Arch. Biol. Sci., Belgrade, 61 (2), 285-288, 2009 DOI:10.2298/ABS0901285S

PARTIAL ROOT DRYING IRRIGATION TECHNIQUE: PRACTICAL APPLICATION OF DROUGHT STRESS SIGNALING MECHANISM IN PLANTS

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Abstract — Partial root-zone drying (PRD) technique, a novel approach to watering crops, was developed on the basis of knowledge of root-to-shoot signaling in drying soil. The aim of the present paper was to investigate the effects of the PRD treatment on tomato growth and the water regime. The obtained PRD results showed significant reduction in shoot but not fruit growth in the absence of any changes in shoot water status, indicating the involvement of chemical root-to-shoot signals. Higher water use efficiency (WUE) results mean that the PRD technique can be used to reduce irrigation water without significant reduction of tomato yield.

Key words: Partial root drying, tomato, growth, water use efficiency

UDC 581.144.2:581

INTRODUCTION

Drought is one of the most common environmental stresses that may limit agricultural production worldwide. Increasing demand for water stimulated development of new irrigation techniques designed to increase water use efficiency (WUE). Recent results have demonstrated that partial root drying (PRD) irrigation techniques can increase the efficiency of water use with many crops (Dry et al., 1996; Liu et al., 2005; Topcu et al., 2006; Liu et al., 2007; Tahi et al., 2007). With the PRD technique half of the plant root zone is irrigated, while the other half is allowed to dry out partially (Stoll et al., 2000). The treatment is then reversed, allowing the previously well-watered side of the root system to dry out while fully irrigating the previously dry side (Fig. 1). The PRD technique is based on knowledge of root-to-shoot chemical signalling in drying soil. Chemical signalling involves synthesis and transfer of chemicals (particularly the hormone abscisic acid-ABA) from the roots to shoots via the xylem (Jones, 1980; Gowing et al., 1990; Loveys et al., 2000). Abscisic acid signaling can also be regulated by other factors, including pH, root growth-promoting rhizobacteria, ions, and apoplastic β-glucosidases in the leaves (Wilkinson, 1999; Davies et al., 2005; Dodd et al., 2006; Jiang and Hartung, 2007). Chemical or non-hydraulic signaling is different from hydraulic signaling, which represents transmission of reduced soil water availability via changes in the xylem sap tension (Dodd et al., 1996). The main PRD effects on plants are reduction of stomatal conductance, reduction of plant growth, and improvement of water-use-efficiency (Davies et al., 2000). The aim of the present study was to investigate the effects of PRD on tomato plant growth, the water regime, and water use efficiency.

MATERIAL AND METHODS

Experiments with PRD were performed according to a modified version of the procedure of Davies et al. (2000). Tomato (*Lycopersicon esculentum* L., hybrid Astona F_1) seeds were germinated in commercial compost in a growth cabinet until the appearance of the fifth leaf. In the growth cabinet, the photoperiod was 12 h, light intensity at the level of the plants was 250 μmolm^{-2} s^{-1}, temperature was 28/18°C, and relative humidity was 70%. In the phase of the fifth leaf, the plants were removed from their pots and the root system of each plant was divided in two parts and put into two separate plastic bags (with volume of 10 dm^3 each). The root system of each plant was thereby split into two hydraulically separate compartments. The pots were watered daily to drip point for 10 days to ensure that the root systems were established in both compartments before starting the treatments. Ten days after transplanting the plants, the following two treatments were applied:

1) full irrigation (FI), in which the whole root system was irrigated daily to a soil water content close to field capacity, determined before the experiment to be 35%; and

2) partial root drying (PRD), where 50% water of FI was applied to one half of the root system while the other half was allowed to dry, and the irrigation was shifted when soil water content of the dry side had decreased to15-20%.

Plants were irrigated daily and the amount of water to be applied was calculated on the basis of soil water content readings. The volumetric soil water content was measured daily for both irrigated and non-irrigated compartments with a theta probe of the ML2X type (Delta-T Device, Ltd., UK). Leaf water potential was measured with a pressure chamber. Ten plants per treatment were selected randomly for measurements of growth parameters. Plant growth was characterized by plant height, number of leaves, leaf area, number of flower trusses, fruit diameters, and number of fruits per plant at the end of the experiment. Final plant height was measured and final leaf area determined after destructive sampling. Water use efficiency was calculated as the ratio between produced fruit DW and dm^3 of water used for watering the plants.

Student's unpaired t-test (Sigma Plot 6.0 for Windows - SPW 6.0, Jandel Scientific, Erckhart, Germany) was used to test traits for significant differences between irrigation treatments.

RESULTS AND DISCUSSION

The effect of PRD on plant growth was significant and by the end of experiment plant height of PRD-treated plants was 33.8% less than that of FI plants (P<0.001) (Table 1). Partial root drying also caused significant reduction of leaf growth by decreasing both leaf number (c. 6.6%) and area (c. 21.7%). Thus, our results confirmed that the applied partial root drying of the root system was sufficient to trigger a shoot response. Consistent with the evidence from other split root procedures (Davies et al., 2000; Dry et al., 2000), water potentials of PRD plants did not differ significantly from those of

Table 1. Investigated traits of the tomato crop grown under PRD regime.

Traits	FI	s.e.	PRD	s.e.	Significance
Plant height (cm)	143.0	2.1	94.7	1.9	P<0.001
No. of leaves per plant	24.3	0.9	22.7	0.3	ns
Leaf area (dm^2)	54.4	2.1	79.6	1.0	P<0.001
No. of flower trusses per plant	5.8	0.2	4.8	0.2	P<0.01
Fruit diameter (mm)	43.9	0.9	45.9	1.4	ns
No. of fruits per plant	9.0	0.6	8.3	0.9	ns
Water potential (-MPa)	0.41	0.03	0.43	0.03	ns

Table 2. Effect of PRD on shoot DW, fruit DW, fruit DW/leaf DW ratio, and WUE.

Traits	FI	s.e.	PRD	s.e.	Significance
Plant shoot DW (g)	51.8	0.8	37.4	1.9	P<0.01
Plant fruit DW (g)	26.9	2.7	24.1	0.7	ns
Fruit DW/leaf DW	0.8	0.1	1.0	0.1	ns
WUE (g fruit DW/dm^3 H_2O)	0.8	0.1	1.2	0.03	P<0.01

well-watered plants (Table 2). These results support the hypothesis that a root-sourced chemical but not hydraulic signal may be responsible for triggering growth reduction in these PRD plants. Compared to the PRD effect on vegetative parts, PRD did not cause any significant reduction in fruits numbers and diameters (Table 1).

Fruit dry weight did not significantly differ between treatments in either of the investigated crops. The obtained results also showed an increased fruit DW/leaf DW ratio in PRD versus control tomato plants (from 0.8 to 1.0). These results confirmed that the applied PRD system, in agreement with the results of other tomato PRD experiments, was sufficient to trigger a shoot response. The results of several PRD experiments also showed that due to the maintenance of fruit biomass and reduction of transpiration (induced by PRD), very high increase in water use efficiency was achieved in tomato plants. Moreover, our results showed that PRD tomato plants produced more fruit biomass per dm^3 of water (1.2) compared to control plants (0.8). It is therefore clear that significant increases in crop WUE were achieved (Table 2).

We did not measure hormones or xylem pH as PRD-induced chemical signals (Stoll et al., 2000; Mingo et al., 2003), but reduced shoot dry weight and sustained fruit dry matter accumulation in PRD-treated plants indirectly indicate that PRD treatment induced a change of assimilate partitioning and source/sink relationships. For tomato, as for other horticultural plants, photosynthetically active tissue of mature leaves is an active source of assimilate for sink tissues, such as flowers, fruits, or roots. Among sink organs, fruits are defined as a high priority in the context of competition for assimilates between alternative sinks. Dry et al. (1996) and Davies et al. (2000) stated that reduction of carbohydrate strength (side shoots) in PRD-treated plants resulted in a relative increase in the sink strength of tomato fruit such that carbohydrate previously partitioned towards the side shoots is redirected towards the fruit. Our previous results with a similar PRD system showed that PRD fruits had higher total sugar content than fruits from control plants (Stikić et al., 2003).

Partial root drying (PRD) caused a significant reduction in shoot but not fruit growth in the absence of any changes in shoot water status. This clearly indicates involvement of chemical root-to-shoot signals. Water use efficiency was significantly higher in PRD than in control plants. The PRD plants produced c. 50% more fruit biomass per dm^{-3} of water compared to control plants. Significant increases of crop WUE were therefore achieved. These results show that the PRD technique can be used to reduce irrigation water without significant reduction of tomato yield.

Acknowledgments — This study was partly supported by the European Commission FP6 CROPWAT Project (FP6-2005-INCOWBC/SSA-043526).

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ТЕХНИКА ДЕЛИМИЧНОГ СУШЕЊА КОРЕНОВА: ПРАКТИЧНА ПРИМЕНА СИГНАЛНИХ МЕХАНИЗАМА СУШЕ КОД БИЉАКА

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Техника делимичног сушења коренова (PRD), нови приступ у наводњавању биљака, развила се на основу сазнања о сигналима суше на нивоу корен-изданак. Циљ рада је био да се испитају ефекти PRD третмана на растење биљака и водни режим. Резултати су показали да је PRD третман изазвао значајну редукцију растења изданка, али не и плодова у одсуству промене водног статуса изданка што је индикатор утицаја хемијских сигнала на нивоу корен-изданак. Повећање ефикасности у коришћењу воде (WUE) је показало да се применом PRD технике може редуковати количина воде за наводњавање без значајне редукције приноса парадајза.