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ABSTRACT

Water shortage is the most important factor constraining agricultural production all over the world. New irrigation strategies must be established to use the limited water resources more efficiently. This study was carried out in a completely randomized design with three replications under the greenhouse condition at Shahrekord University, Shahrekord, Iran. In this study, the physiological responses of pepper plant affected by irrigation water were investigated. Irrigation treatments included control (full irrigation level, FI) and three deficit irrigation levels, 80, 60 and 40% of the plant's water requirement called DI_{80}, DI_{60}, and DI_{40}, respectively. A no plant cover

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treatment with three replications was also used to measure evaporation from the soil surface. Daily measurements of volumetric soil moisture (VSM) were made at each 10 cm intervals of the soil column, considered as a layer. The differences between the measured VSM and the VSM in the next day and evaporation rate at the soil surface at the same layer of the no plant cover treatment were calculated. Eventually, by considering the applied and collected water in each treatment, evapotranspiration (ET_C) and root water uptake (RWU) in each layer per day were estimated. Furthermore, fruit number per plant, fresh fruit weight/day, root fresh/dry weight, shoot fresh/dry weight, root zone volume, root length and density, crop yield, and water use efficiency (WUE) were measured under different water treatments. The results showed that the maximum and minimum of all the studied parameters were found in the FI and DI_{40} treatments, respectively. ET_C in the DI_{80}, DI_{60}, and DI_{40} treatments were reduced by 14.2, 37.4, and 52.2%, respectively. Furthermore, applying 80, 60, and 40% of the plant's water requirement led to crop yield reduction by 29.4, 52.7, and 69.5%, respectively. The averages of root water uptakes (ARWUs) in the DI_{80}, DI_{60}, and DI_{40} treatments reduced by 17.08, 48.72, and 68.25%, respectively. WUE and crop yield also showed no significant difference in the FI and DI_{80} treatments. Moreover, in the DI_{80} treatment the reduced rate of water uptake was less than the reduced rate of plant's applied water. According to these results, it can be concluded that 20% deficit irrigation had no significant reduction on the yield of pepper, but above this threshold, there was an adverse effect on the growth and yield. Therefore, for water management in the regions with limited water resources, plant's applied water can be decreased around 20%.

Keywords: Deficit irrigation, Pepper plant, Water management, Crop yield, Water scarcity.

INTRODUCTION

Water scarcity is the discrepancy between the availability and demand for water resources. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) stated that water scarcity is regarded as a major challenge for many regions internationally, and estimated that it affects one third of the global population (UNESCO, 2009). Water shortage has becoming a global issue, threatening global economic, local agricultural, and environmental wise due to climate change, causing more extreme events, including drought and flooding (Paula and Gutiérrez, 2014). In a scenario of global water scarcity, population growth, and climate change, conserving water as much as possible and assuring crop production is a must consideration. One option that farmers around the world have, when facing water availability challenges, is limited or reduced irrigation. Deficit irrigation (DI) is a strategy that allows a crop to sustain some degrees of water deficits in order to reduce costs and potentially increase income. It can lead to increase net income where water supplies are limited or where water costs are high (Kirda et al., 2002). DI is a method of irrigation, where the amount of water used is kept below the maximum level and the slight stress that is developed has minimal effect on yield. Studies have shown that DI is advantageous when properly applied. English and Raja (1996) described three DI case studies in which the reductions in irrigation costs were greater than the reductions in revenue due to reduced yields. DI can lead to increased profits where water costs are high or where water supplies are limited. In these case studies, crop value was associated closely with yield, and crop grade and marketability were not germane. Under these circumstances, DI can be a practical choice for growers. DI may range from moderate, and of short duration, to extremely

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severe and prolonged summer drought that has strongly influenced evolution and plant life (Bottner et al., 1995). Crop yields are restricted by water shortages in many parts of the world. The physiological responses of plants to water stress and their relative importance for crop productivity vary with species, soil type, nutrients and climate (Şener and Dorothy, 2012). The decline in water availability for irrigation and the positive results obtained in some fruit tree crops have renewed the interest in developing information on DI for a variety of crops (FAO Report, 2002; Dorji et al., 2005; Fereres and Soriano, 2007). These crops are relatively resistant to water stress, or they can use some strategies in order to cope with the soil moisture limitations. Some of them avoid stress by deep rooting, allowing access to soil moisture lower in the soil profile (Shock and Feibert, 2002). However, DI of pepper may be difficult to manage because reductions in crop yield, quality and quantity can result from even brief periods of water stress on this crop (Katterji et al., 1993; Jaimez et al., 2000; Della Costa and Gianquinto, 2002; Fernandez et al., 2005).

Pepper (Capsicum annum L.) is an important commercial crop, cultivated for vegetable, spice, and value-added processed products (Kumar and Rai, 2005). Its production and consumption is increasing worldwide. Total world production of hot pepper is estimated 18-20 million tons fresh fruit from 1.5 million ha of arable land. Irrigation is essential for pepper production, because pepper is considered one of the most susceptible crops to water stress in horticulture (Doorenbos and Kassam, 1986; Katterji et al., 1993; Jaimez et al., 2000). To optimize pepper production and profitability, and to ensure the most efficient use of limited water resources, there is a clear need for a comprehensive information regarding crop water use of pepper grown in the horticultural

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system. Consequently, in order to maximize pepper production in water scarcity conditions, optimal irrigation management is essential (Fernandez et al., 2005).

Interestingly, an understanding of root water uptake (RWU) patterns has become increasingly important as we seek to develop modern and environmentally friendly practices involving high frequency irrigation and fertilization (Clothier and Green, 1994). Furthermore, knowledge on evapotranspiration (ET) is fundamental when dealing with water resources management issues such as the provision of drinking and irrigation water, industrial water use, or water conservation and management (Verstraeten et al., 2008). Consequently, information on ET, RWU, and physiological growth indices are useful in better understanding crop responses to irrigation, especially with the limited wetted soil volumes. The main objective of this study was to evaluate the physiological responses of pepper plant to drought stress affected by irrigation water under the greenhouse condition in order to use the limited water resources more efficiently.

MATERIALS AND METHODS

In order to evaluate the physiological responses of pepper plant affected by irrigation water level, an experiment was conducted in the greenhouse of the Shahrekord University, Shahrekord, Iran in 2012. Shahrekord has a semi-arid climate by using linear combination (Kham-chin Moghadam and Rezaei Pajand, 2009). Furthermore, it is located at 32° 20′ N latitude and 50° 51′ E longitude. The soil used in this experiment was a mixture of clay, sand and silt with the ratios of 3, 1, and 1, respectively, and manure. Using hydrometer method, loamy - clay soil was determined as the soil texture. Physical properties of the soil such as soil bulk density, field

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capacity, wilting point and saturated soil moisture (using a pressure plate and chamber pressure) were identified and presented in Table 1. Irrigation water quality indexes such as pH, electrical conductivity (EC), chloride, calcium, magnesium, carbonate and bicarbonate (using the titration method), sulfate, phosphate, ammonium, nitrite, and nitrate (using spectrophotometry device) were measured and presented in Table 2.

This study was carried out in a completely randomized design with five treatments and three replications. Irrigation treatments included control (full irrigation level, FI) and three deficit irrigation levels, 80, 60, and 40% of the plant's water requirement called DI_{80}, DI_{60}, and DI_{40}, respectively. A no plant cover treatment was used to measure evaporation rate from the soil surface. Surface irrigation method was applied in this study. Plastic pots were used as lysimeters with 55 and 45 cm height and diameter, respectively. In the present study, alpha pepper plant seeds with the digit number 7 were planted in the nursery. Then, they were transferred to the main pots when seedlings were at the 7 leaves stage of growth. After transplanting, the pots were irrigated with the same amount of water to let the transplants be used to the new location. Deficit irrigation was started 78 days after cultivation and continued for another 64 days. The FI was characterized as the base criterion, and its soil moisture index was used in order to determine irrigation schedule. Accordingly, the daily measurements of the volumetric soil moisture (VSM) were made at each 10 cm intervals of the soil column, considered as a layer (Table 3) by using the moisture meter device namely SM300 on a daily basis.

To estimate root development rate for the FI treatment the following equation was used (Alizade, 2007).

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$$\mathrm{Drz(j)} = \mathrm{Drz_{init}} + \left(\frac{\mathrm{J} - \mathrm{J_{planting}}}{\mathrm{J_{full-cover}} - \mathrm{J_{planting}}}\right) \times (\mathrm{Drz_{max}} - \mathrm{Drz_{init}}) \quad (1)$$

Where, Drz(j) is the root development depth in the desired Julian day, $\mathrm{Drz_{init}}$ is equal to seeding depth plus five cm, $\mathrm{Drz_{max}}$ is the maximum root development depth, J is the Julian day number, $\mathrm{J_{planting}}$ is the Julian day number when the seeding was planted, $\mathrm{J_{full\text{-}cover}}$ is equal to the Julian day number when plant reaches to its maximum growth. The total available water (TAW) and readily available water (RAW) were estimited by θ_{FC}, θ_{PWP} and a MAD=0.3 for the pepper plant (Allen et al., 1998). Irrigation for the control treatment (FI) was done in a point between field capacity (FC) and permanent wilting point (PWP) (namely θ_d= 25.20%). When the average VSM in the plant root zone of the full irrigation treatment reached the θ_d, applying different water regimes were launched. These various water regimes were carried out based on the lack of the soil moisture and the coefficients of each treatment using the following equation:

$$\mathrm{SMD} = (\theta_{FC} - \theta) \times \mathrm{Dr} \times \mathrm{C} \quad (2)$$

Where, SMD is amount of irrigation water (mm), θ_{FC} is the soil moisture at the field capacity (cm^3/cm^3), θ is the average VSM in the plant root zone (cm^3/cm^3), Dr is the root development depth (mm) and C is the irrigation coefficient. This coefficient for the FI, DI_{80}, DI_{60}, and DI_{40} treatments was equal to 1, 0.8, 0.6, and 0.4, respectively. After each irrigation (I), drainage water (D) from the different lysimeters was manually collected and measured daily. Evaporation rate (E) in each layer was estimated by the difference bettween the daily measurement of VSM in each layer of the no plant cover treatment and the VSM of the same layer in the next day. The summation of root water uptake (RWU) in the plant root zone in different treatments on a daily basis was considered as the total rate of daily RWU by the following equation (3).

$$WU = \sum_{i=0}^{5}(\theta_i - \theta_{i+1} - E) \times 100 \quad (3)$$

Where, θ_i, is the VSM in each layer (cm^3/cm^3), θ_{i+1}, is the VSM in each layer in the next day (cm^3/cm^3), E is the evaporation rate in the same layer (cm^3/cm^3), and RWU is the root water uptake rate (mm/day).

Crop evapotranspiration (ET_C) was determined during these 64 days by using the following water balance equation (4).

$$ET_C = (\theta_i - \theta_{i+1}) + I - D \quad (4)$$

Where, θ_i and θ_{i+1}, are the same as the ones in the previous equation (cm^3/cm^3), I and D, are total volumes (cm^3/cm^3) of the applied and collected water, respectively, for the different lysimeters.

At the final harvest, fruit number and total fresh mass of fruit for each individual plant were recorded on 142 days after sowing coinciding with the commercial harvest for fresh consumption. Fruit were oven-dried at $71 \pm 1^{\circ}C$ to a constant mass and the dry mass recorded. Crop yield was then estimated by measured parameters. Shoots and roots of each individual plant were harvested, and then roots were separated from shoot and washed. Dry matter determinations of leaves, stems and roots were made by weighing all of the fresh plant materials immediately after separation, and were then oven-dried at $71 \pm 1^{\circ}C$ for 48 h to a constant mass and dry mass determined. The root length and density (RLD), the length of roots per unit volume of soil, in different treatments were estimated by sampling three different depths of the soil column in which each sample had three replicates (Gao et al., 2010). The root samples were

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collected from the soil profile by pressing sharp-edged iron boxes vertically into the soil surface. Root length in the samples were measured with the modified Newman-line-intersect method (Tennant, 1975), and then RLD was calculated from the volume of the soil cores and the root length for each lysimeter. Root zone volume was also tested by the water displacement method through graduated cylinders (Harrington et al., 1994). Water use efficiency (WUE) was calculated by evaluating crop yield and applied water in all treatments. Finally, the averages of measured parameters in different irrigation treatments were statistically compared. Analysis of variance (ANOVA) was performed using SAS to determine significant differences between all measured parameters, and EXEL software was used to plot the graphs.

RESULTS

Average Daily Root Water Uptake

The details of statistical analysis of the average daily water uptake (ARWU) in all layers are shown in Table 4. The results showed that the ARWU had significant differences among various treatments. Figure 1 shows the averages of daily root water uptakes (ARWUs) during 64 days. The results also showed that the maximum and the minimum ARWUs were found in the FI and DI_{40} treatments by 8.5 and 2.7 mm/day, respectively. The ARWUs in the DI_{80}, DI_{60}, and DI_{40} treatments were reduced by17.08, 48.72, and 68.25%, respectively. Furthermore, only in the DI_{80} treatment, the reduced rate of water uptake was less than that of the plant's applied water. This is probably due to the plant regulatory mechanism that the plant uses under water stress condition

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and adjusts its root water uptake (RWU) with environmental conditions (Aliyari, 2010). The ARWU variance analyses (ANOVA) in all soil layers are tabulated in Table 5. The results showed that the ARWU was significantly different in each layer in different treatments (Figure 2). The results further illustrated that in all treatments, the upper layers of the soil had played a big role in the RWU. However, the role of the lower layers of the soil in the RWU was not noticeable in the DI_{60} and DI_{40} treatments. Moreover, the results indicated that although the applied water in each treatment was different, the highest RWU rates were found in the upper layers of the soil in all treatments. The plant roots in the control treatment were more developed in different layers of the soil and could have the highest water uptake among other treatments.

Average Daily Evapotranspiration

By daily measurement of evapotranspiration (ET_C), the daily values of ET_C in different treatments were identified during the 64 days (Figure 3). The results showed that the maximum and the minimum ET_C were found in the FI and DI_{40} treatments by 6.8 and 2.3 mm/day, respectively. The summations of ET_C across the determined period in the FI, DI_{80}, DI_{60}, and DI_{40} treatments were 401.1, 344, 251, and 191.7 mm, respectively. The results showed that the ET_C values in the DI_{80}, DI_{60}, and DI_{40} treatments decreased by14.2, 37.4, and 52.2%, respectively. It was noticeable that in the deficit-irrigated treatments, the reduced rates of ET_C were less than those of the plant's applied water, especially in the DI_{80} treatment.

Physiological Response of Plant to Deficit Irrigation

The detail of statistical analysis of the measured parameters such as no. of fruits per plant; fruit fresh/dry weight, root fresh/dry weight, shoot fresh/dry weight, and root zone volume in different irrigation treatments are shown in Table 6. Figure 4 shows that the measured parameters were significantly different in different treatments. The results also indicated that the maximum and the minimum of all measured parameters were found in the FI and DI_{40} treatments, respectively. The fruit number in the DI_{80}, DI_{60}, and DI_{40} treatments was reduced by 29.4, 52.7, and 69.5%, respectively. The shoot dry weight in the DI_{80}, DI_{60}, and DI_{40} treatments also decreased by 16.9, 33.9, and 53.1%, respectively. Furthermore, the root dry weight decreased by 31, 47.8, and 62.6%, respectively in the DI_{80}, DI_{60}, and DI_{40} treatments. The physiological responses of pepper plant to deficit irrigation showed the sensitivity of pepper plant to water scarcity.

The details of the statistical analysis of the root length and density (RLD) are shown in Table 7. The results showed that the RLD in the first and the second depths of the soil column had significant differences among all treatments. The results also showed that in all treatments, the highest RLD was found in the upper depths of the soil column, and that can be the main reason why the highest ARWUs rate occurred in the surface layers of the soil (Figure 5).

Water Use Efficiency and Crop Yield

The detail of statistical analysis of water use efficiency (WUE) and crop yield in different irrigation treatments are shown in Table 6. The results showed that WUE and crop yield were not significantly different in the FI and DI_{80} treatments; however; they were significantly different

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between the other irrigation treatments (Figures 6 and 7). Increase in irrigation deficit resulted in a decrease in WUE. The highest values of WUE were found in the FI and DI_{80} treatments, while the lowest ones were recorded for the DI_{60} and DI_{40} treatments. These results showed that the total dry mass of fruit was significantly affected by deficit irrigation. The results also showed that the maximum and the minimum WUE and crop yield were found in the FI and DI_{40}treatments by 0.50 and 0.38 L/g for WUE, and 16.7 and 5 ton/ha for crop yield, respectively. Furthermore, the results showed that WUE and crop yield reduced in the DI_{80}, DI_{60}, and DI_{40} treatments by 1, 11.2, and 23.3%, respectively for WUE, and 29.4, 52.7, and 69.5%, respectively for crop yield.

DISCUSSION

Asseng et al. (1998), Aliyari (2010), and Dathe et al. (2014) reported that the maximum and the minimum percentages of water uptake were found in the full irrigation treatment and the treatment that experienced the highest range of deficit irrigation. In the present research, the highest and the lowest ranges of water uptake were also found in the FI and DI_{40} treatments. Additionally, Aliyari (2010) found that in all treatments the reduced rates of water uptake were less than the reduced rate of plant's applied water; however; in the present research, only in the DI_{80} treatment, the reduced rate was less than that of plant's applied water. Luo et al. (2003), Raats (2007), Dathe et al. (2014), and Verma et al. (2014) reported that the maximum percentages of water uptake were found in the top layers of the soil since most of the root systems were distributed in these sections. Huang and Nobel (1992), Zakerinia et al. (2008), and

Besharat et al. (2010) reported that not only the maximum water uptake was found in the top layers of the soil, but also the maximum water uptake occurred in these layers. The present research also showed although the volume of applied water in each treatment was different, in all treatments the highest rate of the RWU was found in the upper layers of the soil. Additionally, in all treatments, the maximum RWU was found in the first and the second layers of the soil.

Vegetative growth of pepper was closely linked to the amount of water applied. Deficit irrigation (DI) throughout the determined period decreased the fruit number; fruit fresh/dry weight, root fresh/dry weight, shoot fresh/dry weight, and root zone volume in different irrigation treatments. The results indicated that the pepper physiological responses to DI were completely negative. Similar results were obtained by Shaozhong et al. (2001), Ismail et al. (2002), Dorji et al. (2005), Kashiwagi et al. (2006), Gonza´lez et al. (2007), Khan et al. (2009), and Ismail (2010) reporting decreases in yield under water stress conditions. Additionally, in the present study, the evapotranspiration values (ET_C) in the DI_{80}, DI_{60}, and DI_{40} treatments substantially decreased by DI, indicating that the effect of DI on the ET_C values in different irrigation treatments was noticeable. The present findings on the ET_C values in DI condition are in agreement with other studies (Moreno et al., 2003; Fernandez et al., 2005; Fereres and Soriano, 2007).

Reduction in crop yield of pepper under deficit irrigation might be due to the reduction in fruit size and numbers (Fernandez et al., 2005). Reduction in pepper fruit size and numbers appears as the controlling factor for fruit yield. In the present study, deficit irrigation significantly reduced crop yield in terms of fresh mass of fruit per plant. Fully irrigated treatment (FI) resulted in the highest yield because increasing soil water content led to increasing plant height and number of branches, resulting in an increase in the number of fruits and total yield. Similar results were reported by Antony and Singandhupe (2004); Dorji et al. (2005); Ismail (2010); Owusu-Sekyere et al. (2010) and Sam-Amoah et al. (2013). It is indisputable that for high yields, an adequate water supply and relatively moist soils are required during the entire growing season. Reduction in water supply during the growing period, in general, has an adverse effect on yield. The greatest reduction in yield occurs when there is a continuous water shortage until the time of the first picking (Jaimez et al., 2000; Delfine et al., 2001; Della Costa and Gianquinto, 2002; Antony and Singandhupe, 2004; Sezen et al., 2006; Owusu-Sekyere et al., 2010; Sam-Amoah et al., 2013).

In the present study, by considering the fact that the total dry mass of pepper plant was markedly affected by DI, DI led to decreased water use efficiency (WUE) and crop yield. This indicates that water movement into fruit may have decreased with progressive development of water deficit together with affecting the translocation of dry matter into the fruit and resulted in a decrease in mass production per unit of water, which led to a lower WUE and crop yield. Interestingly, in regards to WUE and crop yield, there were no significant differences found between the FI and DI_{80} treatments. The results showed that WUE and crop yield were not affected by the moderate water stress (DI_{80}) imposed on pepper plant investigated in the present study. Whereas, under severe water stress (DI_{60} and DI_{40}), WUE and crop yield significantly decreased. Similar findings were reported using a variety of crop plants such as millet, barley, sorghum, and wheat (Ibrahim 1997; Boutraa et al., 2010).

CONCLUSIONS

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The results showed a great sensitivity of this horticultural crop to deficit irrigation. Water stress negatively affected most of the studied physiological parameters. The maximum and the minimum averages of root water uptake (ARWUs), evapotranspiration (ET_C), fruit number, root zone volume, root length and density, and crop yield were found in the FI and DI_{40} treatments. Also, the ARWUs, ET_C, crop yield in the DI_{80}, DI_{60}, and DI_{40} treatments were reduced compared with that of the control treatment (FI), indicating that in the DI_{80} treatment, the reduced rate of uptake was less than the reduced rate of plant's applied water. The maximum RWU was also found in the first and the second layers of the soil. Water use efficiency (WUE) showed no significant difference in the FI and DI_{80} treatments. In addition, there was no meaningful difference among the FI and DI_{80} treatments in crop yield. Based on the results of this study, it can be concluded that 20% deficit irrigation had no significant reduction on the yield of pepper plant, but above this threshold, there was an adverse effect on the plant's growth and yield. Therefore, in the regions with limited water resources, plant's applied water can be decreased by 20%.

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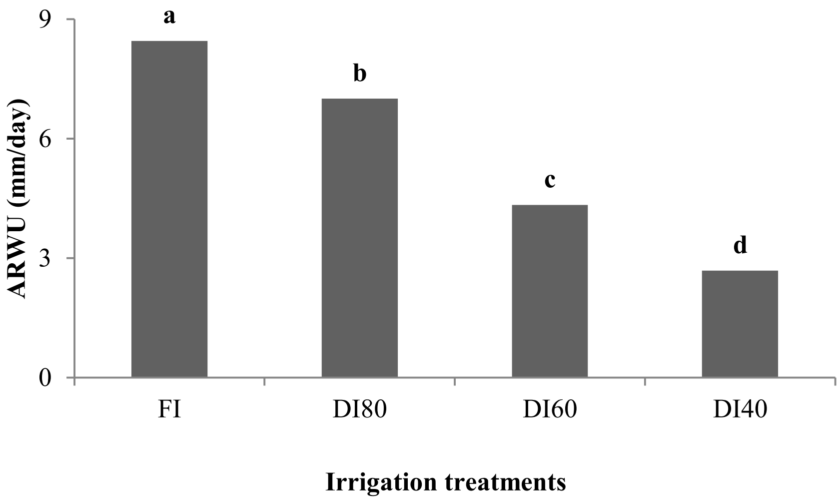
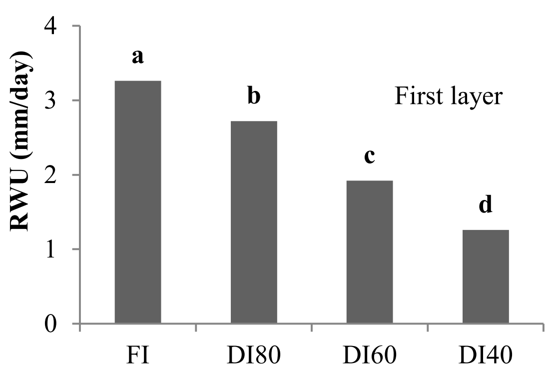
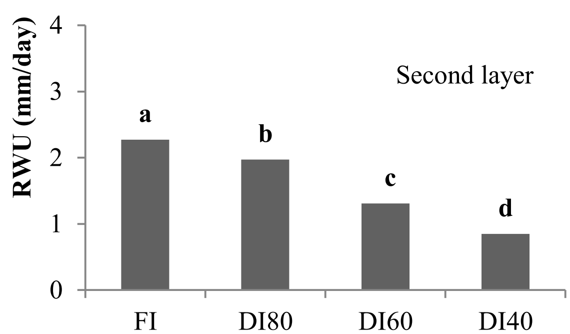


Figure 1. The averages of root water uptake (ARWUs) in different treatments





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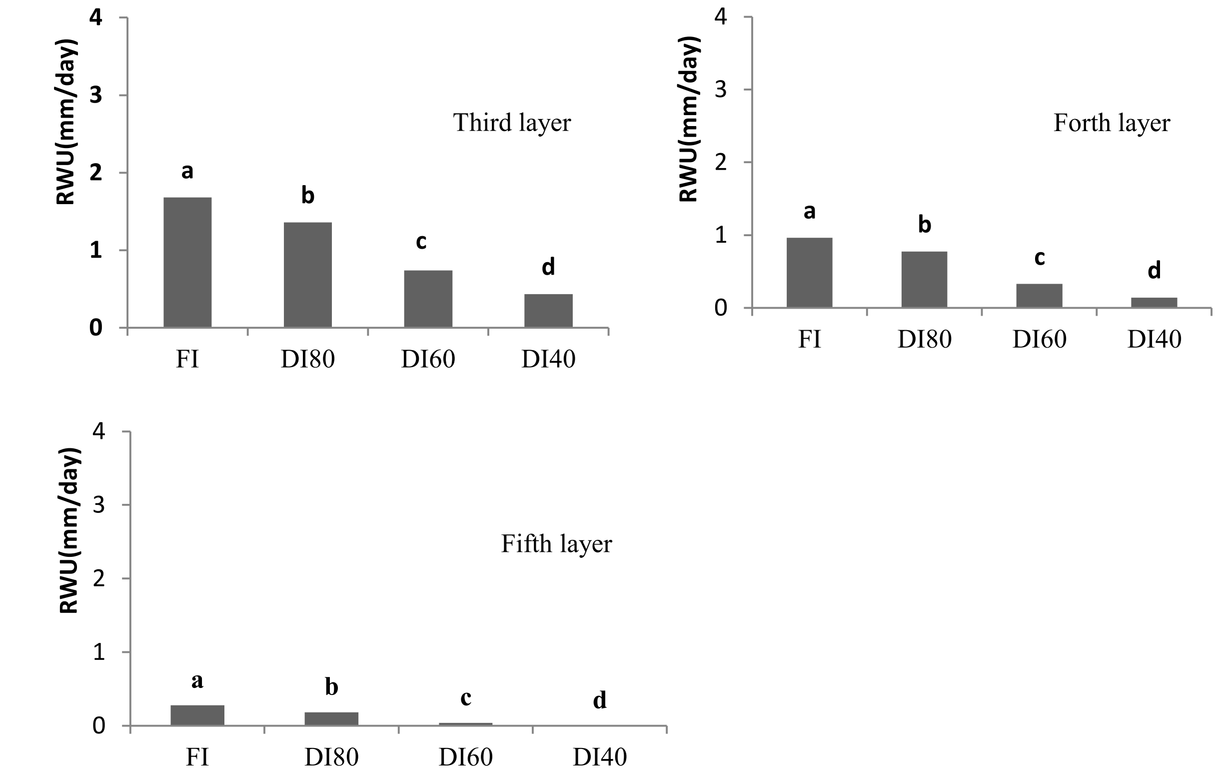

Figure 2. The averages of root water uptakes (ARWUs) in each layer of the soil in different treatments

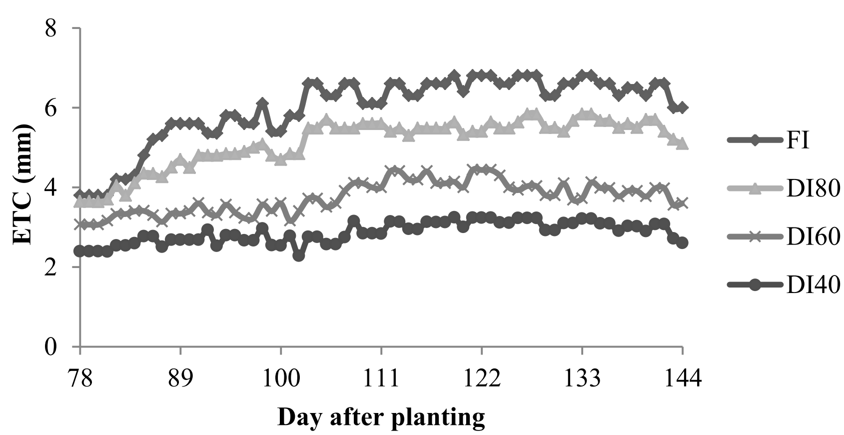

Figure 3. The daily values of ET_C in different treatments

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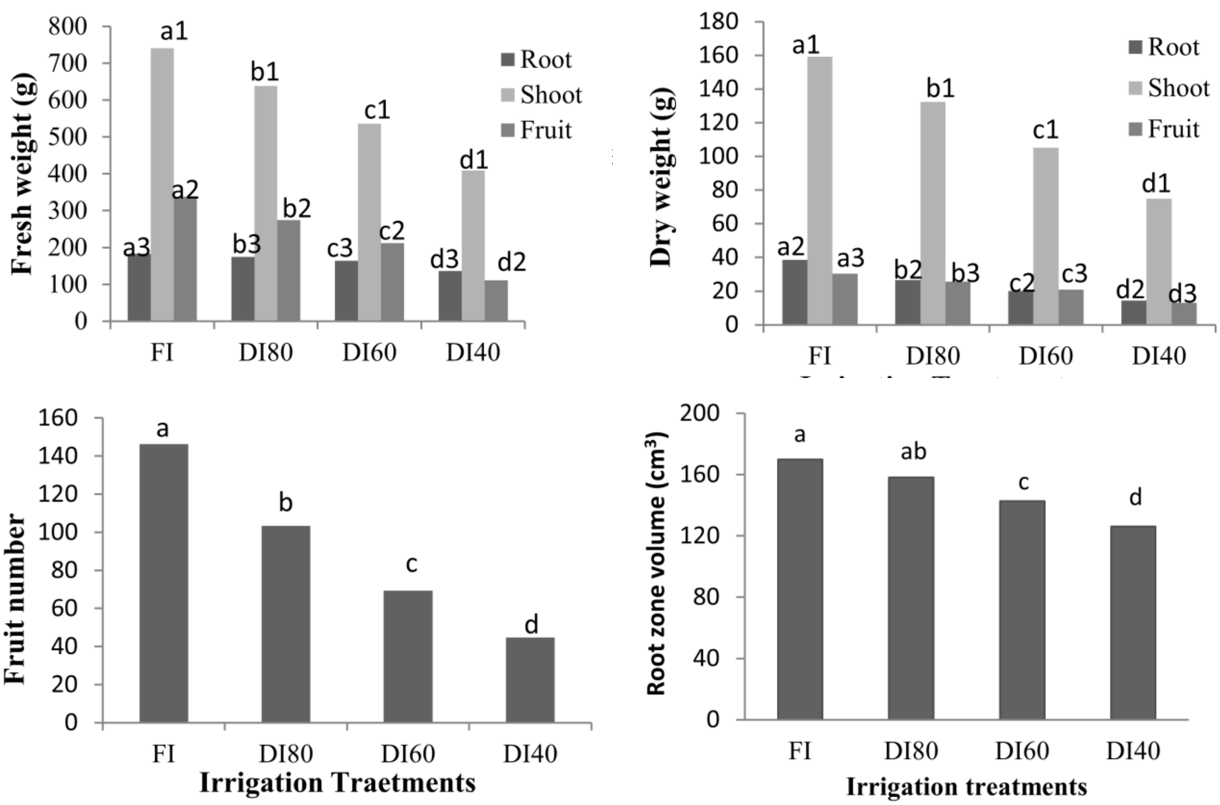

Figure 4. Physiological responses of plant to different irrigation treatments

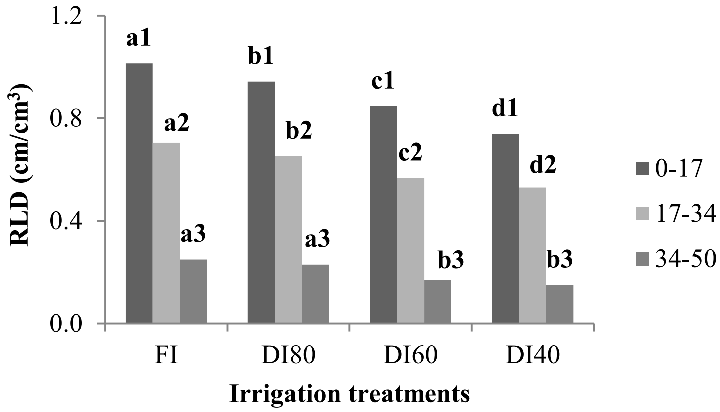

Figure 5. The root length and density (RLD) in all treatments

* Columns with the same letter are not significantly different at 5% level by Duncan's multiple range test

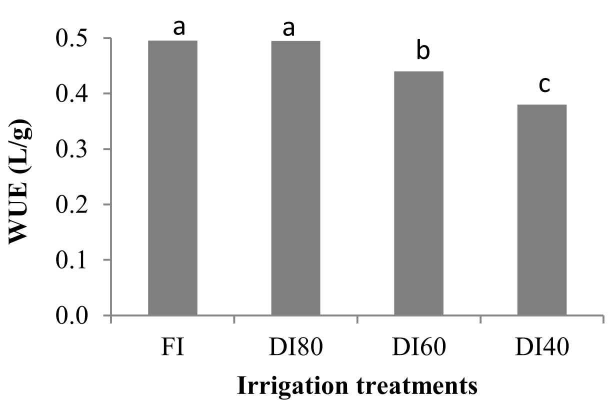

Figure 6. Water use efficiency (WUE) in different irrigation treatments

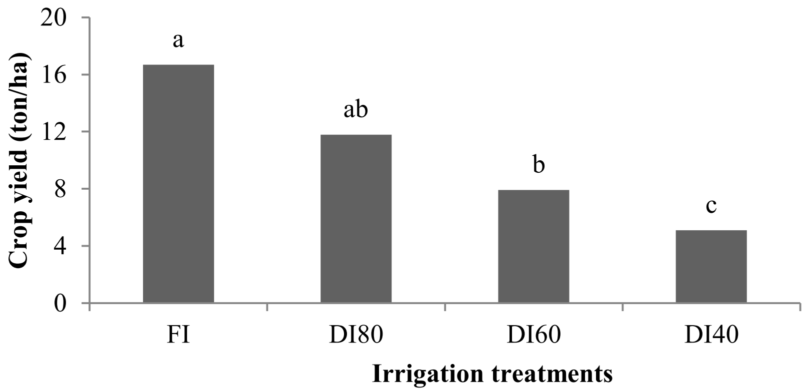

Figure 7. Crop yield in different irrigation treatments

Table 1. Physical properties of the soil

Soil bulk density (gr/cm3)	Clay (%)	Silt (%)	Sand (%)	Moisture saturation (%)	Wilting point moisture (%)	Field capacity moisture (%)	Soil texture
1.35	32.2	27	40.8	47.84	13.93	30.13	loamy-clay

Table 2. Characteristics of irrigation water

NO_3^-	NO_2^-	NH_4^+	PO_4^{3-}	SO_4^{2-}	CO_3^{2-}	HCO_3^-	Cl^-	Mg^{2+}	Ca^{2+}	EC	pH
mg.lit^{-1}										dS.m^{-1}	
28.09	0.05	0.1	0.16	9.8	0	207	12.5	25.7	51.3	0.35	7.93

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Table 3. Introducing each layer

Layers	First layer	Second layer	Third layer	Forth layer	Fifth layer
Depth (cm)	0-10	10-20	20-30	30-40	40-50

Table 4. Analysis of the daily ARWU variance in different treatments

Variance sources	Df	Average of water uptake (ARWU, mm/day)
Treatment	3	0.09*
Prediction error	8	0.018
CV	-	1.59
P	-	< 0.001

*Significant at the 0.05 probability level

Table 5. Variance analysis of the daily ARWUs in all layers

Variance sources	df	First layer	Second layer	Third layer	Fourth layer	Fifth layer
Treatments	3	0.037*	0.012*	0.0033*	0.0077*	0.0055*
Prediction error	8	0.00007	0.00006	0.00007	0.00002	0.00004
CV	-	0.89	0.95	1.65	0.9	1.2
P	-	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

* Significant at the 0.05 probability level

Table 6. Variance analysis of the plant physiological responses to different irrigation treatments

Variance sources	Treatments	Prediction error	CV	P
df	3	8	-	-
No. of fruits/plant	5830*	393.433	21.81	< 0.001
Fruit fresh weigh/plant (g)	27973.86*	749.16	11.70	< 0.001
Fruit dry weigh/plant (g)	164.85*	18.57	19.17	< 0.001
Shoot fresh weigh/plant (g)	62542*	656	4.37	< 0.001
Shoot dry weigh/plant (g)	3935.2*	92	8.13	< 0.001
Root fresh weigh/plant (g)	1250**	7.78	1.69	< 0.001
Root dry weigh/plant (g)	322**	0.512	2.86	< 0.001
Root zone volume (cm^3)	1089*	5.19	1.52	< 0.001
Water use efficiency (L/g)	0.0026*	0.0015	1.21	< 0.001
Crop yield (ton/ha)	24.55*	1.90	19.91	< 0.001

*, ** Significant at the 0.05 and 0.01 probability level, respectively

Table 7. Variance analysis of the root length and density (RLD) in different depths

Variance sources	df	RLD (cm/cm^3)		
		0-17	17-34	34-51
Treatments	3	0.043*	0.0089*	0.0068*
Prediction error	8	010000	0.00021	0.00061
CV	_	7143	6142	06126
P	_	< 0.001	< 0.001	< 0.001

* Significant at the 0.05 probability level

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