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Effect of Partial Rootzone Drying (PRD) on Growth, Water Use Efficiency (WUE) and Yield of Tomatoes Grown in Soilless Culture

[1]HASSAN IBRAHIM ALI, [1]MOHD RAZI ISMAIL, HALIMI MOHD SAUD & [2]MOHD MOKHTARUDDIN MANAN

[1]*Department of Crop Science,*
[2]*Department of Land Management,*
Faculty of Agriculture,
Universiti Putra Malaysia 43400 UPM Serdang,
Selangor, Malaysia

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ABSTRAK

Satu kajian telah dijalankan di Jabatan Sains Tanaman, Universiti Putra Malaysia (UPM) untuk mengkaji pengaruh pengeringan separa akar menggunakan kultur tanpa tanah, campuran 70% habuk sabut kelapa dan gambut (3:2) ditambah dengan 30% kompos jerami padi. Tanaman tomato (Lycopersicon esculentum *Mill cv Red Rock) diberikan dua rawatan air, iaitu pengairan sepenuh (kawalan) dan pengairan secara pengeringan separa akar (PRD). Pengurangan kedapatan air dalam media secara PRD menyebabkan pengurangan signifikan bagi perkembangan daun, luas daun dan konduksi stomata. Prolina meningkat dengan PRD. Tidak terdapat pengurangan yang signifikan dalam pembahagian bahan kering tanaman dan hasil di antara pengairan penuh dan PRD. Kecekapan penggunaan air meningkat secara signifikan dengan PRD.*

ABSTRACT

An investigation was carried out at the Department of Crop Science, Universiti Putra Malaysia (UPM) to examine the effect of PRD using soilless media, a mixture of 70% coconut coir dust and peat (3:2 respectively) amended with 30% rice straw compost. Tomato (Lycopersicon esculentum *Mill cv Red Rock) plants were exposed to two different water treatments, which was either well-watered (control) or partially irrigated on half of the roots (PRD). Reduction in water availability in the media with PRD treatment caused a significant decrease in leaf expansion, leaf area and stomatal conductance. Proline was significantly increase with PRD. There was no significant reduction in dry matter partitioning and yield between well-watered and PRD-treated plants. Water use efficiency also was significantly increased with PRD.*

INTRODUCTION

Increasing water use efficiency (WUE) is one of the main strategic goals for the researchers as well as decision makers world wide due to water scarcity and continuing high demand of water for agricultural irrigation. The efficiency of utilization of irrigation water is often low leading to around 50% increase in the demand for water that could be met by increasing the effectiveness of irrigation. However, the agricultural irrigation uses over 70% of the world supplies of clean water and most of this clean water is especially used in the protected environments (Ismail and Razi 2002). The use of clean water and chemical solutions as fertilizers are very costly. In addition, the fast growing industrial sector competes with agriculture for water resources and the pollutants emitted were the source of underground water pollution and this will push the agricultural activities to remote areas where water and salinity are the major problems.

Tomato has more acreage than any vegetable crop in the world (Ho 1996) and is the second most common grown vegetable crop in Malaysia. Therefore, studying the effect of low cost irrigation technique such as partial rootzone drying (PRD) could make substantial contribution to saving water especially with soilless culture, since many studies conducted under a protected environment showed the significance of the use of a soilless culture (Ismail and Razi 2002). Thus, the use of this low technological agronomic manipulation can also exploit recent understanding of plant functions and physiological basis of yield production under limited resources. In this way, yield can be sustained and resource use can be optimized.

PRD is a relatively new irrigation strategy, where at each irrigation time only a part of the root system is wetted with the complement being left to dry to a pre-determined level or time. It could save water by 50% and yet maintain yield as shown for some grape cultivars (Loveys *et al.* 2000). Implementing PRD technique is simple, requiring only the adaptation of irrigation systems to allow alternate wetting and drying part of the rootzone. Although the theory of PRD has been developed, little is known about how tomatoes growing under warm and humid climatic conditions will respond to this irrigation technique. However, it is also important to understand the basis of the plant's finely-tuned sensitivity to environmental stresses to overcome the problems by using either agronomic or genetic techniques and the advantages of crop growth and food production may be substantial. The objective of this study therefore, is to understand how PRD works within soilless media amended with rice straw compost through monitoring of water use efficiency; fruit yield and vegetative growth, as well as quantifying the impacts of PRD on proline accumulation within the leaf. The hypothesis is that PRD may decrease leaf area and growth of the plant without significant reduction in yield and hence, increase water use efficiency. Stomatal conductance will be significantly reduced and proline will be increased in response to PRD technique and that will be correlated with soil drying.

MATERIALS AND METHODS

Plant Materials

A study was conducted at the Department of Crop Science, Faculty of Agriculture, UPM, Malaysia. Tomato (*Lycopersicon esculentum* Mill.) cv Red Rock F_1 hybrid was used in this study. Seeds were sown on germination trays with media of peat amended with rice straw compost (3:1) and transplanted four weeks later. Seedlings with the same vigor were transplanted to double pots, where taproot was removed and the roots of each plant were approximately divided into two pots. The plants were placed under shade-house condition with daily average temperatures of 32 and 28°C day and night, respectively and average relative humidity of 65% and 80% day and night respectively. The plants were trained vertically, as single stems. Plants were also staked or trained by using raffia string tied to an overhead support. At weekly intervals, all auxiliary buds were removed. When the plants had produced a total of three trusses, the main growing stem was terminated at the point of two leaves after the final truss.

Treatments and Experimental Design

Soilless media (coconut coir dust and peat 3:2 v/v, respectively) 70%+ 30% rice straw compost were used in this study. Two treatments were used which were either irrigated to drip point daily (100% field capacity) with drip irrigation as a control (C) or partial irrigation PRD on half of the roots alternately (until the moisture content reached within 10% of the control plants). Each cycle of drying was 12 days. Each pot was irrigated with a single drip emitter, with one irrigation per day to maintain soil water close to field capacity. An auto timer was used and the amount of the water used for each treatment was monitored with flow meters placed in each irrigation line and calculated thereafter in kg. Half-Copper solution was used as fertigation fertilizer. The pots were raised to avoid direct contact with the ground and two weeks later the treatments started.

Parameters

Four pots from each replicate were selected randomly from either the both pots irrigated or half of the roots irrigated for determination of soil moisture content. The samples were taken from a depth of 0-5cm and oven dried at 90°C for 72 hours and the moisture content of the soil sample was determined.

Measurements were carried out on matured fully expanded leaves (leaf number four from the apex of the plant). The measurements were taken on the abaxial surface of the leaf daily between 11:00 and 14:00. All readings were accomplished within a one-hour period to avoid the diurnal pattern of variation in leaves, using a transit- time promoter (AP-4, Delta T Devices Ltd., Cambridge, UK). Similar leaves were used for leaf water potential determination using a pressure chamber (PMS, Soil Moisture

Equipment, Santa Barbara, USA). Leaf water potential was measured between 12:00 and 15:00.

Newly emerged leaves from four plants within each treatment were chosen randomly, labeled and tagged and the length of leaf blade was measured from the point of petiole insertion with the leaf blade to the tip of the leaf. The length was measured every two days at midday using a standard ruler.

Determination of free concentration of proline was based on the method described by Bates *et al.* (1973). Proline was extracted from liquid nitrogen-frozen tissue by homogenizing 0.5 g of sampled leaves with 10 ml of 3% aqueous solution of sulfosalsilic acid at 25°C. The homogenate was filtered through Whatman No. 2 filter paper. Two ml of the filtrate was reacted with two ml of glacial acetic acid and two-ml acidninhydrin in a test tube for one hour in a water bath at 95°C. The reaction mixture was then cooled in an ice bath. Following that, 4 ml of toluene was added to the reaction mixture and mixed vigorously with a test tube stirrer for 20 seconds. The toluene layer at the top, which is a pink-red color, was collected with a pipette. The absorbency of the toluene layer was read at 520 nm with a spectrophotometer using toluene as a blank. Standard curve was produced ranging from 0 to 30 g/ml of L-proline (Sigma Chemical Co., St. Louis, Mo.) dissolved in 3% sulfosalsilic acid. Proline standard curve was used to calculate proline concentrations in the samples on fresh weight basis.

A destructive sample method was used to determine leaf area and dry matter production (dry biomass). Total leaf area was measured in cm^2 using leaf area meter (Delta-T Cambridge, U.K.). Each plant part was put in a paper bag and placed in an oven at 85°C for 72 hr till a constant weight was reached for dry weight determination. Root to shoot ratio and total dry matter production in g per plant was calculated thereafter. Yield per plant was determined after each harvest from an average of ten plants.

Water use efficiency (WUE) was calculated for each treatment as function of the harvest yield and total dry biomass (shoot + roots) divided by the actual total amount of water irrigated as described by Kang *et al.* (2001).

$$WUE^1 = \frac{Yield(g)}{Gross\ irritation(kg)} \qquad (1)$$

$$WUE^2 = \frac{Dry\ biomass(g)}{Gross\ irritation(kg)} \qquad (2)$$

Statistical Design and Analysis of Data

The treatments (control (C) and PRD (P)) were arranged in a completely randomized design with three replicates. Data were analyzed using analysis of variance and means separation performed using least significant differences (LSD) at 0.05 levels. Both analyses were done using SAS (1997).

RESULTS AND DISCUSSION

Stomatal behavior varied significantly ($p < 0.05$) in response to PRD(*Fig.* 1). PRD significantly reduced the stomatal conductance gradually. This gradual reduction in stomatal was also shown in many studies with different crop species (Loveys *et al.* 1998; Stoll *et al.* 2000; Awad 2001) might be attributed to the signal coming from the dry part of the root system through the xylem stream. The signal, which may lead, to the partial closure of stomata of PRD plant may be attributed to root sourced chemical signals. Media drying presumably enhanced different hormones and enzymes such as proline and the accumulation resulted in stomatal closure and leaf growth restriction (*Fig. 6*).

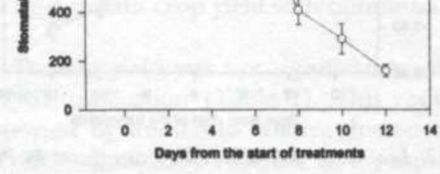

Fig. 1: Stomatal conductance as affected by PRD applications or tomato plants grown on soilless culture

Leaf water potential (LWP) showed different trend in response to PRD treatment (*Fig.* 2). This clearly suggested that LWP is strongly affected by plant age and the amount of water applied under environment of high evaporative demand occurred, although there were no visual symptoms due to desiccation in PRD treatment.

LWP values measured for control and PRD treatments as a mean for the whole cycle period were -0.41 and -0.51 MPa, respectively. Mean LWP value at day 0 was -0.39 MPa and reached -0.64 MPa on day 12. The minimum LWP observed with two tomato species under complete drying of media to all plant roots under water stress were -1.8 and -1.4 MPa for *L. esculentum* and *L. pennellii*, respectively after seven days of withholding water from the plants as stated by Torrecillas *et al.* (1995). In most split-root experiments, where half of the root was irrigated by 50% of the control, conducted under low evaporative demand (Ague' and Duan 1991; Blackman and Davies 1998; Zegbe-Dominguez *et al.* 2003) concluded that leaf water status did not change under water deficit. However, the maintenance of leaf water potential with decreasing soil water status is expected due to low evaporative demand of the atmosphere as reiterated by Hsiao (1990). This might be the reason why differences were not measurable or due to other limitations such as sensitivity of instrumentation, sporadic measurement of water status or the behavior of the stomata to maintain relatively stable leaf water potential during mild drought (Ague' and Moore 2002).

Fig. 2: Leaf water potential (LWP) as affected by PRD application for tomato plants grown on soilless culture

PRD significantly reduced leaf expansion (*Fig. 3*). There was also a significant relationship (r^2 = 0.98) between media drying and leaf expansion (*Fig. 6*). The concept of using PRD as a technique to control water deficit responses originated from observation that root-derived abscisic acid was an important factor in regulating grapevine stomatal conductance and leaf expansion in order to regulate shoot growth (Loveys 1991).

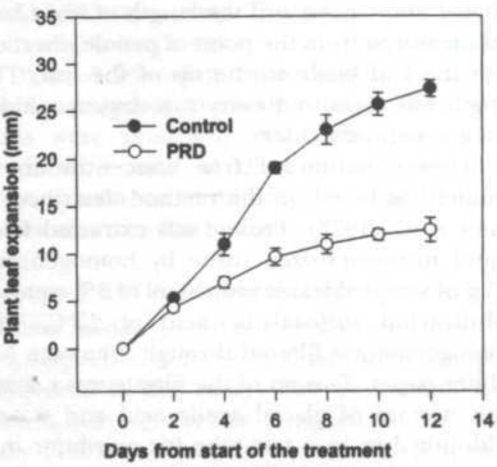

Fig. 3: Leaf expansion as affected by PRD application for tomato plants grown on soilless culture

Free proline accumulation seems to be a widespread stress response in higher plants, which can reach very high levels within a short time after stress induction (Gzik 1995). This accumulation is always induced by hydraulic stress for osmotic adaptation. However, little was known about the role of non-hydraulic signaling in responses to PRD in accumulation of the proline. However, proline increased significantly in response to PRD (*Fig. 4*). This indicates that proline accumulation was dramatically influenced by the root drying. The increase in proline content in stressed plants parts was predominantly due to *de novo* synthesis (Gzik 1995). Therefore, understanding the mechanism behind the accumulation of proline in response to PRD under non-hydraulic signaling needs further clarification.

PRD significantly reduced leaf area as shown in Table 1. The reduction of leaf area of PRD plant was almost 13% compared to control plants. These results were quite similar to those observed with PRD tomato plants (Davies *et al.* 2000). Dry biomass, dry shoot and root weights and root to shoot ratio were not significantly different between them for both PRD and control plants. There was very little data that suggested that root growth can actually be increased by soil drying in support of this present study. Authors that do (Sharp and Davies 1979), attribute such effects to a stress of particular magnitude which

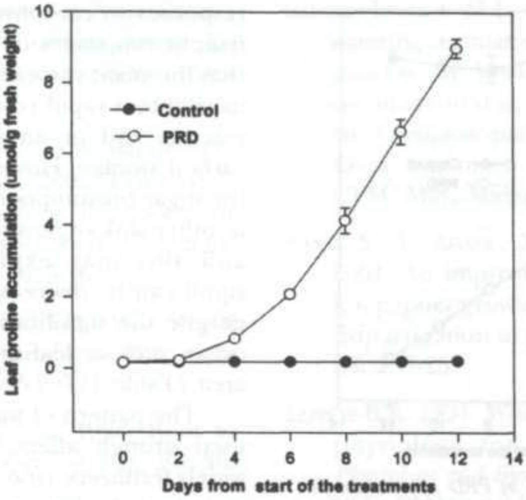

Fig. 4: Proline accumulation as affected by PRD application for tomato plants grown on soilless culture

TABLE 1
Effect of partial rootzone drying system (PRD) on leaf area, dry matter partitioning, total and marketable yields and water use efficiency (WUE) of tomato plant grown on soilless culture

Parameter	Control	PRD	LSD	C.V.
Leaf area (cm^2)	1739.53a	1507.45b	156.7	4.26
Dry whole plant biomass (g)	45.67a	41.67a	9.39	9.49
Dry shoot wt. (g)	40.00a	35.17a	6.58	7.72
Dry root wt. (g)	5.67a	6.50a	3.31	24.02
Root to shoot ratio	0.14a	0.19a	0.07	19.52
Total yield (g)	852.8a	744.30a	292.12	16.14
Marketable yield (g)	786.76a	721.77a	113.32	6.63
Water use efficiency1 (g/kg)	1.56b	2.39a	0.47	10.40
Water use efficiency2 (g/kg)	34.48b	43.99a	7.49	8.42

Means with the same letter in the same row is not significant difference with Least Significant Difference (LSD) at $p < 0.05$.

results in increased availability of assimilates to roots, as shoot growth is limited by water deficit in the absence of any effect on carbon gain. More recently, however, Mingo (2003) reported that root growth can be stimulated when roots are dehydrated after a drying episode, relative to roots in moist soil.

In the well-watered plants in which both sides of the roots were irrigated, moisture content remained high. Moisture content decreased progressively in PRD with time until 10% of the control plants (*Fig. 5*). This suggested that during the stress cycle, part of the plant received sufficient water when the other part received a sign of water deficit conditions resulting in different physiological and biological changes, and thus sustain crop yield with minimum water use.

Tomato yield was not significantly affected by PRD application (Table 1). This result was supported by numerous studies demonstrating that PRD application resulted in no significant reduction of crop yield (Loveys 1991). Recent evidence had showed that fruit growth was regulated by non-hydraulic regulations (Mingo *et al.* 2003). They concluded that restrictions in fruit growth rate in plant growing in a partial drying soil can occur in the absence of any changes in fruit cellular turgor. It was suggested that signals borne within the xylem can travel

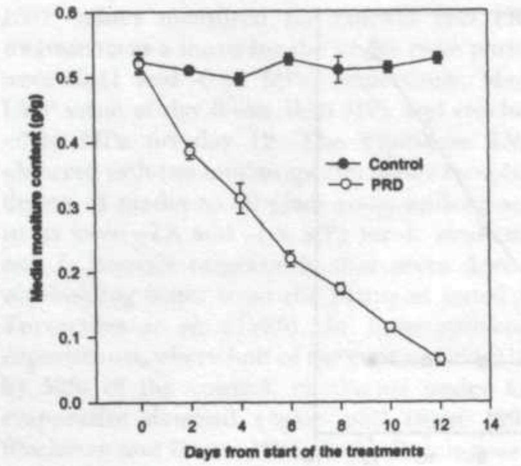

Fig. 5: Media drying as affected by PRD application for tomato plants grown on soilless culture

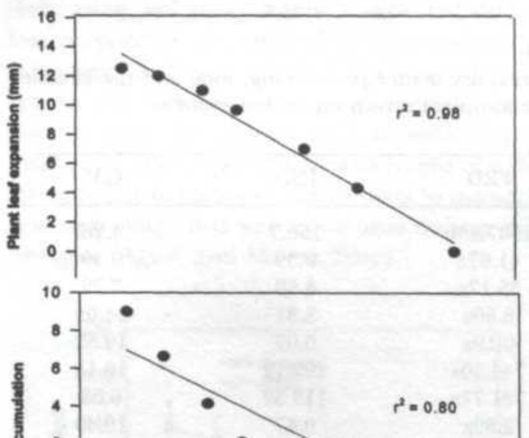

Fig. 6: Relationships between media drying, proline accumulation and leaf expansion as affected by PRD application for tomato plants grown on soilless culture

from root-to-shoot and shoot-to-fruit to elicit a powerful regulatory effect on fruit cell expansion. Other evidence might be that carbohydrate limitations, as showed in this study (data not shown) increased in both leaf and fruit in responses to PRD application. This might be due to maintenance of carbohydrate either directly by some active mechanism or indirectly via a relative increase in the sink strength of the fruit (Davies *et al.* 2000). This idea was strongly supported by Baldet *et al.* (2002) who contrasted responses to carbohydrate limitation in tomato fruit at two stages of development. They stated that the plant responses to sugar depletion were usually by a rapid consumption of carbohydrate reserves and/or an arrest of the processes of carbon storage. However, in tomato fruit where the sugar consumption is slowest when compared to other sink organs such as tomato young roots and this may explain why yield did not significantly decrease with PRD application despite the significant reduction of the source organ such as leaf expansion (*Fig. 3*) and leaf area (Table 1).

The pattern of water use by the crop can be used strongly affect by the agronomic means, widely fertilizers, type of soil, water and irrigation technique. In this present study PRD significantly increased WUE in the two different calculations as presented in Table 1. These results were in agreement with many findings dealing with PRD (Loveys *et al.* 1998; Stoll *et al.* 2000; Davies *et al.* 2000; Zegbe-Dominguez *et al.* 2003). These findings strongly support the idea behind using PRD with grapes to save and increase water use efficiency without significant reduction (Loveys 1991).

CONCLUSION

PRD decreased leaf expansion, stomatal conductance as well as plant leaf area, whereas it increased proline accumulation. PRD, on the other hand, increased water use efficiency (WUEs) of tomato plants by up to 50%and 28% compared to control plants as dry biomass and total yield espectively, without a significant reduction in yield.

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