal apertures, which leads to the inhibition of transpiration (Munns and Tester, 2008). Salt induction also causes the accumulation of Na$^+$ and Cl$^-$ ions in root tissues and an imbalance of acquisition of the other nutrients, which consequently reduces root water uptake due to the toxic effect (Aroca et al., 2012).

Table 4 shows that there was no significant difference
Effects of salinity stress on fruit quality (Different ST4 ST2 ST3 ST5 bcd d ab a Acid ST1 (40) showed an increasing trend with increasing salinity of the CT. These results are in agreement with findings by et al. (2005) was much higher than that used in the present study and that by Qaryouti et al. (2007). In addition, the cultivation condition and cultivars were also different.

3.4 Fruit Quality
The average sugar and acid content (n = 48, ST3: n = 40) showed an increasing trend with increasing salinity (Fig. 5). In particular, the sugar content under ST3 and acid content under ST4 were significant different to those of the CT. These results are in agreement with findings by Auerswald et al. (1999), who reported that higher EC (1.0, 3.5, and 6.0 dS m\(^{-1}\)) values resulted in higher contents of reducing sugar and titratable acid. Ullah et al. (1994) also reported that salinity increased the contents of sugars and acids (ascorbic and citric acid) of the tomato fruits.

4. CONCLUSIONS
1. The growth variables such as plant fresh weight, SPAD value (leaf chlorophyll) and dry weight were significantly affected by salinity under the ST5 treatment (1.58 dS m\(^{-1}\)). Meanwhile, these variables also showed obviously lower values under the ST4 (1.41 dS m\(^{-1}\)) treatment compared with the other treatments, although there were no significant differences. Therefore, the threshold values of tomato growth occurred between 1.41 dS m\(^{-1}\) (ST4) to 1.58 dS m\(^{-1}\) (ST5).

2. The growth performance indicators did not show salinity stress phenomena at the same growth stage. Plant fresh weight was significantly reduced from day 49, whereas the SPAD value (leaf chlorophyll) was reduced from day 35. The SPAD value (leaf chlorophyll) was more sensitive than plant fresh weight to salinity stress.

3. The plant fresh weight, SPAD value (leaf chlorophyll), and dry weight were significantly affected by salinity under the ST5 treatment (1.58 dS m\(^{-1}\)); however, the yield decreased significantly when EC reached 1.41 dS m\(^{-1}\) (ST4). It can be concluded that the salinity threshold of tomato yield was 1.41 dS m\(^{-1}\) under a low salinity concentration using Vegetable Life A nutrient solution. It also indicated that tomato yield was more sensitive than growth variables to salinity stress.

4. ET values were obviously influenced by the salinity under the ST5 treatment. However, WUE values for yield and plant fresh weight were not influenced by salinity stress at EC values <1.58 dS m\(^{-1}\).

5. The fruit sugar and acid content were increased with increasing salinity, but at EC values <1.58 dS m\(^{-1}\).

REFERENCES


