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Short note

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Impact of partial root-zone drying on growth, yield and quality of tomatoes produced in green house condition

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Abstract: Water resources are limited for irrigation worldwide especially for the arid and semi-arid regions; therefore, there is an urgent need to reassess an alternative technique for conventional irrigation. Partial root-zone drying (PRD) is considered a new water-saving irrigation technique which has been tested for some crop species. The PRD technique simply requires wetting half of the rooting zone and leaving the other half dry, thereby utilizing reduced amount of irrigation water. The wetted and dry sides are interchanged in the subsequent irrigations. The focus of this article is to evaluate the effect of PRD on growth, yield and quality of tomatoes as compared to conventional irrigation. To evaluate the effect of PRD, a greenhouse experiment was conducted where two irrigation treatments were tested during a 160-day growing period: (1) control treatment where drip irrigation was applied to both sides of the plants; (2) PRD treatment in which half of the irrigation water in drip irrigation was given alternately only to one side of the root system with each irrigation. PRD treatment had 15% and 7% decreases in shoot fresh weight and leaf area of plant, respectively; however, PRD had 20% higher fruit per cluster and 18% increase in fruit production in comparison to the control treatment. No significant difference was detected on fruit size between PRD treated plants and control plants. But, fruits from PRD treated plant exhibited better appearance, higher lycopene content, firmness, total soluble solid (TSS), and TSS/titratable acidity (TA) ratio than control ones. Fruit from control treatment contained higher chlorophyll content than fruit from the PRD treatment. Postharvest storage results indicated that higher percentage of rot and chilling injury were observed in control fruits than PRD treated fruits. The results of this study indicated that PRD is a promising water saving irrigation technique which is able to produce higher yield and better quality tomatoes than conventional drip irrigation.

1. Introduction

Worldwide, agriculture accounts for 70% of all water consumption, as compared to 20% for industry and 10% for domestic use. The world's population is growing by roughly 80 million people each year. More than

99% of the world's food supply comes from the land. As the world population continues to grow geometrically, great pressure is being placed on irrigation water to provide an adequate food supply. Therefore, there is a big challenge on how to increase food production with limited water resources. This is especially true for tomato (*Lycopersicon esculentum* Mill), which is the second most important vegetable crop with a total world production of 130 million tons in 2016 (Euro-fresh, 2016).

The challenge becomes even more severe in arid and semi-arid regions where water availability is decreasing and competition for water is increasing between agriculture and industry. Therefore, water resources should be used with a higher efficiency as well as a higher productivity.

Partial root-zone drying irrigation (PRD) is one of the new efficient and productive water-saving irrigation methods that can save irrigation water up to 50% in processing tomatoes (Casa and Rouphael, 2015). This technique has the potential to significantly reduce crop water use (El-Sadek, 2014), reduce canopy vigor, but able to maintain crop yields and quality of crops (Sun *et al.*, 2014) as compared to conventional irrigation methods. Although processing tomatoes accounts for the majority of tomato tonnage, while the comparatively higher prices of fresh market tomatoes make them higher ranked in terms of value. To evaluate the effect of PRD on fresh market tomatoes, an experiment was conducted in greenhouse with the objective to compare the effect of conventional drip irrigation (CDI) to PRD drip irrigation on the growth, yield and quality of the fresh market tomatoes.

2. Materials and Methods

Experimental conditions

The experiment was conducted in a greenhouse (approximately 24°C in day time and 15°C at night time, Relative Humidity (RH) 65%, 15 hour's photoperiod and ambient light condition) at the Chateau Fresno Nursery, 13505 South Fresno, California 93609, USA from April to September 2015. Seeds of the fresh market tomato (*Lycopersicon esculentum* Mill cv. Vibelco) were sown on March 1st, 2015. Thirty days after seeding, uniform plants were transplanted into 12 wooden boxes (2.53 m length × 0.65 m width × 0.20 m height each). Each box had 4 compartments (0.50 m length × 0.50 m width × 0.20 m height) with one experimental plant per compartment. To avoid lateral water movement, a small piece of plastic (0.50 m length × 0.025 m width × 0.04 m height) was placed centrally on the base of each compartment. Plants were grown in a vermicast and coconut fiber mixture (70:30 v/v). Plants were fertilized with 15-15-15 (NPK) at 120 kg/ha, purchased from Lowes, Elk Grove, California, USA. Bees were used for pollination.

Irrigation treatments

Two weeks after transplanting two irrigation treatments were tested. Treatments were: control (conventional drip irrigation, CDI) to both sides of the root system, and half of irrigation water in drip irrigation given alternately only to one side of the root system with each irrigation (PRD) (Fig. 1). Irrigation treatment was given 0.10 m away from the main stem and on both sides of the row. Irrigation covered a total area and soil volume of 0.24 m^2 and 0.048 m^3, respectively. But half of it at 10:00 h and the other half at 16:00 h by manual drip irrigation system. Two irrigation lines were set up and operated separately for the PRD treatment. Two emitters per plant (one on each line) each emitting 4 L/h were placed 0.15 m away from the main stem of each plant. Irrigation in CDI treatment covered a total area and soil volume of 0.018 m^2 and 0.004 m^3, but half of irrigated area and soil volume was wetted in PRD treatment at each irrigation. There was some drainage in all treatments, but this was not measured. However, water losses by drainage were minimized by adjusting the amount of water as the crop developed. So, values of the irrigation use efficiency

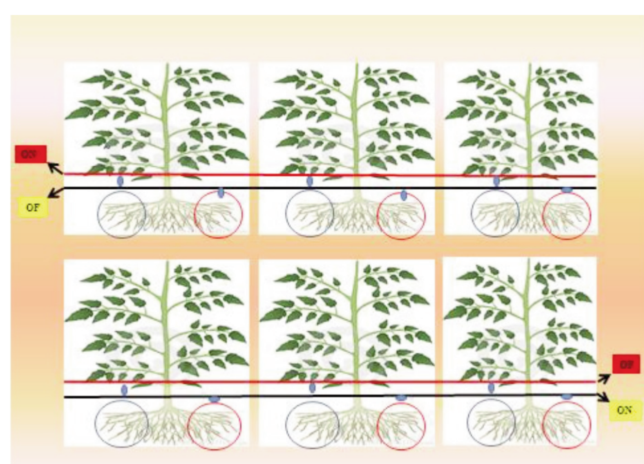

Fig. 1 - Schematic diagram of partial root-zone drying (PRD) irrigation in tomato plants.

presented here might have been under-estimated considering the water losses by drainage.

Growth, yield, yield component, fruit firmness, fruit water content and blossom-end rot measurements

Growth, yield, yield components and blossom-end rot were measured from twelve (12) randomly selected plants/fruits from each treatment. The plant heights were measured with a tape from the base of the plant to the tip of the plant. Plant growth and development data were taken on the sampled tagged plants monthly for three months. Leaf area was measured using a destructive method. Total leaf area (cm^2) was measured by leaf area meter (Model, Delta-T, Cambridge, UK). The numbers of clusters were counted per plant from the first to the last cluster during the growing period. The numbers of fruits were counted when the plants started fruiting. The fruit weights were determined after harvesting the tomato using a weighing balance. After 150 days, one plant per treatment per replication was destroyed and the total vegetative fresh weight was assessed and expressed as kg/plant. Mature green tomato fruit firmness was measured using an Instron Universal Testing Machine with a 0.5 cm^2 plunger, measurement was taken at the mid-section of the fruit. Water content of fruit was expressed on a dry weight basis. Fruit blossom-end rot incidence was recorded and calculated in percentage of fruit affected per plant.

Fruit quality at harvest or postharvest

For postharvest quality evaluation, six (6) replicates of five (5) mature green (Cascio, 2017) fruits from each treatment were randomly chosen approximately 130 days after transplanting and were stored in a dark refrigerated room at 3°C with 95% RH. After a storage period of 2 weeks, all fruits were moved to a ventilated room without supplemental light at 24°C with 65% RH and held for 7 days. The following attributes were checked for quality measurements: weight loss, chilling injury, decay, appearance/color change, total soluble solids (TSS), pH, titratable acidity (TA), chlorophyll and lycopene content.

Fruit weight loss was determined prior to and after storage. It was calculated as the percentage of initial fresh weight. Color development was observed visually using a subjective scale with mature green (MG) = 1, breaker (B) = 2, pink (P) = 3, light red (LR) = 5 and Red (R) = 6 (USDA, 2005). Chilling injury (surface pitting) was rated visually by estimating the percentage of the injured fruits. Decay (unidentified) was rated visually and calculated as a percentage of fruit affected.

Chlorophyll and lycopene content were determined from three randomly selected fruits from each treatment by grinding pericarp tissue (about 5 g) in 15 ml acetone. The extract was taken for centrifugation at 35,000 rpm for 10 minutes. Before centrifugation, the tubes were covered with aluminum foil to prevent light-induced lycopene oxidation. After centrifugation, the supernatant was decanted and adjusted to 20 ml with acetone. Absorbance of the extracts at 664 nm for chlorophyll and 503 nm for lycopene was measured with a spectrometer (Model 160 A). Total chlorophyll content in milligram per 100 gram of tissue was calculated according to the formula developed by Holden (1976). Lycopene content was calculated using the molecular extension coefficient of 3240 (Davis, 1976) and expressed as micrograms per gram of fresh weight.

Total soluble solid (TSS), pH and titratable acidity (TA) were measured on juice extracted from fruit. TSS content was determined with a digital refractometer (Atago, Model 1, Tokyo, Japan). TA was determined by a Metler Auto titrator (Model V 20) and pH was measured with an autocal pH meter (Model PHM 83).

Experimental design and data analysis

A completely randomized design was used with the two treatments replicated six times with four plants per replication for each treatment. Data were analyzed by a complete randomized model using the GLM procedure of SAS software version 8.2 (SAS Institute, Cary, NC, USA). Student's t-tests were used to determine significant effects between two treatment means.

3. Results and Discussions

Mean plant height over the 3 months are illustrated in figure 2. The maximum height was obtained from tomato plant irrigated with CDI/full water regime. PRD treated plants resulted in the lower height. Similar results were reported by Pal *et al*. (2016) who grown tomato plant under deficit irrigated conditions plus paclobutrazol application.

PRD treatment had 15% and 7% decreases in shoot fresh weight and leaf area of plant, respectively. However, PRD had 20% higher fruit per cluster and 18% increase in fruit production in comparison to the CDI treatment (Table 1). The difference between CDI and PRD treated plant's shoot fresh weight, leaf area, and fruit production were significantly different at

0.001, 0.01 and 0.05% level respectively. The CDI treated plant appeared to have excess moisture in root zone, which causes root inactivity contributing to lower yield and delayed maturity of the crop as compared with the PRD treated plant.

Mean cluster per plant, fruit per cluster, total fresh weight of fruit per plant and fruit weight (individual) were lower in CDI treated plants as compared to PRD treated plants. The difference was statistically significant only in case of cluster per plant and total fresh weight per plant (Table 1). The lower cluster number, less fruit per cluster and less weight of fruit per plant in CDI treated plant might be due to the excessive vegetative growth as a result of luxurious amount of water application.

PRD treated plant's fruit exhibited significantly higher percentage of blossom-end rot as compared to the CDI treated ones. The blossom-end rot is a physiological disorder of tomato fruit caused by calcium deficiency or excessive soil moisture fluctuation which reduce uptake and movement of calcium into

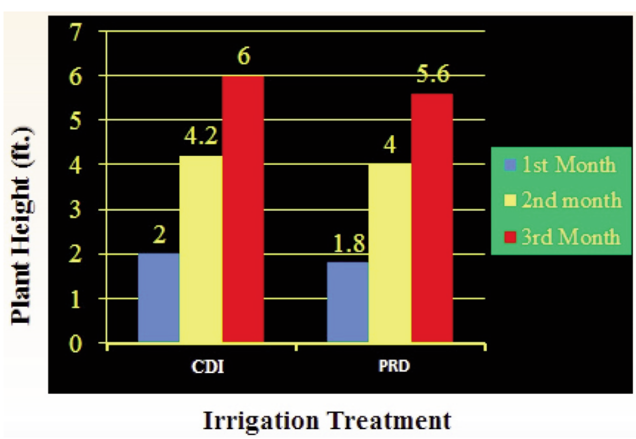

Fig. 2 - Effect of CDI (conventional dripping irrigation) and PRD (partial root-zone irrigation) on plant height over 3 months.

the plant (Mathew and Salvadore, 2007). The higher percentage of blossom-end rot in PRD treated fruit might be due to the reduced movement of calcium to the PRD treated plants. However, no calcium was analyzed either from leaf or from fruits in this study.

Fruit size, water content and fruit weight were influenced by PRD treatment. There were some differences in fruit size, weight and water content in PRD and CDI treated plant's fruit; however, the difference were not statistically significant (Table 1).

Reduced weight loss in the PRD treated tomatoes during the storage is a positive quality attribute in tomato fruit especially for distant market (Table 2). Yadav and Singh (2014) indicated that the weight loss of fruits in storage condition is mainly from water loss and from solid constituents. The lower water loss in PRD treated fruit might be due to lesser incident of micro-cracks in the skin. However, no skin micro-cracks were examined in this study.

In this study, when compared to fruits from CDI treated plants, fruits from PRD treated plants exhibited significantly lower chlorophyll and higher lycopene content on the 7th day at 24°C followed by a 2-week storage period at 3°C (Table 2). Klunklin and Savage (2017) also detected significantly higher lycopene content in PRD treated tomato fruit.

According to Gindi *et al*. (2016), 63 percent of consumers' purchase interest depends on color of fruits. Table 2 demonstrated that fruits from PRD treated plants exhibited less visible chilling injury (fruit surface pitting) and decay, but similar color change as fruits from CDI treated ones. In the regions of the world where irrigation water is expensive, such as arid and same-arid regions, PRD treatment would be beneficial in terms of economic return, where water supply is crucial.

Soluble solids are an important tomato quality

Table 1 - Effect of PRD on tomato fruit size, total fresh weight, water content, fruit firmness, cluster/plant, fruit/cluster, shoot fresh weight, leaf area, and blossom-end rot

Physiological parameters	Treatment		Difference (PRD-CDI)
	CDI Group	PRD Group	
Fruit size, diameter (mm)	68.4	67.8	0.6 NS
Total fresh weight of fruit (kg/plant)	5.1	7.03	1.93 ***
Fruit water content (%)	95.2	94.8	0.4 NS
Fruit weight (g)	95.2	95.0	0.2 NS
Fruit firmness after harvest (kg/cm^2)	9.1	9.0	0.1 NS
Cluster/plant	8.1	10.2	2.1 ***
Fruit/cluster	6.1	6.3	0.2 ns
Shoot fresh weight (kg)	10.6	9.1	1.5 ***
Leaf Area (cm^2)	451.54	418.26	33.28 *
Blossom end rot (%)	5.5	6.0	0.5 ***

NS, *, **, *** Non-significant or significant at t≤0.05, 0.01 or 0.001 respectively.

parameter. Tomato flavor is generally determined by the content of soluble solids and acid (titratable acid). According to Aoun *et al*. (2013), tomato flavor impact is co-related to total sugar and acid. In this study, total soluble solid (TSS), TSS/TA and pH increased, while TA decreased in PRD treated fruits (Table 2). In an earlier study, Sun *et al*. (2014) also detected higher TSS in tomato fruit produced under PRD condition. The higher TSS and lower TA in fruit from PRD treated plants were probably due to the less retained water in fruit from PRD treated plant than fruit from CDI treated plant. The higher pH in fruit from PRD treated plant was compatible with the lower TA in fruits from PRD treated plant than in fruits from CDI treated plant.

4. Conclusion

The result of this study demonstrated that "Vibelco" tomato plant treated with PRD slowed its vegetative growth, but produced higher yield and better quality fruit at the same time saved water by 50%. This study proved that PRD is a noble water saving method which can prevent excess water use and increases economic returns due to the reduction of water use.

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Table 2 - Effect of PRD on weight loss, chilling injury, decay, chlorophyll content, lycopene content, color change, pH, titratable acidity (TA), total soluble solid (TSS), and TSS/TA in mature green tomatoes on the 7th day at 24°C following a 2-week storage period at 3°C

Physiological parameters	Treatment		Difference (PRD-CDI)
	CDI Group	PRD Group	
Weight loss (%)	2.15	1.96	0.19 ***
Chilling injury (%)	15.00	10.00	5.0 NS
Decay (%)	13.00	8.00	5.0 ***
Chlorophyll (mg/100 g fresh weight)	3.90	3.20	0.7 **
Lycopene (µg/g fresh weight)	7.10	7.70	0.6 *
Color Change	4.50	4.50	0.0 NS
pH	4.40	4.55	0.15 NS
TA (% Citric Acid)	0.49	0.46	0.03 *
TSS	4.30	4.50	0.2 NS
TSS/TA	8.77	9.80	1.01 ***

NS, *, **, *** Non-significant or significant at t≤0.05, 0.01 or 0.001 respectively.

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