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Does Partial Rootzone Drying Alternation Frequency Enhance Water Stress Resistance and Improve Water Saving?

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Abstract
The objective of the work was to assess if the variation of alternation frequency when applying partial rootzone drying irrigation strategy (PRD) does affect tomato crop water shortage resistance and water use efficiency (WUE). Hence, physiological responses in terms of stomatal conductance, maximum daily shrinkage (MDS), root initiation were monitored and water use efficiency was determined. Three treatments were applied: a control (T0) and two PRD treatments. The control received 100% of tomato crop water requirements (ETc) whereas PRD50-20 and PRD50-40 were both irrigated at 50% of ETc. PRD50-20 was alternated at 20% of rootzone dry side water storage depletion while PRD50-40 was alternated when the water storage within rootzone dry side decreases by 40%. PRD treatments showed a decrease in leaf stomatal conductance while the control was characterized by the highest stomatal conductance levels. In addition, PRD50-20 registered higher values than PRD50-40 showing that the later restrict more its water loss. Stem diameter micro-variation results corroborated previous finding since PRD50-20 registered higher MDS than PRD50-40. Besides, when compared to T0, root initiation was enhanced by 78% and 32% for PRD-5040 and PRD50-20, respectively. In terms of water use efficiency (WUE), PRD treatments registered higher values than the control (61g/l) and PRD50-40 (84g/l) performed better WUE than PRD50-20 (73g/l).

Keywords: PRD, Stomatal conductance, MDS, root initiation, WUE, tomato

1. Introduction

Scarcity of water will increase in the near future in many regions of the world due to climate change [1] and also to urbanization. World population is predicted to double in the next 50 years, so greater yields must be extracted from the current agricultural areas along with more marginal areas [2]. 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 [3, 4]. The PRD is potential water saving irrigation strategy that utilizes plant-to-shoot chemical signaling mechanisms to influence shoot physiology. When the crop is irrigated, soil on only one side of the row receives water while the other is allowed to dry [5]. At each irrigation time, only a part of the rhizosphere is wetted while the other side is kept dry [6].

Regarding the alternation frequency, some researchers demonstrated that prolonged drying of one compartment of the root system eventually diminished the effects of chemical signals on stomatal conductance [7] as water uptake from this compartment contributed proportionally less to the transpiration stream [8]. Other scientists confirmed that prolonged exposure of roots to drying soil may cause anatomical changes in the roots, such as suberization of the epidermis, collapse of the cortex, and loss of succulent secondary roots [9]. Hence, alternate watering and re-watering, after a period of soil drying, induces new secondary roots [10] that sense further soil drying and may also enhance the nutrient uptake from this soil zone. Since stomatal response is due to a signal from roots that are exposed to drying soil, some of the most important question is how long such signal is expected to be continuously produced? And since roots exposed to drying soil for a long time may lose their contact with the soil and therefore the sensibility of it, how long these roots can survive and what effects will be brought on them if the wetting and drying cycle is shifted more frequently or less frequently [11].

In the frame of such reflection and with the goal of answering, even partially, to that question, our experiment was carried out. It had as object to assess the effect of two alternation frequencies on physiological parameters of tomato crop cultivated under greenhouse and on soilless. The alternation frequencies were fixed through percentage of water storage depletion within the dry side of roots. Hence, two treatments that were irrigated at 50% of tomato water requirements were alternated at 20% and 40% of dry side water storage depletion.

2. Experimental

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 m^2.

Plant Material

The used tomato cultivar is '*Pristyla*' that was grafted on 'beaufort'. The crop was planted in 25^{th} 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: 5 cm coarse gravel layer and 5 cm 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. Global radiation was measured by a pyranometer (kipp and Zonen model splite):

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

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 (10%), 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 Etc/NMD ratio.

Experimental Design

A complete randomized design was used. Two 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 $P \leq 0.05$.

Adopted Treatments

Besides control treatment that received 100% of its daily water requirement, two PRD treatments were applied:

- PRD50-20: that treatment combined PRD and 50% of crop water requirements and was alternated when the substrate water storage depletion of the non irrigated rootzone side reaches 20%.
- PRD50-40: It consists of 50% tomato water requirements supply and alternation at 40% of substrate water storage within the dry side depletion.

Measured Parameters

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

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

Where, e_s is the saturation vapor pressure at a given air temperature and e_a is the actual vapor pressure.

- Stem Diameter Micro-Variations*:* In order to monitor, continuously and at real time, stem diameter microvariations, 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).
- Stomatal Conductance: Its weekly measurements were performed using a porometer (Leaf_Porometer, SC1, Dacagon, USA) and occurred between 12:00 and 14:00.
- Root initiation: 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.
- Total and cumulative yield: 28 harvests were achieved beginning on 27th November 2011. During each harvest, fruits were weighted and counted in order to determine total produced yield.
- Water use efficiency: It was calculated as the ratio between total produced yield and total supplied water volume.

3. Results and Discussion

Greenhouse internal climate

The greenhouse climate is characterized by a large variation within the time. The end of the first month after planting is characterized by a continuous VPD decrease that lasted for three months. At the end of that period, averaged diurnal VPD reached 3kPa and began an increase trend during the remaining period of crop cycle. The vapor pressure deficit presented many peaks during high evaporative demand period that started in the 101th day after planting. It reached its maximum level (8 kPa) during the 274th day after planting. Those VPD variations influenced the potential evapotranspiration level that adopted the same trend since the 101th day where it began to increase during almost the remaining crop cycle period.

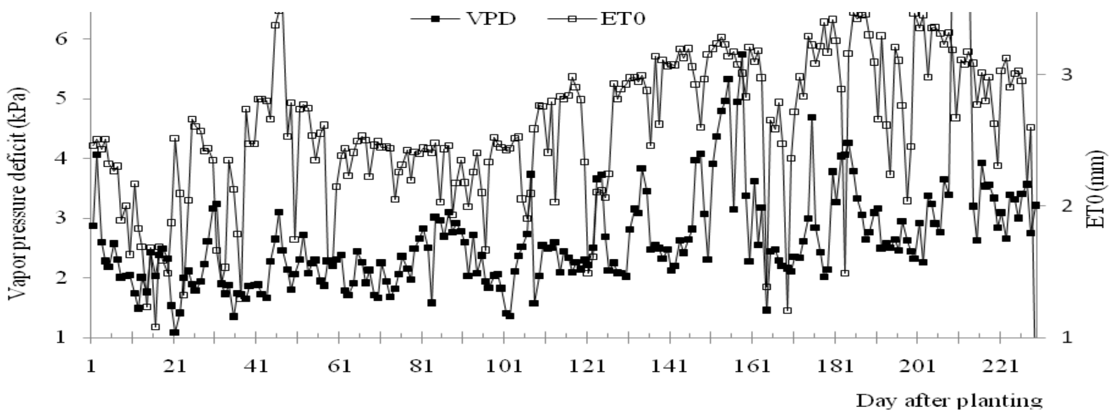


Figure 1. Vapor pressure deficit and potential evapotranspiration variation inside the greenhouse during the trial period

Stomatal conductance

Stomatal conductance monitoring during trial period shows a continuous decrease trend beginning at the 189th day after planting. The stomatal aperture is influenced by weather [12,13] which explains that noted decrease is a response to the increased air VPD inside the greenhouse as confirmed by [14]. As far as treatment responsiveness to stomatal conductance variations, the control registered the highest stomatal conductance during almost the measurement period except some days which could be explained by irrigation events that may influence plant response. PRD50-40 showed the lowest stomatal conductance when compared to the more watered treatments (15): From the beginning of the trial period until the 11th of April which represented the law VPD period, PRD50-20 register higher values of stomatal conductance than PRD50-40. During the 181th DAP (12/3/2012), the difference between PRD50-20 and PRD50-40 is statistically significant and the former registered 35% higher stomatal conductance than the later which indicates that PRD50-40 showed more water shortage resistance than PRD50-20.

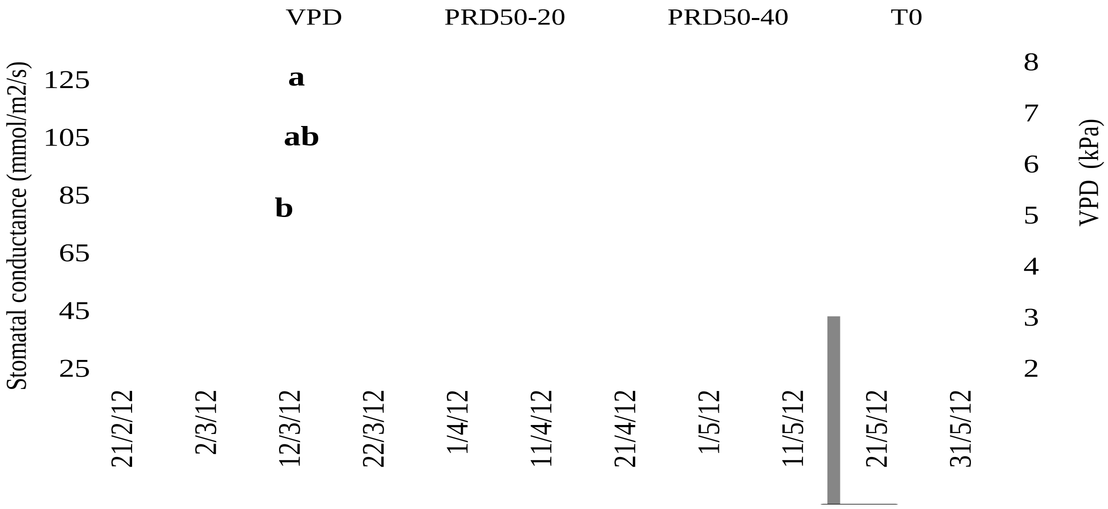


Figure 2. Midday Stomatal conductance measurements during the trial period

Maximum Daily Shrinkage (MDS)

Climatic conditions seem to not be the only factor influencing plant water relations reflected by stem micro-variations. In fact, some periods of low evaporative demand occurred similarly at different stages of the crop cycle (114th DAP - 135th DAP – 208th DAP and 227th DAP- 240 DAP) with different MDS trends which shows that phenological stage of the crop influences the plant response in terms of stem variations [16]. Comparing different treatments, it can be noticed that PRD50-20 shows higher MDS than PRD50-40 indicating a greater sensitivity of the former toward water shortage [17, 18]. The difference between treatments in terms of MDS becomes clearer at the end of the measurement period where climatic demand was very high. During that period, MDS of both frequently alternated treatments (PRD50-20) notably increased comparing to PRD50-40.

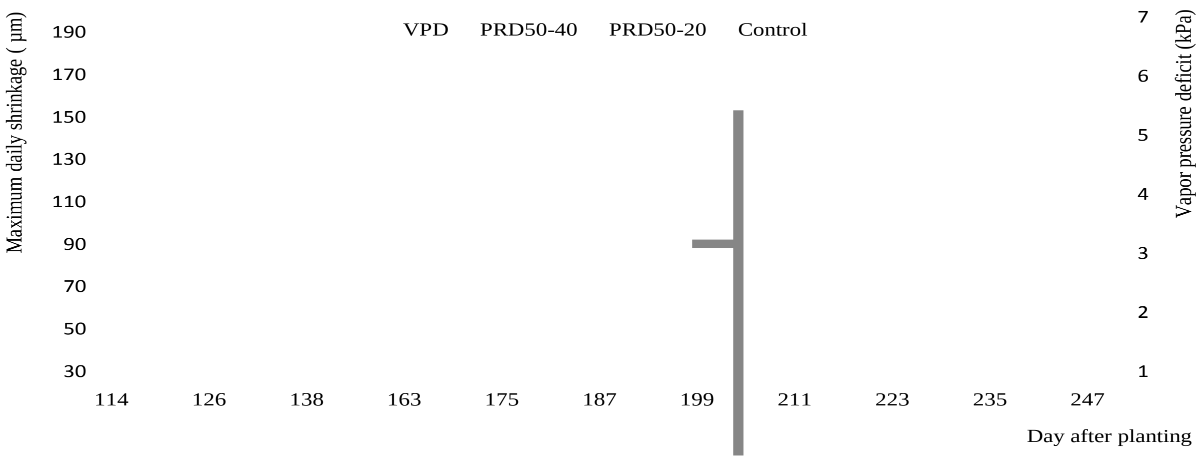


Figure 3. Registered maximum daily shrinkage (MDS) of PRD50-20, PRD50-40 and the control

Root initiation

Spatial and temporal variations in soil water availability, matric potential, aeration, and soil strength affect the resultant root system architecture and activity patterns [19, 20, 21, 22]. Concerning PRD strategy effects on roots, it was demonstrated that exposing a portion of the rootzone to drying initiates rapid root growth upon rewetting with enhanced hydraulic conductivity [23]. According to our trial results, in response to PRD water distribution specifications, root hair development showed t distribution patterns. In fact, when comparing total root hair number within the shallow substrate horizon (0cm-10cm), we note the prevalence of PRD50-40 for which total root hair number is 177% and 131% greater than control and PRD50-20, respectively. The same schema is observed within the deeper 10cm (10cm-20cm) where PRD50-40 total root hair number is 181% and 139% greater than control and PRD50-20. Generally, When roots sense soil water shortage, root cells change in growth rate and differentiation, and the root system architecture changes in the degree of branching or rate of branch root elongation [24].This fact is observed when comparing PRD treatments and the control. When comparing PRD50-40 and PRD50-20, it seems that alternation factor enhanced root hair initiation and that longer alternation period improved root development.

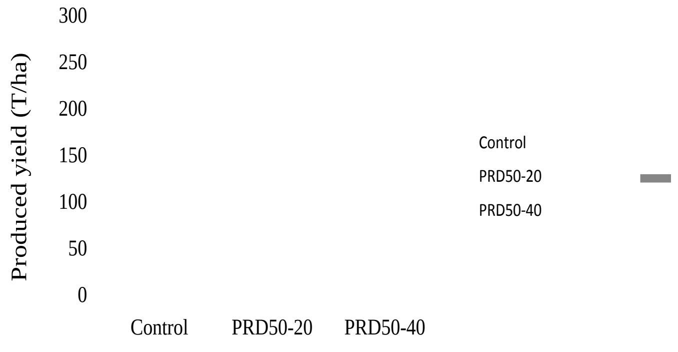
Table 1. Root number (Ø <2mm) distribution within the substrate profile made at 15 cm from stem

		Horizontal distribution				
Depth (cm)	**Treatment**	**0-10**	**10-20***	**20-30**	**30-40**	**Total**
0 – 10 cm	PRD50-20	25	22	31	21	100
	PRD50-40	29	42	43	18	131
	Control	20	24	18	12	74
10-20 cm	PRD50-20	17	16	10	12	56
	PRD50-40	16	24	25	14	78
	Control	13	7	18	6	43
Total (0-20cm)	PRD50-20	43	38	42	34	155
	PRD50-40	44	66	68	32	209
	Control	33	30	37	18	117

*Dripper position

Produced yield

The Control performed the highest total yield (272 T/ha). Statistically, there was a highly statistical significant difference (P = 0,000007 ≤ 0,001). Three homogeneous groups were distinguished: the first one is composed of control, the second one contains PRD50-40 and PRD50-20 with respective yields: 156T/ha and 179T/ha. Comparing control to PRD treatments, the noted decrease of the yield wasn't found by other researches carried by [25] and [26] which reported that PRD did not significantly decrease yield of tomato. In our case study, PRD50-40 yield decrease was 50% compared to control whereas PRD50-20 yield reduction was 70%. It was shown that, when roots in the dry soil were re-wetted, the rate of water uptake increases by two folds which could, sometimes, be even higher than the well irrigated controls [27]. That conclusion is consistent with our results concerning PRD50-40 and PRD50-20 yield's comparison but remains non consistent when comparing control and PRD treatment yield trial results.



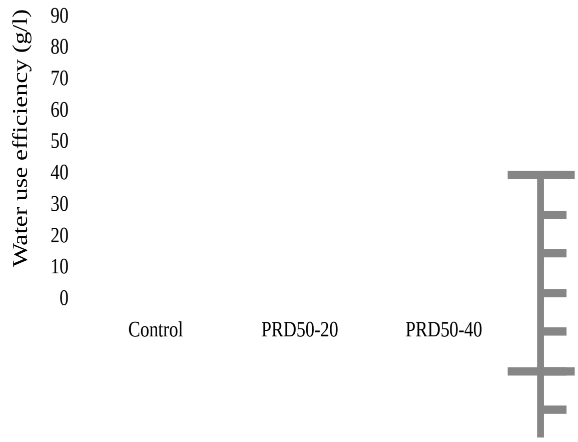


Figure 4. Total produced yield (Ton of fresh fruit/ha) of different treatments

Figure 5. Water use efficiency comparison

Water use efficiency

Stomatal conductance is a physiological process affected by PRD, thus the partial stomatal closure can lead to a decrease of transpiration, and possibly to an increase in water use efficiency compared with control [28].

Similarly, our trial results showed that PRD50-20 and PRD50-40 performed better WUE than control. It reached, in fact, 73g/l and 84g/l, respectively when control's WUE didn't exceed 61g/l. That result could be explained, as previously described, by PRD50-40's higher stomatal closure and smaller MDS. Similarly, [29] recognized that intrinsic WUE commonly increases in response to water deficit due to stomatal closing induced by drought.

Conclusion

The trial showed that the variation of alternation frequencies applied with irrigation PRD strategy affected the physiological parameters of tomato crop. In fact, applying 50% of water requirements with alternation at 40% of water storage depletion within the dry side of rootzone seem**s** to enhance water shortage resistance reflected by lower MDS and explained by greater stomatal conductance reduction. In terms of yield and water use efficiency, PRD50-40 appeared more productive and more efficient since it performed the highest WUE (84g/l).

Aknowlegements

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References

1. Martin P., Osvaldo C., Jean P., Paul V., Clair H. Printed in USA at the University Press, New York. (2007).
2. Chaves M. M., Davies B. *Func. Pl. biol.* 37 (2010)3.
3. Kang S., Zhang J. *J. Exp. Bot.* 55 (2004) 2437.
4. Loveys B. R., Dry P. R. *Vitis*. 39 (2000) 3.
5. Mingo D. M., Theobald J. C., Bacon M. A., Davies W. J., Dodd I. C. *Func.pl. biol.* 31 (2004) 971.
6. Zegbe J. A., Behboudian M. H., Clothier B. E. *Agr. wat. Manag.* 68 (2004) 195.
7. Stoll M., Loveys B.R., Davies W.J., Bacon M. A. Ed, Blackwell, Oxford. (2004)113.
8. Yao C., Moreshet S. B. *Plant, Cell & Envir*. 24 (2001) 227.
9. North G. B., Nobel P. S. *Am. J. Bot.* 78 (1991) 906.
10. Liang J., Zhang J., Wong M. H. *Plant and Soil*. 186 (1996) 245.
11. Kang S., Zhang J. *J.Exp. Bot*. 55 (2004) 2437.
12. Fulai L., Ali S., Mathias Sven E. J., Christian R J. *J.Exp. Bot.* 57 (2006) 3727.
13. Maurel M., Robin C., Simonneau T., Loustau D., Dreyer E., Desprez M. L. *Func. Pl. Bio.* 31(2004) 41.
14. Grange R.I., Hand D.W. *J. hort. Scien*. 61(1987) 361.
15. Huitzimengari C., Carlos T., Cecilia B., Ramirez-Ayala C., Sanchez-Garcia P. *Sci. Hort.* 120 (2009) 493.
16. Gallardo M., Thompson R. B., Valdez L. C., Perez C. *Acta. Hort.* 664 (2004) 253.
17. Klepper B., Browing V. D., Taylor H. M. *Plant Physiol*. 48 (1971) 683.
18. Gallardo M., Thompson R. B., Valdez L.C., Fernandez M. D. *Irrig. Scien.* 24 (2006) 241.
19. Feddes R. A., Kowalik P., Kolinska-Malinka K., Zaradny H. *J. Hydrol*. 31(1976) 13.
20. Herkelrath W. N., Miller E. E., Gardner W. R. *Soil Sci. Soc. Am. J.* 41 (1977) 1033.
21. Michelakis N., Vougioucalou E., Clapaki G. *Agric. Water Manage*. 24 (1993) 119.
22. Taylor H. M., Klepper B. *Agron. J*. 65 (1973) 965.
23. Gersani M., Sachs T. *Plant Cell Environ*. 15 (1992) 463.
24. Munns R. *Adv. Bot. Resea*. 57(2011)1.
25. Zegbe-Domınguez J. A., Behboudian M. H., Lang A., Clothier B. E. *Scien. Hort*. 98 (2003) 505.
26. Kirda C., Cetin M., Dasgan Y., Topcu S., Kaman H., Ekici B., Derici M.R., Ozguven A.I. *Agr. Wat. Manag.* 69 (2004) 191.
27. Kang S., Hu X., Goodwin I., Jerrie P. *Sci. Hort*. 92 (2002) 277.
28. Bravdo B. A. *Acta Hort.* 689 (2005) 267.
29. Chaves M. M., Osorio J., Pereira J. S., Blackwell Publishing Ltd. London, UK (2004) 42.

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