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Effect of partial root-zone drying on grafted tomato in commercial greenhouse

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Abstract: For two years, the tomatoes (cv. 'Belle' and 'Clarabella'), ungrafted, self-grafted and grafted onto the 'He-man' rootstock, were grown under two irrigation regimes, i.e., partial-root zone drying (PRD) and fully irrigated (FI), to investigate whether grafting can alleviate drought stress and promote water-use efficiency (WUE). The grafted plants under the FI regime had the highest vegetative growth, which was the result of more leaves and greater leaf area and were only significantly different from the PRD grown ungrafted plants. The grafted plants had the highest yield as a result of the greater number of larger fruits and the yield did not differ between the irrigation treatments. No differences were found in the leaf NPK concentrations, while the Ca and Mg were higher under the PRD regime. The ungrafted plants under the PRD regime had the highest total soluble solids and acidity in the fruit juice. The grafted plants had a significantly higher WUE, more pronounced in the PRD regime. The different types of irrigation did not influence the vegetative growth and the yield in the greenhouse grown grafted tomato. The PRD and rootstock effects should be additionally investigated with deficit irrigation.

Keywords: rootstock; vegetative growth; yield; water-use efficiency; fruit quality

The tomato (*Solanum lycopersicum* L.) is an important crop in Croatia as well as worldwide (FAOSTAT 2017) and is among the crops most often grown in protected cultivation. Due to the limited availability of arable land and water resources, and the large market demand for fruiting vegetables, Cucurbitaceae and Solanaceae crops are frequently cultivated in unfavourable soil conditions. Furthermore, as a consequence of the monoculture or narrow crop rotations, problems with abiotic and biotic stressors seriously limit their production. One of the ways to avoid or reduce vegetable production losses caused by adverse environmental conditions is to graft onto rootstocks that are capable of alleviating the effects of abiotic or biotic stresses. Schwarz et al. (2010) reviewed the main advantages of using grafting to alleviate abiotic stresses. The grafting of fruiting vegetables, especially the tomato and eggplant, has increased over recent years (Lee et al. 2010).

A worldwide shortage of freshwater resources in many arid and semiarid regions, such as the Mediterranean basin, and the increased competition among agriculture, industry, and urban areas and tourism has stimulated the continuous improvement of water-saving irrigation practices. One way to reduce losses and improve the water use efficiency of high yielding genotypes is to graft them onto drought resistant rootstocks, such as that which occurs with grapes (Satisha et al. 2007). However, there has only been a limited number of studies on grafting fruit vegetables. Grafted mini-watermelons had a higher yield when grown under a deficit irrigation (DI) regime compared to ungrafted plants (Rouphael et al. 2008). Experiments with abscisic acid (ABA) deficient

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mutants of the tomato showed that the stomata can close independently to the leaf water status, which suggested that signalling by the roots controlled the stomatal conductance (Holbrook et al. 2002).

Another way to improve the growth under the water stress conditions is to use a water saving irrigation technique, such as partial root-zone drying (PRD). PRD allows one part of the roots to dry while the other part is kept irrigated in order to keep the leaves hydrated. The half of the roots being irrigated is then periodically swapped over. PRD has been shown to improve deficit irrigation and has resulted in respectable water savings, promoted water use efficiency and it is superior to DI in terms of the yield maintenance (Kirda et al. 2007; Dodd 2009). Previous studies investigated the PRD effect on the tomato (Kirda et al. 2004) and hot pepper (Dorji et al. 2005) and showed that the yield could be maintained and there were improvements in some quality parameters. Both the PRD and DI induce ABA signalling by the roots, but it is the PRD irrigation, rather than the changes to ABA, which regulates the stomatal conductance and leaf expansion, that finally leads to the greater improvements in water-use efficiency (WUE) (Dodd 2009). The literature reviewed by Kumar et al. (2017) showed that grafting can mitigate the negative effect of drought stress and increase WUE. For the crops subjected to some degree of water stress, PRD is a successful alternative when compared to DI. The possible different responsiveness between the species to PRD can occur, although other factors may influence the outcome, such as the soil type or location parameters (Sepaskhah, Ahmadi 2010). The nutrient uptake could be increased in the grafted plants as a result of the enhancement in the vigour by the rootstock root system. A drought reduces the nutrient uptake by the root and also the nutrient transport to the shoot, thus, the plant mineral content could be a useful tool to ascertain the influence of these two factors (Sánchez-Rodríguez et al. 2014). In these two experiments, the growth, yield, mineral concentrations, fruit quality and water–use efficiency were investigated after the tomatoes were subjected to grafting and/or PRD in intensively managed greenhouses. Our objective was to examine the hypothesis that grafting under PRD conditions will promote the tomato growth and yield when compared to ungrafted plants. As far as can be ascertained, this is the first report on the influence of a PRD treatment on the grafted tomato or any other fruiting vegetable.

MATERIAL AND METHODS

Experiment 1: Irrigation based on weekly shifting between two sides of the root zone. The first experiment was conducted in an unheated, commercial glasshouse in the Kaštela bay area, (latitude 42°32′N, longitude 16°17′E) located in the Mediterranean region of Croatia. The greenhouse roof was 4 m high. The soil type was a clay loam with a pH (H^2O) of 7.44, a pH (KCl) of 7.25, a soil organic matter of 2.2% and with high concentrations of available K_2O of 150 mg and P_2O5 of 174 mg/100 g of the soil. At the beginning of the experiment, cv. 'Belle' (Enza Zaden, the Netherlands) and the rootstock variety 'He-Man' (Syngenta Seeds, Switzerland) seeds were sown in polystyrene plug trays with 160 cells per tray and a volume of 23 mL on 17 March in an organic substrate (Brill Type 4, Brill Substrate, Georgsdorf, Germany). The polystyrene trays containing 'He-Man' were put in a heated greenhouse (day/night 27 °C/18°C) because they had a lower germination rate, while the 'Belle' trays were left in an unheated greenhouse. The cv. 'Belle' seedlings were grafted onto 'He-Man' rootstock and self-grafted onto their own roots at 30 days after sowing. "Splice grafting" was applied by hand at the lower epicotyl position and fixed with a simple silicone clip. The grafted seedlings were maintained under reduced light conditions (10% of the daily light intensity), at a relative humidity above 95% and a temperature from 22 °C to 25 °C until callus formation. After callus formation, all the seedlings (grafted on 'He-Man', self-grafted and ungrafted) were maintained by standard procedures for the tomato transplant cultivation. The tomato seedlings with four to five true leaves were transplanted on 9 May in a two-row system with rows that were 60 cm apart and where the plants were spaced 50 cm apart in each row.

The plants were irrigated by a drip irrigation system and no fertiliser was applied during the growing period due to the high concentrations of the available nutrients in the soil. Thirty five days after transplanting, during flowering and fruit establishment, half the plants were subjected to PRD. The PRD was established by placing irrigation points with drippers – pressure-compensating emitters (Toro, USA) with a 3 L/h flow rate opposite each other in the rows of plants (Figure 1). The two laterals with drippers were spaced 50 cm apart and were arranged in such a way that there was always one dripper centred between two plants, but installed alternately on the two sepa-

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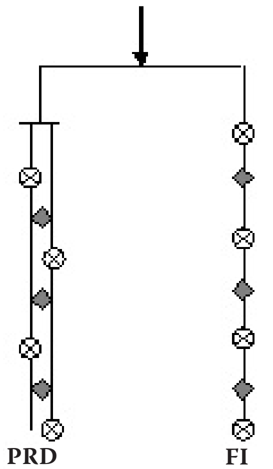

Figure 1. Scheme with two irrigation types: partial root-zone drying (PRD) and full irrigation (FI)

Key to symbols: diamonds represent tomato plants, crossed circles represent drippers

rate laterals in the PRD treatment. The wetted side of the root zone was changed by turning on the laterals, alternatingly wetting only one half of the roots during irrigation. The fully irrigated treatment had only one lateral with a dripper every 50 cm. The irrigation water was measured by collecting water from one dripper at the end of a line. The irrigation was applied according to the standard cultivation practice obtained by the farmers. The amount of water we used was 92 L/plant in the FI and 60 L/plant in the PRD treatment over the entire growing period, while 60 L/plant in the FI and 30 L/plant in the PRD were used after starting the PRD treatment. The PRD plants received only 65% and 50% of the water supplied to the FI plants in the whole growing period or after the PRD initiation, respectively. The PRD was rotated to the other side of the roots on a weekly basis.

The plant height (from the substrate to the top of the plant) and the number of leaves (longer than 2 cm) on the main stem were determined every week from the 2nd to the 9th week after transplanting until the tops of the plants were cut above the third leaf of the last cluster. At the beginning of the harvest, the whole plants were pulled out, divided into the leaves, stems and fruit and subjected to drying to determine the dry biomass (DM).

The experiment contained three plant treatments and two irrigation systems. It was a completely randomised experimental design with four replications. Each treatment comprised of 20 plants in four replications (five plants each).

Experiment 2: Partial root-zone irrigation based on soil moisture measurements by tensiometers. This experiment was conducted in an unheated, plastic greenhouse in Podstrana, near Split, Croatia (latitude 42°32′N, longitude 16°17′E). The greenhouse roof was 4 m high. The soil type was a clay loam with a pH (H_2O) of 7.89, a pH (KCl) of 7.35, a soil organic matter of 0.7% and with high concentrations of available K_2O of 63 mg and P_2O_5 of 28 mg/100 g of the soil.

In this experiment cv. 'Clarabelle' (Rijk Zwan, Netherlands) was used because cv. 'Belle', from the previous experiment, was not available on the Croatian seed market. The 'He-Man' rootstock was used (Syngenta Seeds, Switzerland). Both seeds were sown on 28 February. The grafted seedling production procedure was the same as in Experiment 1. The tomato seedlings with four to five true leaves were transplanted on 5 May in a two-row system with rows that were 60 cm apart and where the plants were spaced 50 cm apart in each row. The plants were irrigated by a drip irrigation system and fertiliser (KNO_3) was applied regarding the tomato growth phases in the amount recommended for greenhouse tomato production. The plants in both experiments were pollinated with bumblebees (Biobest, Belgium). PRD was established 35 days after transplanting with the same irrigation scheme as in Experiment 1. The plants were irrigated so that half of the plant roots were kept watered to a soil moisture content of 65–75% of the field capacity, while the other half of the roots were dried until the soil moisture reached 35–40% of the field capacity and then the irrigation was shifted between the two parts of the root system. The soil moisture content was measured by tensiometers which were calibrated for the soil. The amount of water used was 138 L/plant in the FI and 83 L/plant in the PRD treatment during the whole growing period, while 110 L/plant in the FI and 55 L/plant in the PRD were used after starting the PRD treatment. The PRD plants only received 60% and 50% of the water supplied to the FI plants in the whole growing period or after the PRD initiation, respectively. The fruits were harvested as they matured (light red colour) in order to measure the fruit yield characteristics. Eleven fruit harvests were taken over 45 days during the experiment and were categorised as early yield, starting on 7 July, 30 days after the PRD was started and 62 days after transplanting. The average fruit weight and fruit number were recorded. On the day of the last harvest,

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the aboveground parts of the plants were removed and divided into the leaves, stems and green fruits, weighed for the fresh biomass (FM), and put into an oven and dried at 70 °C to a constant weight to obtain the DM. The experiment contained three plant treatments and two irrigation systems. It was a completely randomised experimental design with four replications. Each treatment comprised of 20 plants in four replications of five plants each.

The relative water content (RWC) of the leaf was determined on the fully expanded young leaves in the morning using 1 cm diameter discs cut from the upper part of the leaves. The discs fresh weight (FW) was determined after cutting and the discs were rehydrated in the dark for at least 18 h for the leaf-turgid weight (TW). The dry weight (DW) was determined after oven drying at 105ºC to a constant weight. The RWC was calculated from the equation: RWC = 100 [(FW – DW)/(TW – DW)].

The biomass WUE (WUEb) was calculated for both years as the aboveground dry biomass divided by the water amount supplied to each plant, while the yield WUE (WUEy) in 2015 was calculated as the yield divided by the supplied water.

The leaf mineral concentrations were assessed in the youngest fully developed leaves to assess the grafting effect on the nutrient content. The leaves were dried in an oven with circulating air at 70 °C for 48 h and then ground for further analysis. The total leaf N concentration was measured by micro-Kjeldahl digestion (Kjeltec System 1026, Tecator, Höganas, Sweden). Subsequently, 0.5 g of the powdered material was subjected to dry ashing in a muffle furnace at 550 °C for 5 h, and used to extract the P and K after dissolving the samples in 2 mL of HCl. The P concentration was determined by the vanadate-molybdate yellow colour method using a UV visible spectrophotometer (Cary 50 Scan, Varian, Palo Alto, CA, USA) at 420 nm. The K concentration was measured using a flame photometer (Model 410, Sherwood Scientific, Cambridge, UK).

In the second season, four representative fruits per treatment were analysed for the fruit quality parameters. The total soluble solids (TSS) content in the juice was determined by a DR201-95 refractometer (Kruss optronic, Germany) and expressed in °Brix at 20 °C. The acidity was determined by titration with 0.1 M of NaOH and the results were expressed as the citric acid in the juice. The pH of the juice was determined with an MP230 pH meter (Mettler Toledo, UK).

In both experiments, the data were analysed by an analysis of variance (ANOVA) using StatView statistical software (StatView for Windows, Version 5.0, SAS Institute, Cary, NC, USA). When one of the factors showed significance, although the interaction of factors was not significant, comparisons of the treatment means were undertaken using Tukey's HSD test at $P \leq 0.05$ (Wei et al. 2012).

RESULTS AND DISCUSSION

Vegetative growth parameters. Although measuring the soil water content is an important requirement in the PRD experiments, we did not have access to these data during our first experiment. Our weekly based PRD rotations between the root parts were based on the findings by Zegbe et al. (2006). They found that the total fresh mass of the plant and fruit and the total dry mass of the plant (including the fruits) of the processing tomato did not differ when compared to switching irrigation after two, four and six days. They also implied that more water should be used on the wet side of the plants. In our case, this was followed by the growers' practice of supplying water in excess. Even though there were no differences in the height of plants in either experiment (data not shown), the number of leaves at 60 days after transplanting did vary (Table 1). Mohammad et al. (2009) also found no differences in the height of the plants. The grafted plants under full irrigation had the most leaves in both years, with differences only observed in the ungrafted (first year) and self-grafted (second year) plants. The increase in the number of leaves can be attributed to the improved vigour of the grafted plants. The type of plant significantly affected the dry mass of the leaves, the leaf areas, the dry mass of the stems, and the total plant dry biomass in both years (Table 1). As expected, the highest values among all the parameters were observed in the plants of both cultivars grafted onto the 'He-man' rootstock under both irrigation treatments. However, the differences were more pronounced under full irrigation. We must point out that, for some parameters, the self-grafted plants subjected to the partial root-zone drying showed higher values than the self-grafted plants under the full irrigation. It is well-known that the partial root-zone drying affects the ABA-induced stomatal closure and decreases the leaf expansion growth (Dodd 2009). Our data did not confirm this. The only significant influence on the leaf area

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Table 1. The effect of the irrigation treatment and the rootstock on the tomato vegetative characteristics

Treatments		Leaf area						Stem		Total biomass	
		Number (60 DAT)		(cm²/plant)		DM (g/plant)		DM (g/plant)		DM (g/plant)	
		2014	2015	2014	2015	2014	2015	2014	2015	2014¥	2015
Irrigation (I)	**Rootstock (R)**										
Full irrigation	Ungrafted	29.0ab*	28.0ab	10 190c	12 900b	63.1c	175b	41.3c	85.5ab	205c	508B
	Self-grafted	29.8ab	27.0b	8 821c	14 839ab	58.9c	178b	39.1c	102ab	204c	535B
	Grafted	32.1a	29.6a	27 416a	18 457a	187a	228a	69.3a	104a	404a	620A
PRD	Ungrafted	27.8b	29.5ab	9 623c	13 481b	67.6bc	180b	44.3bc	83.8b	228c	450B
	Self-grafted	29.9ab	27.4b	15,333bc	15 557ab	86.8bc	190ab	47.5bc	88.1ab	263bc	462B
	Grafted	31.3a	28.4ab	19,125ab	16 559ab	113b	209ab	55.3b	94.8ab	329ab	596A
Significance	I	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	R	**	**	***	**	***	**	***	*	***	*
	I × R	ns	ns	**	ns	**	ns	**	ns	*	ns

*Different lower-case letters within the columns indicate significant differences between the treatments and the capital letters indicate the differences between the factors by Tukey's HSD test at $P \leq 0.05$; ***significant at $P \leq 0.001$; **significant at $P \leq 0.01$; *significant at $P \leq 0.05$, ns – non-significant; ¥the total biomass also includes the fruits DM (harvested and green)

in both years was the rootstock type/grafting. The grafted plants under full irrigation had a significantly bigger leaf area than the ungrafted plants. The same was found under the PRD regime, but only in 2014. The differences found between the years could be the result of the rootstock-cultivar combination, and also of the different system of water supply. Excessive vegetative growth is a common issue in the cultivation of grafted tomatoes. The grafting onto rootstocks for the most part resulted in a highly improved plant vigour. Although this was confirmed by many previous studies, such studies also point out that the variability in the cultivar, rootstock and rootstock-scion interaction occurs. Mohammad et al. (2009) used the combination 'Cecilia F1'/'He-man' and found that, in comparison to the ungrafted plants, the grafted plants had a considerably higher shoot and root dry weight. Since the source strength does not influence the assimilate partitioning (Heuvelink 1996), it is important to balance the vegetative and reproductive growth in order to deal with the sink (fruit) limitations inherent to grafted tomato plants. Some practices that are used to control the dry matter allocation to the fruits include leaf pruning (Gaytán-Mascorro et al. 2008) and double-stem cultivation, which increases the DM allocation to the different organs (Rahmatian et al. 2014). We did not measure the root biomass in our study, even though it has been previously demonstrated that the partial root-zone drying increases the root growth (Mingo et al. 2004).

Yield, and WUE parameters. The marketable yield attributes from the second-year experiment are presented in Table 2. The fruits from the grafted plants were significantly bigger than the fruits from the ungrafted plants. We have also confirmed that the mean mass of the fruit from the grafted plants was similar under both irrigation treatments. We observed a reduction in the size of the fruit from the ungrafted plants under both irrigation treatments. This can be partially attributed to the reduction in the fruit water content, as previously demonstrated for processing tomatoes (Zegbe et al. 2006), and explained by the fact that the fruits are the strongest sink for the assimilates in the tomatoes when an adequate amount of water is supplied. The grafted plants had a significantly higher yield per plant than the ungrafted or self-grafted plants of the cultivar 'Clarabella'. There were no differences in the yield among the grafted plants under either irrigation treatment. The high marketable yield of the grafted plants subjected to the PRD was due to the mean mass of the fruit and the number of fruits per plant. Such results were consistent with the results obtained by Rouphel et al. (2008), who found that grafting mini-watermelons boosted the production by increasing both the mean mass of the fruit and the number of fruits. In contrast, previous studies showed that tomato plants of the cv. 'Belladonna' that were either self-grafted or grafted onto the 'He-man' rootstock and grown using non-saline soilless cultivation techniques produced

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Table 2. The effect of the irrigation treatment and the rootstock on the yield parameters in 2015, the relative water content (RWC), the WUEb (biomass WUE) and the WUEy (yield WUE) in the tomato

Treatments		Mean mass (g)	Number /plant	Yield /plant (g)	RWC (%) 20150	WUEb [¥](g/L)		WUEy(g/L)
						2014	2015	
Irrigation (I)	**Rootstock (R)**							
Full irrigation	Ungrafted	116^{B*}	31.4	$3\,670^{B}$	75.3^{b}	175^{b}	41.3^{c}	205^{c}
	Self-grafted	138^{AB}	25.7	$3\,360^{B}$	79.7^{a}	178^{b}	39.1^{c}	204^{c}
	Grafted	146^{A}	28.8	$4\,225^{A}$	80.3^{a}	228^{a}	69.3^{a}	404^{a}
PRD	Ungrafted	106^{B}	25.6	$2\,743^{B}$	73.5^{b}	180^{b}	44.3^{bc}	228^{c}
	Self-grafted	122^{AB}	23.4	$2\,871^{B}$	76.4^{b}	190^{ab}	47.5^{bc}	263^{bc}
	Grafted	150^{A}	27,9	$4\,193^{A}$	77.6^{a}	209^{ab}	55.3^{b}	329^{ab}
Significance	I	ns	ns	ns	**	ns	ns	ns
	R	*	ns	**	***	**	***	***
	I × R	ns	ns	ns	ns	ns	**	*

*Different lower-case letters within the columns indicate significant differences between the treatments and the capital letters indicate the differences between the factors by Tukey's HSD test at $P \leq 0.05$; [¥]the WUE parameters were calculated using the total used irrigation water, 92 L/plant in 2014 and 138 L/plant in 2015; ***significant at $P \leq 0.001$; **significant at $P \leq 0.01$; *significant at $P \leq 0.05$; ns – non-signficant

the same yield as the ungrafted plants (Savvas et al. 2011). The same result was obtained for the self-grafted cv. 'Jaguar' that was grafted onto five different rootstocks (Estañ et al. 2005).

Both the grafting and irrigation treatments significantly influenced the RWC (Table 2). The RWC was lower for the plants subjected to the PRD, while the self-grafted and grafted plants had higher RWC values than the ungrafted plants. RWC is considered an important criterion of a plant's water status and was proven to be a more stable parameter than the leaf water potential (Sinclair, Ludlow 1985). A decrease in the leaf RWC caused by water stress also reflects the metabolic activity in the plant tissues. A difference in the RWC among the ungrafted plants under full irrigation could indicate that the root system was not able to compensate for the water. This was even more pronounced for the plants subjected to PRD. A higher RWC in the grafted tomato plants under water stress could result in improved osmoregulation (Kumar et al. 2017).

The highest WUEb was achieved by the grafted plants subjected to the partial root-zone drying. The difference observed for the grafted plants under the full irrigation treatment was not as significant in 2014 as in 2015 (Table 2). The self-grafted and ungrafted plants achieved higher WUE values when subjected to the partial root-zone drying, with such values being more pronounced in the first year. On average, the plants subjected to the PRD used the water more efficiently, just like the water-stressed watermelons (Rouphel et al. 2008). Also, Yang et al. (2012) reported that an alternate PRD improved the tomato yield slightly and the yield WUE greatly when compared to conventional irrigation. Greenhouse grown hot peppers had a significantly higher irrigation WUE under alternate PRD than in plants grown under deficit or full irrigation (Shao et al. 2008). Regarding WUEy, the highest value was noted for the grafted plants subjected to the PRD, while the values significantly differed for the plants under all the other treatments. This study showed that the grafted plants achieved higher values for both types of WUE and that such higher values were more pronounced for the plants under the PRD irrigation treatments.

Mineral composition and fruit quality parameters. The leaf analysis revealed that the N, P and K concentrations were not significantly influenced by the treatment in either year (data are not shown). All the values were within the range of sufficiency proposed by Sonneveld, Voogt (2009) for the greenhouse tomato. Many studies found that certain graft combinations are more efficient in absorbing and transporting nutrients than in non-grafted plants (reviewed by Savvas et al. 2010). Our results also suggest that the partial root-zone drying did not improve the N content in the leaves, as shown by other studies on tomatoes (Wang et al. 2010). In addition, the N content was not affected by grafting when under the same water supply regime, which is not in line with the findings on melons reported

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Table 3. Effect of irrigation treatment and rootstock on tomato leaf mineral concentrations (Ca and Mg) and fruit quality characteristics

Treatments		Ca (g/kg)	Mg (g/kg)	TSS (Brixº)	TA (g/L)	pH
Irrigation (I)	**Rootstock (R)**					
Full irrigation	Ungrafted	33.7[ab*]	3.70[B]	5.3[b]	5.3[ab]	4.35[a]
	Self-grafted	30.0[b]	3.13[B]	5.3[b]	4.9[b]	4.38[a]
	Grafted	42.0[ab]	2.87[B]	5.1[b]	4.9[b]	4.39[a]
PRD	Ungrafted	36.9[ab]	4.47[A]	5.9[a]	5.7[a]	4.31[ab]
	Self-grafted	50.1[ab]	4.20[A]	5.5[ab]	5.5[ab]	4.18[b]
	Grafted	53.0[a]	3.83[A]	5.3[b]	5.2[ab]	4.34[a]
Significance	I	*	*	**	**	**
	R	ns	ns	**	ns	*
	I × R	ns	ns	ns	ns	*

*Different lower-case letters within columns indicate significant differences between treatments and capital letters indicate differences between factors by Tukey HSD test at $P \leq 0.05$; ***significant at $P \leq 0.001$; **significant at $P \leq 0.01$; *significant at $P \leq 0.05$; ns – non-significant; TSS – otal soluble solids; TA – titratable acidity

by Ruiz et al. (1997), who demonstrated that the rootstock genotype effects the crop N uptake. In the second-year experiment, a significant difference was observed for the leaf Ca and Mg (Table 3). On average, the leaves of the plants subjected to PRD had more Ca and Mg, while the plants grafted on 'He-man' had more Ca under both irrigation treatments. The enhanced Ca uptake induced by grafting and the higher Ca translocation rates is important for the Solanaceae fruits due to the possibility of blossom-end rot incidence. More leaf Mg in the plants under the deficit irrigation was also observed for the mini-watermelons (Rouphel et al. 2008). The lowest Mg leaf concentrations were found in the grafted plants, which is in agreement with the previous findings demonstrating that the Mg uptake largely depends on the rootstock genotype, such as 'He-Man' (Kyriacou et al. 2017). No significant differences were found in the fruit mineral concentrations between the treatments (data not shown), but it should be pointed out that the fruit from the grafted plants subjected to the PRD had the highest Ca concentration.

Even though the total soluble solids (TSS) and titratable acidity (TA) of the fruit were higher in the plants subjected to the PRD, the tomato juice pH was higher under the FI treatment (Table 3). In addition, the TSS was affected by the rootstock type and was the highest in the ungrafted plants subjected to the PRD. This can be attributed to the effect of the water deficiency, which decreases the plant growth, yield and fruit water content (Kyriacou et al. 2017). The higher acid concentration (i.e., TA) under the PRD irrigation together with higher the sugar concentration (i.e., TSS) may bring an improvement in the general taste of the tomato fruits as proposed by Sun et al. (2014).

CONCLUSION

The results of the present studies indicate that the partial root-zone drying, as a water-saving technique, did not have a negative effect on the vegetative growth and fruit yield of the tomato cultivars 'Belle' and 'Clarabelle' grafted onto the 'He-Man' rootstock and cultivated in a greenhouse. The grafted plants had higher water-use efficiency, while the N, P and K concentrations were not significantly influenced by the treatments. The leaf Ca and Mg levels were the highest in the plants subjected to the PRD, while the plants grafted onto 'He-man' had the most Ca under both irrigation treatments. In both seasons, on average, 40% less irrigation water was used for the whole growing period, so using PRD could be of high importance in water shortage periods. The profitability of this watering regime for the tomato growth in greenhouses requires the fine tuninig of the irrigation pattern and amount of water supplied to the plant responses, as does the selection of simple control systems for the PRD usage. Even though the PRD irrigation exerted a positive effect on the greenhouse grown grafted tomatoes, in order to properly account for the overall water availability, future studies should

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include a deficit irrigation treatment in which the amount of received water would be the same as in the PRD, but evenly applied to the whole root system.

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