EFFECT OF PARTIAL ROOT DRYING AND DEFICIT IRRIGATION ON YIELD AND WATER USE EFFICIENCY OF TOMATO GROWN UNDER GREENHOUSE

ABSTRACT

Water conservation strategies are becoming increasingly important as a result of the shortage of water and climate change. The purpose of this study is to address water-saving irrigation strategies by evaluating the effect of partial root drying irrigation (PRD) and Deficit Irrigation (DI) practice on the yield and water use efficiency of tomatoes (Shivam variety). The treatments were partial root drying (PRD) at 75% and 50% crop evapotranspiration, ET_c (PRD_{25} and PRD_{50}, respectively), and deficit irrigation (DI) at 75% and 50% of ET_c (DI_{25} and DI_{50}, respectively). The PRD practice requires wetting one half of the root zone and keeping the other half dry, consequently using less amount of irrigation water that was applied. In the successive irrigations, the wet and dry sides were alternated. Over a growing season after transplanting, the highest fruit yield was obtained under FULL irrigation (225 t ha^{-1}). In comparison to deficit irrigation that received the same quantity of water, the PRD treatments produced an increased yield of 5–10%. PRD and DI irrigation improved WUE considerably, and that was 30.35% and 25.71% respectively higher than FI. Results suggest that PRD treatment may be an option in a water shortage.

Keywords: Water saving; Irrigation practice; Full irrigation (FI); Water shortage; Tomato yield.

1. INTRODUCTION

Irrigated agricultural land is the primary user of water resources, representing roughly 70% of total water withdrawal [1]. However, the worldwide irrigated land area must be increased by more than 20%, and the total irrigated crop yield must be increased by 40% by 2025 to ensure food security for 8 billion people [2]. As a result, water resources should be used more efficiently or productively. Improving agricultural water management is the most effective way to maximize the use of limited water resources. Water-saving is needed to deal with competition between industrial and potable water sectors and ensure the long-term viability of irrigation schemes. The traditional irrigation method is now considered a luxury water use that can be improved with or without yield loss [3]. Several water-saving irrigation strategies have been used in recent years for recurrent water scarcity and long drought spells.

Conventional deficit irrigation (DI) is a common and widely recommended practice for mitigating significant yield reductions [4]. However, the effective use of DI requires prior knowledge of specific crop-growth stages demonstrating tolerance to water stress, so growers may have difficulty using it. Partial root-zone drying (PRD), is an advancement of DI and one of the promising techniques for conserving irrigation water [5]. Grimes et al. (1968) were the first to apply this concept in the United States [6]. PRD is an irrigation technique in which half of the root zone is irrigated while the other half is allowed to dry out. The water supply is then reversed cyclically, allowing the earlier well-watered side of the root system to dry whereas fully irrigating the previously dried side. As per PRD treatment, allowing the soil on one side of a root zone to dry out will cause the roots to signal the shoot to use less water by slowing down vegetative development and stomatal conductance. The expected outcome is acceptable yields with significant water savings and increased water use efficiency (WUE). PRD also stimulates the development of secondary roots, which reduces drought susceptibility [7].

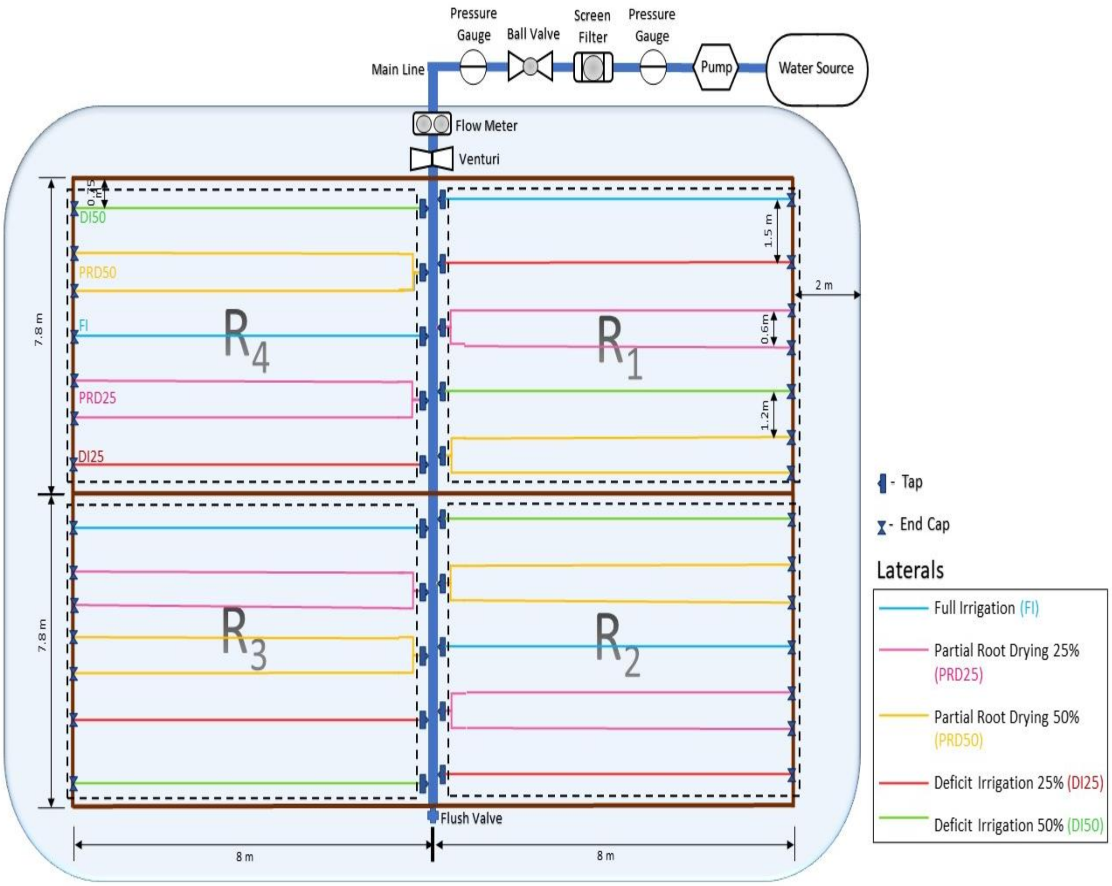
Many studies have proven the benefit of PRD in reducing water input by 30–50% while maintaining yield or even improving quality [8]. PRD was applied to apple trees in a humid climate and showed that it did not reduce yield or fruit quality while increasing IWUE by 20% [9]. Several crops, including tomatoes, corn, cotton, and others, have benefited from the usage of PRD. It also works well on grapevines and other vegetables. [10] [11]. Nevertheless, PRD could be successfully applied to tomatoes and impact bioactive compounds and antioxidant activity [12] [13]. A tomato cultivated in a greenhouse was used to test partial root drying (PRD), a new irrigation technique for saving irrigation water. The ideal technique to assess plant responses to PRD is in a greenhouse under controlled conditions on plants with a split-root system. [14].

This paper aimed to evaluate the effect of partial root drying and deficit irrigation on the yield and water use efficiency of greenhouse-grown tomatoes.

2. MATERIAL AND METHODS

2.1 Experimental Site

The experiment was carried out under the greenhouse from March to June 2022 in the Tamil Nadu Agricultural University, Coimbatore. The crop was Tomato (*Lycopersicon esculentum* L). The site location was 11.00689^{o}N, 76.93606^{o}E, and the altitude is 426.6 m above mean sea level. An area of planting was 240 m^2 (15 × 16 m) for the experiment, divided into four randomized blocks with a 2 m buffer distance from all sides of the experimental field. Each block, with an area of 60 m^2 (7.5 m × 8 m). The soil of the experiment site was sandy clay loam. The soil sample was taken to a depth of 45 cm at every 15 cm for performing physical and chemical analyses of the soil with standard methods [15]. Soil texture, field capacity (FC), wilting point (WP), saturated hydraulic conductivity (K_S), saturation moisture content (Sat), and bulk density (b) were investigated in the physical analysis (Table 1). Hydrogen ion concentration (pH), electrical conductivity (EC), and available N, P, and K were examined in the chemical analyses and 213 kg/ha, 330 kg/ha, and 555 kg/ha were observed. The layout of the experimental setup is shown in Figure 1.



R_1=Replication 1, R_2= Replication 2, R_3= Replication 3, and R_4= Replication 4

Fig. 1. Experimental Plot

Table 1. Physical properties of soil

Depth/ cm	**Particle size %**			**Texture**	**FC/ %**	**WP/ %**	**KS /mm·h^{-1}**	**Sat/%**	**ρb/g·cm^{-3}**	**pH**	**EC**
	Clay	**Silt**	**Sand**								
0-45	32.3	12.4	48.2	Sandy clay loam	19.8	13.7	3.41	33.37	1.43	7.71	1.45

2.2 Transplanting and Irrigation treatments

A surface drip irrigation system was used for irrigation. Drip lines 16 mm in diameter with in-line emitters 0.30 m apart delivered 4L/h each at an operating pressure of 100 kPa.

The field was ready for laying out the irrigation system after the completion of initial preparatory works (i.e., plowing, grading, and leveling). Soil samples were collected from every 0.2 m to 0.45 m depth and Physical analysis was carried out as shown in Table 1. Seedlings were taken from the nursery and transplanted on March 16, 2022. Soil drenching was done by treatment of *Trichoderma* on the next day of transplanting for better establishment of seedlings. The seedlings were planted at 0.30 m distances. Treatmentwise fertilizers were applied as 131 kg/ha NPK (19: 19:19), 499 kg/ha potassium nitrate (KNO_3), 61 kg/ha mono-ammonium phosphate, and 222 kg/ha urea (NH_2CONH_2) through a drip irrigation system with different phase.

Irrigation treatments such as Full irrigation (FI) at 100% crop evapotranspiration (ET_c), Deficit irrigation (DI) at 75% of ET_c (DI_{25}), Partial root drying (PRD) at 75% of ET_c (PRD_{25}), DI at 50% of ET_c (DI_{50}) and PRD at 50% of ET_c (PRD_{50}) as shown in table 2. In full irrigation treatment water is applied at 100% ET_c, in PRD_{25} and DI_{25} water is applied at 75% of ET_c, and in PRD_{50} and DI_{50} water is applied at 50% of ET_c. A randomized complete block (RCB) design was used. For FI and DI water was applied on both sides of the plant root zone and in PRD two laterals were laid on both sides of the plant and water was applied alternatively in successive irrigation to the plant root zone. In FI and DI, laterals were installed at the center of two crop rows, whereas in PRD two laterals (separated by a distance of 0.6m) for each crop row were used. A separate valve was used to control the water flow of these two laterals. In PRD irrigation was shifted between the two sides of the plant root zone in every successive irrigation. The flow meter was installed in the water delivery unit of the irrigation system to measure the irrigation water applied to the experiment plot. The screen filter was installed in the water delivery unit to prevent the clogging of drippers. Irrigation interval had fixed once a week, until mid-season after transplanting, after that at 3- and 4-day intervals two irrigations were applied in a week. The Growth period was divided into four stages as given in Table 3.

Table 2. Irrigation Treatments

S. No.	Irrigation treatments	Description
1.	T_1	Full irrigation at 100% crop evapotranspiration (ET_c)
2.	T_2	Deficit irrigation (DI) at 75% crop evapotranspiration ET_c (DI_{25})
3.	T_3	Partial root drying at 75% crop evapotranspiration ET_c (PRD_{25})
4.	T_4	Deficit irrigation (DI) at 50% crop evapotranspiration ET_c (DI_{50})
5.	T_5	Partial root drying at 50% crop evapotranspiration ET_c (PRD_{50})

Table 3. Growth stage time (days)

Growth stage	Initial	Development	Mid-season	Late-season
days	25	30	30	25

2.3 Weather conditions

All the meteorological parameters such as maximum and minimum air temperature were recorded during the growing period of the crop as shown in Figure 2, air relative humidity i.e. maximum relative humidity and minimum relative humidity RH I and RH II respectively as shown in Figure 3, Also solar radiation were recorded during the growing period of the crop as given in Figure 4, wind speed, and direction at 2 m above ground, etc were recorded throughout the growing season as shown in Figure 5. For estimation of the actual ET_c. The crop coefficient (Kc), with the values of 0.6 in the beginning, 1.15 in the middle, and 0.80 at the end of the growing season was used [16].

The estimation of ET_c is given below:

$$ET_c = K_c \times ET_o \tag{1}$$

From the climatic data, Daily reference evapotranspiration (ET_o) was estimated using the Penman–Monteith FAO-56 equation as shown in Figure 6 [16], [17].

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T_a+273}\mu_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\mu_2)} \tag{2}$$

Where, ET_o is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation (MJ m^{-2} day^{-1}), Δ is the slope of the saturation vapor pressure-temperature curve at mean air temperature (kPa $°C^{-1}$), μ_2 is the wind speed at 2 m height (m s^{-1}), G is the soil heat flux (MJ: m^{-2} day^{-1}), T_a is the mean air temperature at 2 m height (°C), γ is the psychrometric constant [kPa $°C^{-1}$], e_a is the actual vapor pressure (kPa), and e_s is the saturation vapor pressure (kPa).

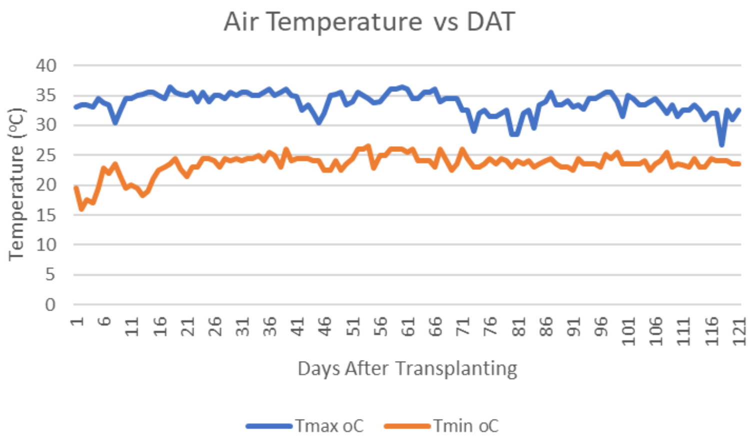


Fig. 2. Air temperature vs Days After Transplanting (DAT)

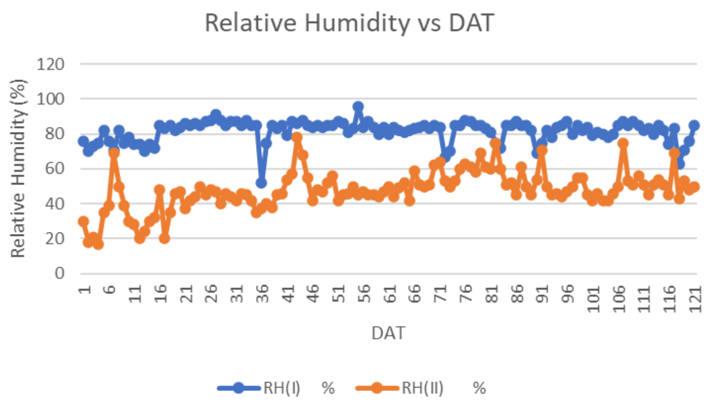


Fig. 3. Relative humidity vs Days After Transplanting (DAT)

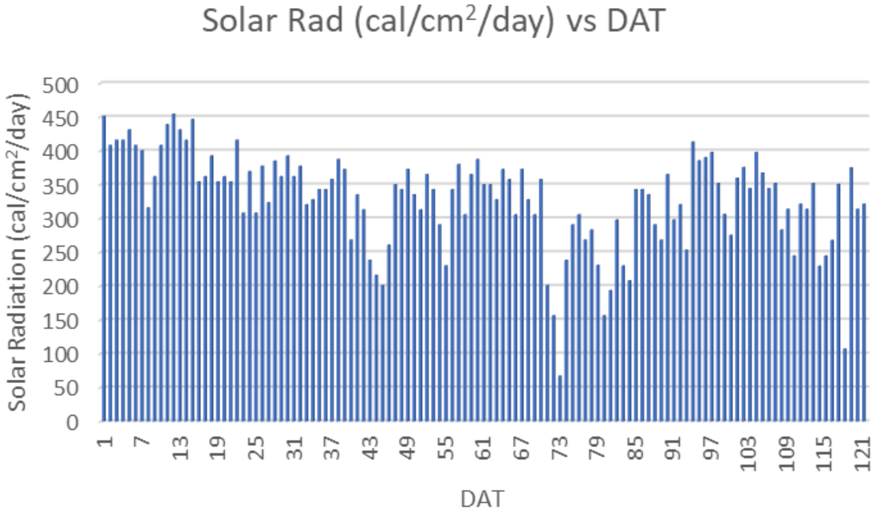


Fig. 4. Solar radiation vs Days After Transplanting (DAT)

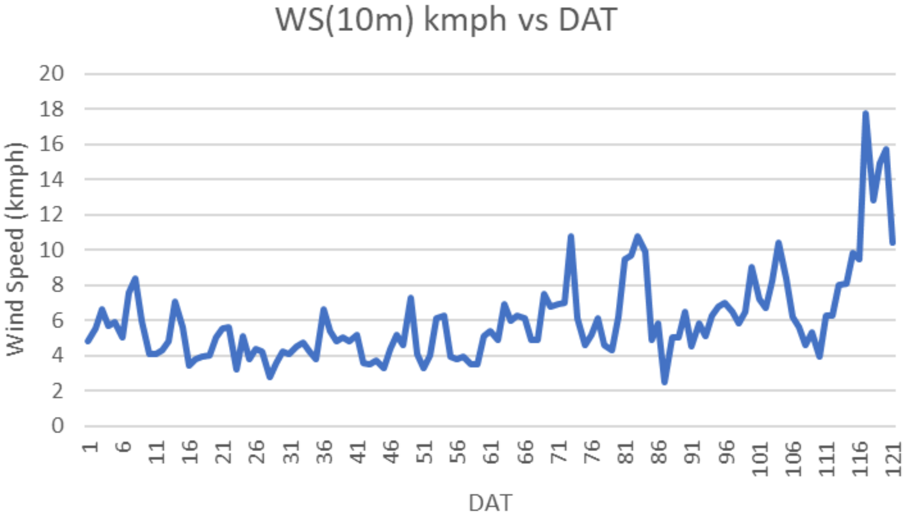


Fig. 5. Wind speed vs Days After Transplanting (DAT)

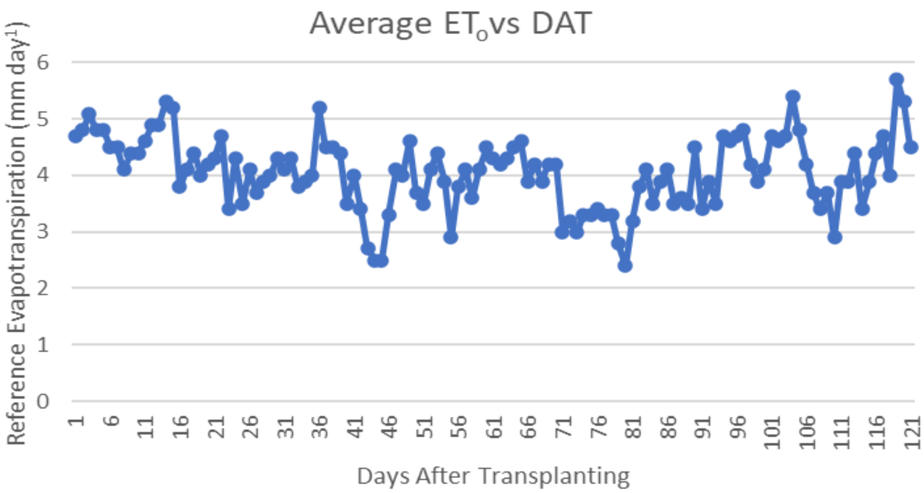


Fig. 6. Average ET$_o$ vs Days After Transplanting (DAT)

Water-use efficiency was used for the evaluation of comparative benefits of the irrigation treatments. It was calculated using the equation [18]:

$$\mathrm{WUE}=\frac{Y}{ET}\times 100 \tag{3}$$

Where WUE is the water use efficiency (t ha^{-1} cm^{-1}), Y is the marketable yield (t ha^{-1}) and ET is the total evapotranspiration (mm).

3. RESULTS AND DISCUSSION

3.1 Effect of Partial Root Drying and Deficit Irrigation on Plant Growth

Throughout the growing season, tomato plants grew well in all the t_1, t_2, t_3, t_4, and t_5 treatments. Plant height at different stages such as 20, 60, and 90 days after transplanting (DAT) was measured. Average plant height for t_1 (FI), t_2 (DI$_{25}$), t_3 (PRD$_{25}$), t_4 (DI$_{50}$), and t_5 (PRD$_{50}$) is given in Table 4. The average plant height for t_1 (FI) at 20, 60, and 90 days after transplanting were 45.2, 94.8, and 142.8 cm which was observed higher than PRD and DI irrigation treatment. As compared to the full irrigation treatment, vegetative parts produced throughout the experimental period were observed less for the DI and PRD treatment, indicating that vegetative growth may have been slightly suppressed. The results have shown that the maximum vegetative growth was found in full irrigation treatment than in the DI$_{50}$ and PRD$_{50}$ irrigation treatments. As a result, the plant heights recorded for DI$_{50}$ and PRD$_{50}$ were found that 18.04 and 19.20% respectively less than full irrigation treatment.

Table 4. Average plant height (cm)

Treatments	20 (DAT)	60 (DAT)	90 (DAT)
T_1 (FI)	45.2	94.8	142.4
T_2 (DI25)	35.3	83.6	128.5
T_3 (PRD25)	34.4	84.7	129.1
T_4 (DI50)	29	76.6	119.3
T_5 (PRD50)	30.2	77.7	120.7

3.2 Effect of Partial Root Drying and Deficit Irrigation on Yield

The effect of Partial Root drying and Deficit irrigation treatment (FI, DI_{25}, PRD_{25}, DI_{50}, PRD_{50}) on the tomato yield is shown in Table 5. In this context, tomato yield for all the irrigation treatments is given in table 5. The maximum yield was achieved in the treatment FI and it was equal to 225 (t ha^{-1}).

Then, the yield for PRD_{25} was more i.e. 173.25 (t ha^{-1}) than the yield in DI_{25} i.e 169.50 (t ha^{-1}). The yield in DI_{50} and PRD_{50} were 154.75 and 161.52 (t ha^{-1}) respectively. The yield in FI was more than in PRD and DI irrigation treatments and it was increased by 24.67 and 23% as compared to DI_{25} and PRD_{25} respectively. Also, it was increased by 31.23 and 28.23% compared to DI_{50} and PRD_{50} respectively. The yield of tomatoes was obtained lower for the treatments DI_{25} and DI_{50}, which revealed that the PRD_{25} and PRD_{50} treatments had higher yields than the DI. Results of this study showed that the partial root drying and deficit irrigation practice can save up to 50% of irrigation water with only marginal yield reduction in tomato yield as shown in Table 5. The irrigation treatments i.e. PRD_{25} and PRD_{50} treatments had higher yields than the DI with the same amount of water applied. These water usage decreases at the DI and PRD have resulted in savings of 23 and 46 mm of irrigation water, respectively.

3.3 Effect of Partial Root Drying and Deficit Irrigation on water use efficiency (WUE) of tomato

Water use efficiency (WUE) was influenced by different irrigation treatments such as FI, DI_{25}, PRD_{25}, $DI_{50,}$ and PRD_{50}. WUE i.e. 24.45, 24.56, 25.11, 32.91, and 35.10 t ha^{-1} cm^{-1} for the irrigation treatments FI, DI_{25}, PRD_{25}, $DI_{50,}$ and PRD_{50} respectively, as shown in table 5. WUE ranged from 24.45 t ha^{-1} cm^{-1} for (FI) to 35.10 t ha^{-1} cm^{-1} for (PRD_{50}). The WUE was found highest i.e. 35.10 t ha^{-1} cm^{-1} in PRD at 50% of ET_c (PRD50), and lowest i.e. 24.45 t ha^{-1} cm^{-1} in Full irrigation (FI) at 100% of ET_c. The WUE for The DI and PRD treatments resulted in significantly lower evapotranspiration (ET) than the full irrigation treatment (FI) [19]. The PRD and DI treatments utilized 50% less water and increased WUE by 30.35% and 25.71% respectively.

Table 5. Water Use Efficiency (WUE) (t ha^{-1} cm^{-1}) of tomato

Treatments	Water applied (cm)	Yield (t/ha)	Water use efficiency (t ha^{-1} cm^{-1})
T_1 (FI)	9.2	225	24.45
T_2 (DI25)	6.9	169.50	24.56
T_3 (PRD25)	6.9	173.25	25.11
T_4 (DI50)	4.6	154.40	32.91
T_5 (PRD50)	4.6	161.50	35.10

4. CONCLUSION

The findings of this study imply that the PRD method can be a practical and advantageous alternative, to conventional deficit irrigation, for mitigating agricultural output reduction when there is water scarcity. If the PRD technique is used, high crop yields can also be maintained under water shortage conditions. It can be concluded that the use of PRD and DI with 50% of ET_C methods of irrigation has an advantage compared to full irrigation in terms of improving the water use efficiency while maintaining the same yield as that of full irrigation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1] Hashem MS, El-Abedin TZ, Al-Ghobari HM. Assessing effects of deficit irrigation techniques on water productivity of tomato for subsurface drip irrigation system. International Journal of Agricultural and Biological Engineering. 2018: 11(4):156-67.

[2] Huffaker R, Hamilton J, Evett SR, Lascano RJ, Letty J, Cardon GE, Kan I, Trout TJ, Kincaid DC, Buchleiter GW, Scott HD. Irrigation of Agricultural Crops, Volume 30.

[3] S.Kang and J. Zhang, “Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency,” in the journal of experimental botany, 2004, vol. 55, no. 407, pp. 2437–2446.

[4] Kirda C, Çetin M, Dasgan Y, Topçu S, Kaman H, Ekici B, Derici MR, Ozguven AI. Yield response of greenhouse-grown tomato to partial root drying and conventional deficit irrigation. Agricultural water management. 2004 ; 69(3):191-201.

[5] Dodd IC, Puértolas J, Huber K, Pérez-Pérez JG, Wright HR, Blackwell MS. The importance of soil drying and re-wetting in crop phytohormonal and nutritional responses to deficit irrigation. Journal of experimental botany. 2015;66(8):2239-52.

[6] Grimes D, Walhood V, Dickens W. Alternate-furrow irrigation for San Joaquin Valley cotton. California Agriculture. 1968;22(5):4-6.

[7] Zhang j, Tardieu F. relative contribution of apices and mature tissues to aba synthesis in droughted maize root systems. Plant and Cell Physiology. 1996;37(5):598-605.

[8] Du T, Kang S, Zhang J, Li F, Yan B. Water use efficiency and fruit quality of table grape under alternate partial root-zone drip irrigation. Agricultural water management. 2008;95(6):659-68.

[9] Dos Santos TP, Lopes CM, Rodrigues ML, de Souza CR, Maroco JP, Pereira JS, Silva JR, Chaves MM. Partial rootzone drying: effects on growth and fruit quality of field-grown grapevines (Vitis vinifera). Functional plant biology. 2003;30(6):663-71.

[10] Dorji K, Behboudian MH, Zegbe-Dominguez JA. Water relations, growth, yield, and fruit quality of hot pepper under deficit irrigation and partial rootzone drying. Scientia Horticulturae. 2005 ;104(2):137-49.

[11] Zegbe JA, Behboudian MH, Clothier BE. Responses of ‘Petopride’processing tomato to partial rootzone drying at different phenological stages. Irrigation Science. 2006;24(3):203-10.

[12] Bogale A, Nagle M, Latif S, Aguila M, Müller J. Regulated deficit irrigation and partial root-zone drying irrigation impact bioactive compounds and antioxidant activity in two select tomato cultivars. Scientia Horticulturae. 2016;213:115-24.

[13] Sun Y, Holm PE, Liu F. Alternate partial root-zone drying irrigation improves fruit quality in tomatoes. Horticultural Science. 2014;41(4):185-91.

[14] Liu F, Shahnazari A, Andersen MN, Jacobsen SE, Jensen CR. Physiological responses of potato (Solanum tuberosum L.) to partial root-zone drying: ABA signaling, leaf gas exchange, and water use efficiency. Journal of Experimental Botany. 2006 ;57(14):3727-35.

[15] Sparks DL, Page AL, Helmke PA, Loeppert RH. Methods of soil analysis, part 3: Chemical methods (Vol. 14). Madison, WI: John Wiley & Sons. 2020.

[16] Mattar MA, Zin El-Abedin TK, Alazba AA, Al-Ghobari HM. Soil water status and growth of tomato with partial root-zone drying and deficit drip irrigation techniques. Irrigation Science. 2020 ;38(2):163-76.

[17] Allen RG, Pereira LS, Raes D, Smith M. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome. 1998;300(9):D05109.

[18] Liu H, Li H, Ning H, Zhang X, Li S, Pang J, Wang G, Sun J. Optimizing irrigation frequency and amount to balance yield, fruit quality, and water use efficiency of greenhouse tomato. Agricultural Water Management. 2019;226:105787.

[19] Nouna BB, Rezig M, Bahrouni H, Ammar HB. Effect of partial root-zone drying irrigation technique (PRD) on the total dry matter, yield, and water use efficiency of potato under Tunisian semi-arid conditions. Journal of Agricultural Science. 2016;8(7):129-41.