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Der Pharma Chemica, 2012, 4(6):2402-2407
(http://derpharmachemica.com/archive.html)

ISSN 0975-413X
CODEN (USA): PCHHAX

Comparative effects of partial rootzone drying and deficit irrigation on physiological parameters of tomato crop

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ABSTRACT

The experiment object was to compare the effects of the partial rootzone drying (PRD) and the deficit irrigation (DI) strategies applied with 50% of water requirements on leaf stomatal conductance, signal intensity, root development and water use efficiency (WUE) of tomato grown under greenhouse and on soilless. Three treatments were applied: control that was fully and conventionally irrigated, PRD and DI in which 50% of water requirements were applied using PRD and DI irrigation strategies, respectively. For PRD treatment, alternation between the two rootzone sides took place each three days. When vapor pressure deficit rises, PRD and DI stomatal conductance was 26% and 15% respectively lower than control. The comparison between treatments in terms of signal intensity revealed a better resistance to water deficit for PRD-50. Root profile results corroborated previous findings. In fact, when compared to Control, the total number of root hairs is increased by 11% and 90% for DI-50 and PRD-50, respectively. Compared to control, water use efficiency was improved for both treatments: DI and PRD were, respectively, 155% and 160% more efficient.

Keywords: PRD, DI, signal intensity, stomatal conductance, root profile, WUE

INTRODUCTION

Available water resources for agriculture have been decreasing in recent years with the increased demands for irrigation and other non agricultural water uses. New water-saving techniques such as the partial root-zone irrigation (PRI) or partial root-zone drying (PRD) have been proposed as an agronomic practice for more efficient use of the limited water resources [1, 2]. The PRD is potential water saving irrigation strategy that utilizes plant-to-shoot chemical signaling mechanisms to influence shoot physiology. It works in drip irrigation or furrow irrigated crops where each side of the row is watered independently. When the crop is irrigated, soil on only one side of the row receives water while the other is allowed to dry [3]. At each irrigation time, only a part of the rhizosphere is wetted while the other side is kept dry [4].

Earlier results demonstrated that PRD induced compensatory water absorption from wetted zone, reduced transpiration, and maintained higher level of photosynthesis [5]. Besides, it was showed that the PRD increase root biomass by 19% over well watered plants. That promotion of root biomass was associated with the alternation of wet and dry compartments and occurs in the re-watered compartment after previous exposure to soil drying which explained the ability of PRD plants to maintain similar leaf water potentials. As far as water use efficiency, it has been significantly improved by the use of PRD. This finding was demonstrated for several crops: apple [6], cotton [7], tomato [8], grapevine [9] and pepper [10]. Tomato crop water use efficiency was treated by many researches [11, 12] which proved that the PRD application save water and increase the WUE compared to well watered plants.

MATERIALS AND METHODS

Experiment Location

The experiment was carried out in the Agronomic and Veterinary Institute Hassan II-the Horticultural Complex of Agadir in a multi-tunnel greenhouse and on an area of 1322 m2.

Plant Material

The used tomato is Pristyla that was grafted on 'beaufort'. The crop was planted in the 25th of November 2010 and was conducted in vertical trellising and on a single stem. Crop cycle lasted for 8 months.

Soilless System

Soilless system consists of containers (10 m length, 25 cm depth and 40 cm width). Each container is an experimental unit composed of 20 plants. The used substrate is sandy-silty (78% sand, 19% silt and 3% clay). This later was deposed over two drainage layers: 5cm coarse gravel layer and 5cm fine gravel layer. As far as the separation between root sides for PRD treatments, each container consists of two juxtaposed substrate filled containers and plants were planted on the juxtaposition line to allow root separation.

Irrigation

The irrigation was performed using double ramp drip irrigation system with 40 cm spaced emitters that generate a flow of 2l/h/emitter. Concerning PRD treatments, switching was allowed throw small valves that are placed in the beginning of each ramp. Irrigation and fertilization management were made within a fertigation station throw electro-valves. Daily reference evapo-transpiration ETo was calculated using the De Villele formula [13]. Global radiation (GR) was measured by a pyranometer (kipp and Zonen model splite).

$$ET0\ (mm/j) = 0,0016 \times GR\ (cal/m2/j) \quad (1)$$

To avoid water loss, net maximum irrigation dose was determined referring to granulometric properties of the substrate using the following formula:

$$NMD = f \times (Hcc - Hpf) \times Z \times PSH \quad (2)$$

Where, f is the allowed water stock decrease, Hcc and Hpf are, respectively, field capacity and welting point substrate moistures, Z is the root depth and PSH is the percentage of the wetted zone. According to substrate physical properties, calculated NMD was equal to 0.768 mm. Using irrigation system rainfall (4mm/h), each irrigation supply must last 12 mn. As far as irrigation frequencies, they were variable since they depend on the crop evapotanspiration (ETc)/NMD ratio. As far as irrigation frequencies, they were variable since they depend on the ETc/NMD ratio.

Experimental Design

A complete randomized design was used. Three treatments were applied. Each treatment consisted of 20 plants and was replicated eight times. Data were analyzed using MINITAB software version 15.1.1.0. Treatment means were separated by Tukey's test at $\alpha = 0.05$ or lower.

Adopted Treatments

Besides control treatment that received 100% of its daily water requirement, PRD treatment combined PRD and 50% of crop water requirements, DI treatment consisted of the combination between PRD and 50% of water crop demand.

Measured Parameters

- Climate: Two parameters were automatically and continuously measured: air temperature and air humidity inside the greenhouse (ADCON Model TR1). Measures were used to determine vapor pressure deficit using the following formula:

$$VPD = e_s - e_a \quad (3)$$

The mean daily saturation vapor pressure (e_s) is obtained using the mean between the saturation vapor pressure at the daily maximum and minimum air temperatures. The actual vapor pressure (e_a) is calculated according to [14].

- Stem diameter micro-variations: In order to monitor, continuously and at real time, stem diameter micro-variations, linear variable transducer (LVDT) sensors (Sifatron Model D.F. 2.5) were used as indicators of plant water status in tomato. Indices derived from continuous stem diameter micro-variations data have been developed to interpret these data. Maximum daily shrinkage (MDS) is the studied parameter and was calculated as the difference between maximum daily stem diameter (MXSD) and the minimum daily stem diameter (MNSD)[15, 16]. The Signal intensity values were calculated as the ratio of un-watered plant MDS to well-watered plant MDS [17].
- Stomatal conductance: Its weekly measurements were performed using a porometer (Leaf Porometer, SC1, Decagon, USA) and occurred between 12:00 and 14:00.
- Root profile: At the end of the trial period, root profiles were performed using a grid (80cm x 20cm) with (5cm x 5cm) sized mesh. The grid was introduced in the substrate at 15 cm far from the stem and appearing roots (Ø < 2 mm and Ø ≥ 2 mm) were counted.
- Water use efficiency: It was calculated as the ratio between total produced weighted yield and the total supplied water volume.

RESULTS AND DISCUSSION

Greenhouse Climate

The end of the first month after transplanting is characterized by a continuous temperature decrease that lasted for three months: December that coincided with the second truss flowering, January and February which coincided with the Ninth truss flowering. At the end of that period, averaged temperature reached 15°C and began an increase trend during the remaining period of crop cycle. As far as vapor pressure deficit average is concerned, it ranged between 0.5 kPa and 8 kPa and presented many peaks during hot days where temperature reached its highest values. The maximum diurnal VPD values (10.5 kPa,), for instance, was reached during the 21st of June 2011 (Fig. 1).

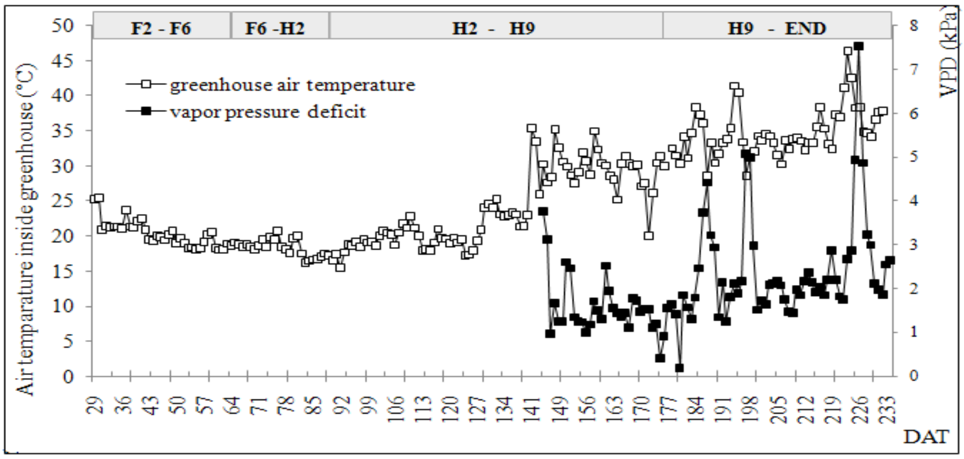

Figure 1. Daily averaged air temperature and vapor pressure deficit inside the greenhouse during different crop stages (F2-F6: flowering of the 2nd and the 6th trusses, H2-H9: harvest of the 2nd and 9th trusses, END: crop cycle end, DAT: day after transplanting)

Stomatal conductance

Stomatal conductance monitoring during trial period shows a continuous decrease trend beginning in the 127th day after transplanting (Fig. 2). The stomatal aperture is influenced by the weather [18, 19] which explains that noted decrease is a response to the increased air VPD inside the greenhouse. It should be noticed that during low evaporative demand period (air temperature ≤ 20°C), PRD treatment had the highest stomatal conductance while DI stomatal conductance decrease reached 24% indicating water shortage stress signs. In response to the high climatic demand (air temperature > 25°C), PRD stomatal conductance decreases by 48% compared to control while DI stomatal aperture was equal to control. The treatment response speed toward air temperature changes showed by curve slopes of fig. 2 indicates that PRD presented the fastest answer whereas DI had the slowest one.

Abscissic acid (ABA) is known to be one of the components involved in the stomatal conductance control as the soil dries [20, 21]. Comparing DI to PRD ABA production, many researches proved that tomatoes grown in the greenhouse with PRD produced more ABA than DI plants [22] which create that greater stomatal sensitivity of PRD plants to atmospheric vapour pressure deficit compared to DI plants [23]. Other researchers went more close to explain that alternation events allow such increase in ABA concentration which occurs following re-watering events of dry soil liberating, thus, ABA pulses accumulated in the dry side during dry period of alternation events [24].

Regarding the lack of statistically significant difference, this finding was also reported by several researchers and could be explained, in one hand, by measurement occurrence with respect to the alternation events and, in the other hand, by the timing of those measurements within different treatments for which it is impossible to have simultaneous measurements [25, 26].

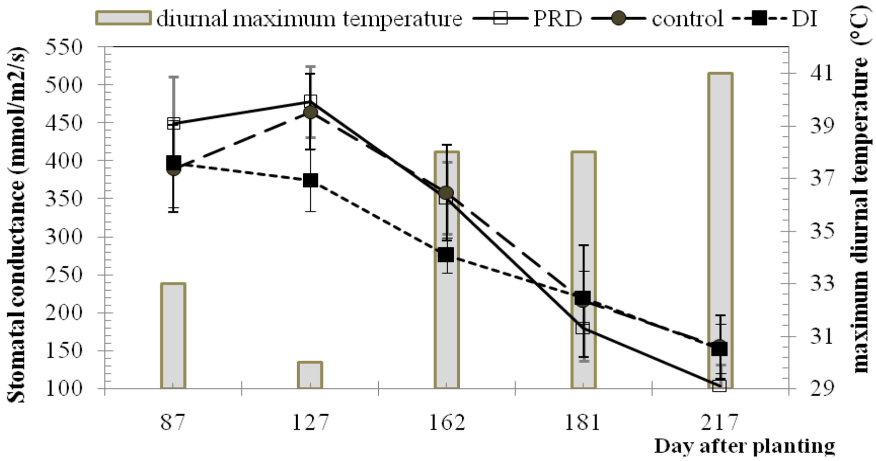

Figure 2. Leaf stomatal conductance variation for different treatments: Presented values are mean ± standard deviation of eight replications

Stem diameter micro-variations

During the low and moderate evaporative demand period (VPD ≤ 2kPa), the PRD signal intensity is almost higher than DI showing that the former is less stressed than the later. The opposite occurs during high evaporative demand period (VPD > 2kPa) indicating that DI is more stressed than the second one since water shortage causes an increase of the daily stem shrinkage which is a water stress sign when added to high evaporative demand conditions, [27]. Hence and in accordance with previous results concerning stomatal conductance parameter it seems that through greater transpiration restriction resulting in a more strict stomatal closure, PRD stem shrinkage was reduced showing that it is more resistant to high climatic demand whereas its stomatal conductance remains higher during moderate climatic demand period. That responsiveness toward greenhouse climate variations during the trial period proves that PRD is more sensitive to VPD variations which is less noticeable for DI treatment.

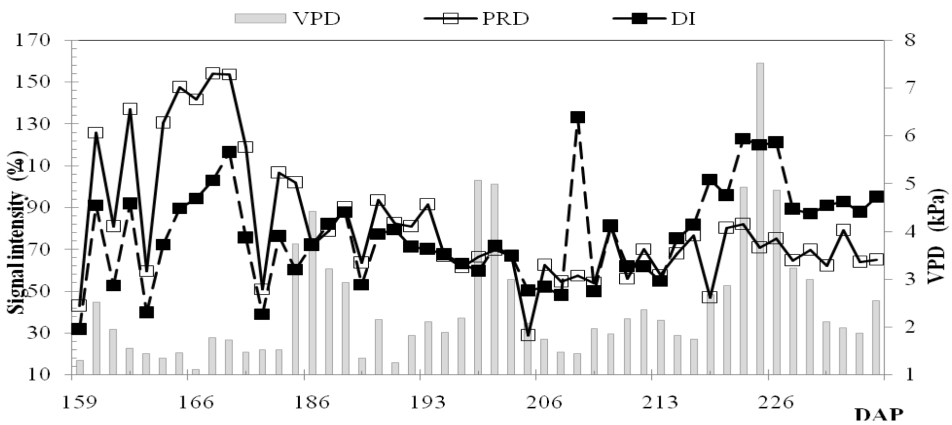

Figure 3. Signal intensity variation during crop cycle

Root profiles

Compared to the control, the number of root hairs (diameter ≤ 2 mm) of both treatments (PRD and DI) recorded respective increases of 90% and 11%. The water deficit has, thus, improved root initiation in order to substitute water shortage through the exploration of a larger substrate volume. The bigger the root's surface area, the more the nutrients and water can be absorbed, and the more the new roots grow [28]. Hence, PRD strategy enhanced root activity and development as confirmed by several authors [29, 30, 31, 32, 33].

Table 1. Root Number (ø< 2mm) counted through root profile method for different treatment: PRD (dose = 50% ETc - PRD), DI (DOSE= 50% ETc – DI) and control (dose = 100% ETc)

		horizontal Distribution								
Depth (cm)	Treat.	0-10	10-20	* 20-30	30-40	40-50	50-60	* 60-70	70-80	Total
0-10cm	PRD	5,75	14,25	14,25	6,00	6,25	12,75	10,75	3,25	73
	DI	4,50	7,00	6,75	4,25	3,75	6,50	4,50	3,75	41
	CONTROL	2,00	4,67	6,33	9,33	9,00	3,67	2,33	1,00	38
10-20cm	PRD	2,75	4,50	4,50	4,50	2,75	4,00	4,75	1,75	30
	DI	2,00	1,75	2,25	1,75	2,50	3,25	3,25	2,50	19
	CONTROL	0,67	0,67	3,00	3,67	3,33	4,00	1,00	0,00	16
Total (0-20cm)	PRD	8,50	18,75	18,75	10,50	9,00	16,75	15,50	5,00	103
	DI	6,50	8,75	9,00	6,00	6,25	9,75	7,75	6,25	60
	CONTROL	2,67	5,33	9,33	13,00	12,33	7,67	3,33	1,00	55
Total (%)	PRD	8,27	18,20	18,20	10,19	8,74	16,26	15,05	4,85	100
	DI	10,83	14,58	15,00	10,00	10,42	16,25	12,92	10,42	100
	CONTROL	4,85	9,70	16,97	23,64	22,42	13,94	6,06	1,82	100

(*): Approximate placement of the 2 emitters.

Water use efficiency

Although no statistically significant difference between WUE of PRD and DI was found, that parameter was improved by 16% for PRD treatment. Compared to the control, both treatments registered an increase of the WUE that reached 150% and 166% for DI and PRD treatment, respectively. Hence, through PRD applying and supplying only 50% of tomato water requirements, the yield was improved by 12%. Thus, it seems that noticed physiological responses didn't significantly affect the yield which may be explain by the fact that those parameters didn't reach the threshold for which stomatal conductance reduction could largely diminish water losses and improve, consequently, the water use efficiency [34, 35, 36,37,38,39].

Many comparisons of the agronomic responses of PRD and DI plants concluded that PRD and DI had similar effects on the yield of bean [40], grapevine [41, 42] and tomato [43]. Some other authors proved that there have been distinct agronomic benefits of PRD irrigation in some trials since when supplied with the same amount of water, PRD increased fruit or grain yield (compared with DI plants) by 37% in bean [44], 24% in capsicum [45], 4–24% in cotton [46] and 7–10% in tomato [47] which is consistent with our trial results.

Table 2. Water use efficiency comparison

	DI	PRD	Control
Total water supply (l/plant)	205	205	410
Total yield (kg/plant)	8	9	11
WUE (g/l)	39 ^{a}	43 ^{a}	26 ^{b}
WUE improvement compared to control (%)	150	166	

CONCLUSION

Physiologically the trial showed that the restriction of water supply added to PRD strategy application gives the tomato grown on soilless under greenhouse greater resistance to high evaporative demand conditions through more restriction of stomatal conductance and root initiation enhancement allowing a better water and nutrient uptake. Despite that both PRD and DI strategies improved the water use efficiency compared to the control, the former seems to be more efficient since WUE improvement reached 166% compared to the control and 116% compared to DI.

Aknowlegements

This work was carried out within the SIRRIMED « Sustainable use of irrigation water in the Mediterranean Region» project which was funded by the European Union within the 7th Framework Program for Research and Development.

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