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Short communication

Deficit irrigation and partial rootzone drying maintain fruit dry mass and enhance fruit quality in 'Petopride' processing tomato (*Lycopersicon esculentum*, Mill.)

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Abstract

Water supply is limited worldwide and there is a need for saving of water in irrigation. This research compared deficit irrigation (DI) with partial rootzone drying (PRD) for their effects on yield and fruit quality of 'Petopride', a processing tomato cultivar. The treatments were: full watering of both sides of the root system (RS) at each irrigation considered as the control (C), half of irrigation water in C divided equally to both sides of the RS with each watering (DI), and half of irrigation water in C given only to one side of the RS with each irrigation (PRD). There were no significant differences in fruit dry mass among treatments at $P \leq 0.06$, and the following treatment effects were observed at $P \leq 0.05$. Fruit number and fruit water content (FWC) were reduced in DI and PRD relative to C, and fruit were redder in the former two treatments. Concentration of soluble solids was higher in DI and PRD fruit than in C fruit. Maturity in PRD fruit was advanced by one week compared to DI and C fruit. But dry mass yield and fruit quality attributes were the same between DI and PRD treatments. DI and PRD are feasible water saving practices for areas with limited water supply.

Keywords: Irrigation; Water conservation; Water saving

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1. Introduction

Water supply is limited worldwide (Postel, 1998) and there is an urgent need to identify and adopt effective irrigation management strategies. As irrigation of agricultural lands accounts for over 85% of water usage worldwide (van Schilfgaarde, 1994), even a relatively minor reduction in irrigation water could substantially increase the water available for other purposes. Tomato has the highest acreage of any vegetable crop in the world (Ho, 1996), therefore adoption of deficit irrigation (DI) and partial rootzone drying (PRD) could make substantial contribution to saving of water. DI, where only a portion of evapotranspiration is given to plants over the entire root system (RS), has been assessed for tomato with mixed results. Pulupol et al. (1996) observed a significant reduction in dry mass yield for a glasshouse cultivar, while Mitchell et al. (1991) reported no reduction for a field-grown processing cultivar. PRD is a relatively new irrigation strategy, where at each irrigation time only a part of the RS is wetted with the complement being left to dry to a pre-determined level. It could save water by 50% and yet maintain yield as shown for some grape cultivars by Loveys et al. (2000). PRD has not been studied for tomatoes and this technique might be more relevant for processing cultivars that are normally grown in the field. Our experiment was done using the processing cultivar 'Petopride' with the objective of comparing the effects of DI and PRD on dry mass yield and on some fruit quality attributes. Because part of the RS is always in contact with moist soil in a PRD treatment, we expected that plant water potential might be maintained and therefore different yield and fruit quality responses could result compared to a DI treatment, where the entire rhizosphere might experience water deficit. The experiment was carried out in a glasshouse to avoid interference by rain and to minimise the adverse effects that frequently changing weather might have on plant responses.

2. Materials and methods

The experiment was conducted under glasshouse conditions at the Plant Growth Unit, Massey University, Palmerston North (latitude 40°2′S, longitude 175°4′E), New Zealand, from January to July 2001. Seeds were sown on 22 January 2001 and 7-week-old individual plants were transplanted into nine wooden boxes each housing three containers with one experimental plant per container with dimensions 600 mm × 600 mm × 200 mm. Plants were grown in a bark:pumice:peat mixture comprising 60:30:10 by volume. They were fertilised (180 g per container) with a 1:2 (w:w) mixture of short-term (15N–4.8P–10.8K) and long-term (16N–3.5P–10K) slow release osmocote fertiliser, respectively (Scotts Australia, Baulkam Hills, NSW, Australia).

Ten days after transplanting, the following three treatments were applied: full watering of both sides of the RS at each irrigation considered as the control (C), half of irrigation water in C divided equally to both sides of the RS with each watering (DI), and half of irrigation water in C given only to one side of the RS with each watering (PRD). Each wooden box was considered as a block to randomly allocate the above three treatments in a randomised complete block design (RCBD) with nine replications.

Saturation and field capacity for this growing medium and their relationship with volumetric water content (θ) were determined before setting up the experiment following Parchomchuk et al. (1997). Field capacity was reached at θ of 20%. The amount of water to be applied was calculated by using θ readings in the control before each irrigation. The values of θ were measured for both sides of the RS, at a depth of 200 mm, after daily irrigation. Time-domain reflectometry was used to measure θ (Trase Systems-Soil Moisture Equipment Corp., Santa Barbara, CA, USA). Plants were hand-irrigated once a day with, on average, 1 l per plant for DI and PRD and 2 l per plant for C. The irrigation in PRD treatment was given 10 cm away from the main stem and covered an area of 600 mm × 200 mm. The treatments started with full irrigation and then the south side of RS for the PRD treatment was allowed to dry while the north side was irrigated daily. Irrigation in PRD was shifted to the dry side when θ for this side dropped below 10%. Leaf water potential was measured on five occasions in two exposed leaves per plant using a Scholander pressure chamber (Soil Moisture Equipment Corp.).

From the first trusses, over each of the four harvests, 45 fruits per treatment (5 fruits per replication) were randomly chosen at the firm red stage for quality measurements. Skin colour, in terms of hue angle, was measured at harvest on two opposite sides of the middle part of each fruit using a chromameter (CR-200; Minolta, Osaka, Japan). After sampling for colour, fruit were cut into halves and few drops from each half were used to measure total soluble solids concentration (TSSC) with a hand-held refractometer with automatic temperature compensation (ATC-1 Atago, Tokyo, Japan). After sampling for TSSC, the fruit were oven-dried at 85 °C to a constant mass for measuring total fruit dry mass. Fruit water content (FWC) was expressed on a dry mass basis. The data were analysed by RCBD model using the GLM procedure of SAS software Version 8.2 (SAS Institute, Cary, NC, USA). Treatment means were separated by least significant difference (LSD) test at $P \leq 0.05$ unless otherwise specified.

3. Results and discussion

Generally, the θ values were significantly lower in DI and in the non-irrigated part of PRD treatment compared to those of C (Fig. 1). Fruit dry mass per plant, measured on all fruit, was the same among treatments at $P \leq 0.06$ (Table 1). Mitchell et al. (1991) also reported that moderate levels of water deficit did not significantly reduce fruit dry mass in the processing cultivar 'UC82B'. Fruit growth in this experiment occurred in autumn and early winter with radiation levels and evaporative demand being generally low. For example, while measuring photosynthesis (data not presented) on 9 April, 10 May, 25 May, and 1 July, we measured photosynthetically active radiation values of 195 ± 11, 213 ± 11, 86 ± 5, and 455 ± 28 μmol m^{-2} s^{-2}, respectively, and daily values of evaporation were 3.0, 1.8, 0.9, and 0.8 mm, respectively. The lower θ for DI and PRD was not reflected in their leaf water potential for the five occasions they were measured. The lowest midday leaf water potential values we measured for DI and PRD treatments were −0.65 and −0.71 MPa, respectively, which were not significantly different from that of C (−0.52). The maintenance of leaf water potential with decreasing soil water status is expected in low evaporative demand of the atmosphere as reiterated by Hsiao (1990).

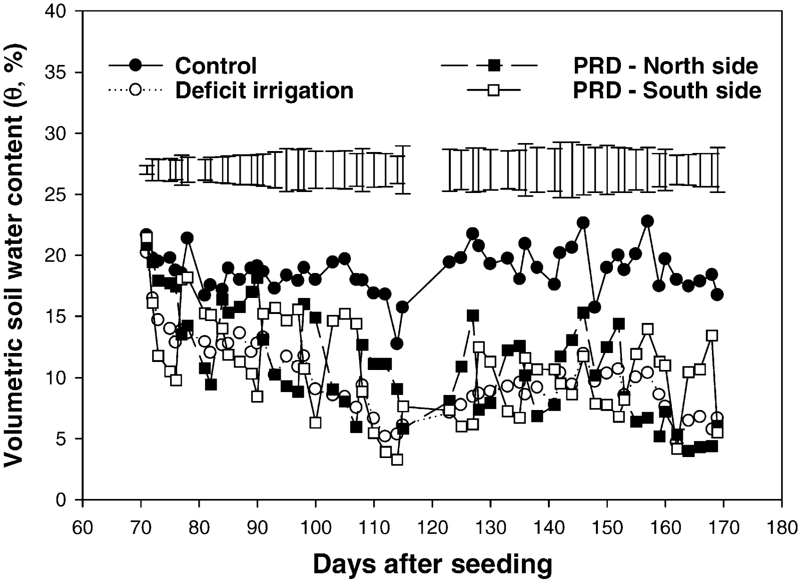

Fig. 1. Changes in volumetric soil water content (θ) in the control, DI, and north and south sides of PRD treatments. Vertical bars represent the LSD at $P \leq 0.05$.

Although, fruit dry mass per plant was the same among treatments at $P \leq 0.06$ (Table 1), C had a higher dry and fresh mass of fruit than DI and PRD treatments at $P \leq 0.05$. Values of fresh mass (kg per plant) for C, DI, and PRD were 5.4, 4.4, and 4.4, respectively. The yield differences between C and the other treatments indicate the importance of irrigation water quantity while the similarity of yield between DI and PRD shows that it does not make a difference, whether the same volume of water is given to the entire RS or only to part of it. The same conclusion was reached for apple by Caspari et al. (2002).

FWC was lower in DI and PRD than in C (Table 1), and this is preferred by the processing industry because less energy would be needed to evaporate water from the fruit. Fruit number reduction in DI and PRD (Table 1) could be the result of floral abortion induced by water deficit (Pulupol et al., 1996). A higher fruit size, in terms of mean fresh

Table 1
Effect of irrigation treatments (ITs) on fruit number (FN) per plant, fruit fresh mass (FFM) per plant, fruit dry mass (FDM) per plant, mean fresh mass of fruit (MFMF), FWC, TSSC, and fruit colour in terms of hue angle (HA°)[a]

ITs	FN	FFM (kg per plant)	FDM (g per plant)	MFMF (g)	FWC (g H_2O g^{-1} dry mass)	TSSC (%)	HA°
C	64a	5.4a	268a	85.5ab	19.3a	4.2b	48.3a
DI	51b	4.4b	245a	87.5a	17.6b	4.7a	46.5ab
PRD	57ab	4.4b	238a	78.2b	17.2b	4.5a	46.0b
P	≤0.05	≤0.05	≤0.06	≤0.05	≤0.05	≤0.05	≤0.05

[a] Different letters within columns indicate differences by the LSD test at the stated *P* levels.

mass, in DI (Table 1) could be due to reduced crop load. The TSSC in fruit was higher in DI and PRD than in C (Table 1), which is also important for processing industry (Mitchell et al., 1991). The TSSC and FWC were highly correlated ($r = -0.80$ and $P \leq 0.0001$) and therefore the increased TSSC in the DI and PRD fruit could be attributed to a lower FWC. This could be further examined by using the formula $C_1V_1 = C_2V_2$, where C and V are TSSC and volume of water in the fruit, respectively. Using the measured FWC values in this equation, the expected values of TSSC (%) were 4.2, 4.2, and 4.5 for C, DI, and PRD treatments, respectively. Except for the DI treatment, these values are identical with the measured values presented in Table 1. Higher conversion of starch to sugars under water deficit (Kramer, 1983, p. 364) could also be another reason for higher measured values of TSSC in DI and PRD treatments.

Although, differences in red fruit colour were not visible among treatments at harvest and fruit were picked based on visual colour uniformity, PRD fruit had the lowest hue angle (Table 1) and were therefore redder. A higher lycopene accumulation under water deficit has been speculated as a reason by Pulupol et al. (1996). The PRD fruit were ready for picking one week before the other treatments and this has positive implications in terms of marketing. This advancement in fruit maturity observed in PRD treatment deserves further study.

We have shown that dry mass yield for 'Petopride', a processing tomato cultivar, did not decrease under DI and PRD compared to full irrigation ($P \leq 0.06$). Statistics notwithstanding this translates into a decrease of fruit dry mass per plant by 9% for DI and by 11% for PRD compared to C (Table 1). This reduction could be justified where water is expensive for tomato production. Irrigation use efficiency values, defined here as dry mass of fruit produced per litre of irrigation water applied, were 1.7, 3.2, and 3.3 for C, DI, and PRD treatments, respectively. Besides saving of water by 50% and increasing irrigation water use efficiency by approximately 200%, some relevant fruit quality attributes were improved in both DI and PRD treatments (Table 1). PRD did not have any advantages over DI except for the advancement in fruit maturity. Field research is recommended not only to confirm this advantage, but also to assess the overall possible advantages of PRD which could potentially save water by 50%.

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References

Caspari, H.W., Einhorn, T., Neal, S., Alspach, P., Leib, B.G., Lombardini, L., McFerson, J.R., 2002. Irrigation volumes rather than placement determine response of apple trees to deficit irrigation. In: Proceedings of the XXVIth International Horticultural Congress and Exhibition (IHC2002), August 11–17, Toronto, Canada.

Ho, L.C., 1996. Tomato. In: Zemaski, E., Schaffer, A.A. (Eds.), Photoassimilate Distribution in Plants and Crops: Source–Sink Relationships, Marcel Dekker, NY, USA, pp. 709–728.

Hsiao, T.C., 1990. Plant–atmosphere interaction, evapotranspiration, and irrigation scheduling. Acta Hort. 278, 55–66.

Kramer, P.J., 1983. Water Relations of Plants. Academic Press, London.

Loveys, B.R., Dry, P.R., Stoll, M., McCarthy, M.G., 2000. Using plant physiology to improve the water use efficiency of horticultural crops. Acta Hort. 537, 187–197.

Mitchell, J.P., Shennan, C., Grattan, S.R., 1991. Developmental changes in tomato fruit composition in response to water deficit and salinity. Physiol. Plant. 83, 177–185.

Parchomchuk, P., Tan, C.S., Berard, R.G., 1997. Practical use of time domain reflectrometry for monitoring soil water content in microirrigated orchards. HortTechnology 7, 17–22.

Postel, S.L., 1998. Water for food production: will there be enough in 2025? BioScience 48, 629–637.

Pulupol, L.U., Behboudian, M.H., Fisher, K.J., 1996. Growth, yield and postharvest attributes of glasshouse tomatoes produced under water deficit. HortScience 31, 926–929.

van Schilfgaarde, J., 1994. Irrigation—a blessing or a curse. Agric. Water Mgmt. 25, 203–219.