Deficit irrigation strategies for production of tomato in greenhouse conditions

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Abstract

The effects of partial root drying (PRD) and deficit irrigation (RDI) on tomato (cultivar 'Amati') yield and fruit quality were researched and compared to full irrigation (FI). Under PRD and RDI tomato plants received 60% of the water that was applied to FI. At harvest, the effects of RDI, PRD and FI on total yield, fruit quality (total soluble solids, titrable acidity and antioxidant activity) and water use efficiency (WUE) were assessed. These results showed that with both deficit irrigation techniques is possible to increase WUE without reduction of tomato yield. Comparison between deficit irrigation techniques showed an increase in antioxidative activity in tomato fruits under PRD and indicated that PRD method could be more beneficial irrigation method than RDI.

Key words: regulated deficit irrigation, partial root drying, tomato, yield quality, water use efficiency

Introduction

Among environmental factors drought is a major limiting factor of tomato productivity and therefore tomato successful production in many areas of the world requires irrigation. However, as a consequence of global climate changes and environmental pollution, water available for irrigation is often reduced. Recent results have demonstrated that regulated deficit irrigation (RDI) and partial root drying (PRD) are new deficit irrigation strategies which may decrease demand for agricultural use of water. The application of these techniques to different crops, including tomato, has demonstrated benefits in terms of improved water-use efficiency and a stable yield, in addition to an increased yield quality (FAO, 2002; Davies et al., 2000). Both deficit irrigation methods are based on understanding of the physiological responses of plants to water supply and water deficit (Morison et al., 2008). In regulated deficit irrigation (RDI) the entire root zone is irrigated with an amount of water less than the potential evapotranspiration during specific periods of the crop cycle (English and Raja, 1996). Partial root drying (PRD) is a further development of RDI. Under PRD only half of the root zone is irrigated while the other half is allowed to dry out. The treatment is then reversed, allowing the previously well-watered side of the root system to dry while irrigating the previously dry side. The principle behind PRD is that irrigating part of the root system keeps the leaves hydrated. When exposing the remaining part of the roots to soil drying, synthesis and transport of chemical signals (particularly ABA) from roots to the shoot via the xylem is triggered (Loveys et al., 2000). Effects of PRD on plant physiology are different from RDI because wet roots under PRD sustain shoot and fruit turgor important for growth (Mingo et al., 2003). Triggering partial stomatal closure under PRD irrigation may prevent excessive water loss and lead to better water balance of the plants, and this also may prevent the metabolic inhibition of CO₂ assimilation that otherwise would occur if drought stress was allowed to develop extensively (Chaves et al., 2002). PRD or RDI research has been focused mainly on tomato yield and water-use efficiency with comparatively less research to characterize the effects of these techniques on fruit quality. One of the very important tomato fruit characteristic is antioxidant activity. Tomato fruit is significant dietary source of important natural antioxidant compounds including carotenoids, flavonoids and other
phenolic compounds. By removing free radicals these compounds might reduce the risk of the developments of chronic diseases, such as cardiovascular disease and cancer (Middleton et al., 2000). Antioxidants are also very important for plants reactions to stress conditions, including drought, because they are acting as oxygen scavenging systems able to detoxify the various forms of activated oxygen generated during stress conditions (Noctor and Foyer, 1998). The aim of presented results was to assess the effects of RDI and PRD techniques on tomato yield, WUE and fruit quality with the special emphasis on fruit antioxidant activity. This could be important not only for saving water for irrigation of tomato but also for production of food with greater human health benefits.

Material and methods
Tomato experiment was carried out in a commercial greenhouse at a local market gardener “Salate Centre” located 10 km north of Belgrade. Greenhouse design was typical for Serbia with the size of 400 m² (width 8 m and length 50 m), covered with a polyethylene film and unheated. Experimental soil in the greenhouse was classified as humogley. Planted species was Lycopersicon esculentum L., hybrid cultivar ‘Amati’. Tomato uniform seedlings were planted into greenhouse soil on the end of April in single rows each having 90 plants of 50 cm spacing in rows. When plants were in the phenological phase of first truss formed (middle of May) three irrigation treatments were tested: regulated deficit irrigation (RDI), partial root drying (PRD) and full irrigation (FI). The irrigation ended on the end of August when plants were in the growth stage 88 (growth stage code 808) (BBCH, 2001). Plants in FI treatment were irrigated every two or three days to a volumetric soil water content of 35%, although PRD and RDI plants received 60% of the water that was applied to FI. The water amount supplied in the period between middle of May and the end of August to FI, RDI and PRD treatments was 103.4 l, 60.4 l and 57.4 l per plant, respectively. The irrigation was provided by drip system (one line for FI and RDI and two for PRD). Switching of water from one to another side in PRD treatment was done for a period of approximately 5 to 7 days. Irrigation timing in all treatments was determined according to the soil moisture data measured by profile probe (PR2/6, Delta-T Device, Ltd, UK). Tomato fruits were harvested when a stage of ripeness had been reached. Yield was expressed as t FW per ha. Tomato quality was characterized on the basis of fruit FW data by measuring total soluble solids (TSS), titrable acidity (TA) and antioxidant activity (AA). Hand-held refractometer (Reichert Analytical Instruments, Depew NY) was used for measuring soluble solids concentration in fruits extracts. Titrable acidity of tomato ethanolic extract was determined by volumetric titration with NaOH and expressed as μmol citric acid content per g FW. The same extract was used to measure sugars with a refractometer. Antioxidant activity of tomato fruits ethanolic extract was evaluated according to Rotino et al. (2005) against ABTS•⁺ radical cation using the modification of the method of Böhm et al. (2002). Results were expressed as TEAC in μmol of Trolox per 100 g of sample fresh weight (Kequan and Liangli, 2006). Water use efficiency (WUE) was calculated as the ratio between yield (fruit FW) and the amount of used irrigation water. Data were processing and analysing by Statistica 7.1 data analyses software system (Stat.Soft, Inc., Tulsa, USA, 2004).

Results and discussion
Results of a tomato experiment are presented in Table 1 and Table 2. The data in Table 1 showed that yield wasn’t slightly higher in FI irrigation (48.71 t FW ha⁻¹) comparing to the RDI and PRD irrigated plants (48.58 and 43.41 t FW ha⁻¹). Although almost all studies confirmed that both PRD and RDI might be successfully applied as water saving strategy, there is a discrepancy in published results concerning the feasibility of these techniques to maintain yield. There are reports in the literature demonstrated that under PRD yield of tomato was maintain and improved in both processing tomatoes (Zegbe-Dominguez et al., 2003, 2004) and fresh market tomato (Kirda et al., 2004). On the contrary, there are also results showing an depressing input on tomato yield of plants under PRD or RDI (Tahi et al., 2007). The phenological stages of tomato or other vegetables may react differently to RDI or PRD and, therefore, scheduling of both technique should be done taking into account the stages in which the vegetables are particular vulnerable to the soil water deficit. Reproductive tomato growth, especially flower and fruit set phases, are a more sensitive phenological stage to water deficit than is vegetative growth (Srinivasa et al., 2000). Results of this research also showed that RDI and PRD tomato plants produced more fruit biomass per m³ water (61.85 and 56.02 kg FW m⁻³) compared to control plants (34.90 kg FW m⁻³) and, therefore, it is clear that an significant increases in crop WUE have been achieved (Table 1). These results confirmed beneficial
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The effect of both techniques in increasing WUE in tomato similarly to other studies (Davies et al., 2002; Fernández et al., 2006; Tahi et al., 2007; Zegbe-Dominguez et al., 2003).

Table 1: Treatments mean differences in total yield (Y) and water use efficiency (WUE) in tomato greenhouse experiment where the full irrigation (FI), regulated deficit irrigation (RDI) and partial root drying (PRD) methods were applied

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Y (t FW ha⁻¹)</th>
<th>WUE (kg FW m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>48.71</td>
<td>34.90 A</td>
</tr>
<tr>
<td>RDI</td>
<td>48.58</td>
<td>61.87 B</td>
</tr>
<tr>
<td>PRD</td>
<td>43.41</td>
<td>56.02 B</td>
</tr>
</tbody>
</table>

A,B - significantly differed after LSD 0.05.

On the basis of the biochemical analysis (Table 2), it was found out that RDI, PRD and control plants fruit did not differ significantly in statistical terms regarding total soluble solids (4.7 , 5.1 and 5.1 °Brix) and titratable acidity (20.1, 19.9 and 19.6 citric acid μmol g⁻¹ FW). Similar improvement in tomato fruit quality under PRD was obtained in earlier results with other tomato cultivar (Stikić et al., 2003). Statistically significant differences were found in antioxidant activity, due to fruits of PRD plants had higher antioxidant activity (50.87 μmol TEAC 100g⁻¹ FW) compared to the fruits of RDI and control plants (43.65 and 33.33 μmol TEAC 100g⁻¹ FW).

In literature there are no data on the effect of PRD on antioxidant activity in yield components (fruits, tubers, seeds) of agricultural crops. Only available data on the effects of PRD irrigation are those of Aganchich et al. (2007) who showed an increase in activity of several antioxidant enzymes in PRD and RDI (regulated deficit irrigation) irrigated olives. According to these authors this increase can be an important protection mechanism of the olive plant against an oxidative stress that might occur under these PRD and RDI irrigation treatments.

Table 2: Treatments mean differences in total soluble solids (TSS), titrable acidity (TA) and antioxidant activity (AA) in tomato greenhouse experiment where the full irrigation (FI), regulated deficit irrigation (RDI) and partial root drying (PRD) methods were applied

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TSS (°Brix)</th>
<th>TA (citric acid μmol g⁻¹ FW)</th>
<th>AA (μmol TEAC 100g⁻¹ FW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>5.10</td>
<td>19.60</td>
<td>33.33 A</td>
</tr>
<tr>
<td>RDI</td>
<td>4.70</td>
<td>20.10</td>
<td>43.65 A</td>
</tr>
<tr>
<td>PRD</td>
<td>5.10</td>
<td>19.90</td>
<td>50.87 B</td>
</tr>
</tbody>
</table>

A,B - significantly differed after LSD 0.05.

Conclusions

Experimental results showed that with both deficit irrigation techniques (RDI and PRD) it is possible to save irrigation water and increase water-use efficiency, without reduction of tomato yield. The increase of the antioxidant activity under PRD is very desirable characteristic that could be beneficial from the aspects of health-promoting value of tomato fruits. Further research of both techniques and application to much more tomato cultivars will allow assessment of potential practical impacts of these techniques for tomato production in the areas with restricting water resources.

Acknowledgements

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Reference


