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ORIGINAL RESEARCH

Comparison of traditional and modern deficit irrigation techniques in corn cultivation using treated municipal wastewater

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Abstract
Purpose Declining water resources, increasing drought period and increasing irrigated area cause a shift to deficit irrigated production which is not based on full water requirement. This study was conducted to investigate the impacts of two different deficit irrigation methods, including traditional deficit irrigation (TDI) and partial root-zone drying (PRD) on water use efficiency (WUE) in corn cultivations located at the lands close to the Shahrekord wastewater treatment plant.
Methods A factorial design was employed, consisted of fifteen treatments and three replications. The first factor was three water applications, including 60, 80 and 100 (control) percent of plant water requirement. The second factor was three water sources, including 100% fresh water (FW), 50% water and 50% wastewater (5050), 100% wastewater (WW). T-Tape irrigation type system was used for irrigation of corn (*Zea mays* L.). The third factor was water management in three levels: full irrigation (FI), PRD and TDI.
Results The result showed that dry and fresh weight, leaf area index (LAI), dry biomass percentage and WUE were affected by water requirement at 5% probability level expect of height plant that is affected at 1% probability level. Water quality was affected on all the study indicators of corn plant expect of WUE. WUE among PRD by deficit irrigation treatments were higher than TDI and it was the minimum in FI. The dry and wet weight and LAI were maximum at FI and then PDR_{80} than TDI_{80}. The height of corn plants were high at FI and TDI_{80} than PRD_{80}.
Conclusion Finally, wastewater application in treatment named 5050-PRD_{80} and 5050-TDI_{80} compensated water deficit in WUE, LAI and dry biomass percentage. PRD method recognized more suitable than TDI for corn plants.

Keywords Deficit irrigation · Partial root-zone drying · Full irrigation · Wastewater

Introduction

Water shortage is assumed as major agricultural production constraint. Therefore, the relationship between crop yield and water use efficiency (WUE) has constantly been the focus of many agricultural researchers in the arid and semi-arid regions (Zhang and Oweis 1999).

In all agricultural systems, low WUE can occur when soil evaporation is high (considering crop evapotranspiration), early growth rate is slow, and water application does not correspond to crop demand and when shallow roots are unable to utilize deep water in the soil profile (Gallardo et al. 1996). Also, in cases of drought, nutrients are not easily available from inorganic sources of soil nutrients for plant (Chemura 2014). New innovations are particularly important in water-scarce regions with the aim of saving irrigation water, and thereby increasing crop WUE (Gencoglan et al. 2006). To do so, one way is to develop new irrigation scheduling techniques such as traditional deficit irrigation (TDI), which are not necessarily based on full water requirement.

Traditional deficit irrigation method is a practice of applying less water than crop evapotranspiration demand

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with the intent of imposing a managed level of water stress to the crop (Grant et al. 2008). The strategy is to maintain plants under certain water deficit for a prescribed duration of the growth season. The aim is to control reproductive and vegetative growth and to improve WUE and crop quality. In addition, correct application of TDI requires a thorough assessment of yield reduction's economic impact caused by drought stress (Geerts and Raes 2009). Maximum yield could be obtained with the fulfillment of complete crop water requirements. However, practicing TDI would increase in the irrigated area or frequency of cultivation. TDI provides a possible solution to the dilemma of sustained and/or increased productions (Geerts et al. 2008).

The effects of deficit and supplemental irrigation are diverse at different crop growth stages and in different soil moisture conditions. So, it is indispensable to supply enough water for crops at the stages; that they are most sensitive to water stress, and thereafter, irrigation water volume could be reduced in other stages. It is then important to monitor soil moisture and supply water based on the soil condition. Partial root-zone drying (PRD) is now considered as a general technique which is applied various methods at the field. The PRD is a more recent irrigation technique developed from TDI (Yazar et al. 2009). These include the controlled alternative drip irrigation of a part of root zone, applied in a vertical soil profile, controlled alternative border irrigation, controlled alternative furrow irrigation (FI), controlled alternative surface irrigation, and subsurface irrigation.

Zegbe-Domínguez et al. (2003) illustrated that leaf water potential, total plant fresh weight and total dry weight of tomato crop were lower in the TDI than the FI and PRD. In the PRD irrigation, WUE improved by 83%. In the TDI, dry mass that classified into stems and leaves was higher than dry mass of FI and PRD; nevertheless, dry mass that categorized into fruits was lower in PRD and TDI than the dry mass of FI. Various methods of water conservation have been investigated in agriculture, such as alternative PRD, TDI, and drip irrigation. In that respect, researchers have shown that WUE can be enhanced (Li et al. 2010). In general, these techniques are a trade-off: a lower yield for a higher WUE. This suggests that the PRD is a better water saving option than TDI. Saved water through PRD can be used for irrigation of additional cultivated areas (Patel and Rajput 2013). Optimum WUE in TDI is obtained by an economic analysis using yield and cost functions as described by English and James (1990).

Mohammad and Mazahreh (2003) studied the effect of wastewater irrigation on soil chemical properties and found that secondary treated wastewater could improve soil fertility parameters. However, more efficient treatment is recommended to reduce the salt content. In addition, proper irrigation management and periodic soil quality parameters' monitoring are required to minimize negative effects on the soil.

Sahin et al. (2014) showed root and sugar yields reduced as 22 and 24% in PRD treatment than FI, respectively. But irrigation water saving was about 42% by PRD treatment. They suggested that PRD technique could be useful strategy by drip-irrigated sugar beet in areas with water shortage regions.

Cantore et al. (2014) obtained enough yield and high quality tuber from 50% less water-applied treatment by TDI as like the FI treatment.

In Isfahan region, Iran, municipal and industrial treated wastewater used as a water resource or irrigation of different production (Tabatabaei et al. 2012). So, it is more necessary to select the best and new irrigation techniques with the management to improve efficiency of irrigation system (Najafi et al. 2016).

Therefore, the objective of this paper was to evaluate the type of irrigation system including PRD and to compare it with FI system as TDI which they both are water-saving irrigation practices. Furthermore, their effects on plant's indicators, such as dry and fresh weight, plant height, dry matter percentage and WUE were investigated.

Materials and methods

Site description

The Shahrekord wastewater treatment station is located 7 km south-west of the Shahrekord city at 32°20′N latitude and 50°51′E longitude. Shahrekord has a semi-arid climate using combination climatologic methods (Kham-chin Moghadam and Rezaei Pajand 2009). The average height of this region above the sea level and rainfall are about 2060 m and 321.5 mm, respectively (without any rainfall during experimental period). The average temperature of this city is 12.5 °C and the maximum and minimum relative humidity are 71 and 16%, respectively.

Soil and wastewater characteristic

Field experiments were carried out during the July–October 2010 (growth period). In general, the soil texture is clay in which its characteristics and also chemical analysis of treated wastewater by sequence batch reactor (SBR) method and water sources are presented in Tables 1 and 2 (Karizan 2011).

Experimental design

The field selected for the research was plowed and fertilized using macro- and micro-fertilizers in July 2010 based

Table 1 Chemical and physical properties of soil

Depth (cm)	EC (dS/m)	pH	Soil texture	ρ_b (g/cm^3)	FC (%)	PWP (%)
0–45	1.8	7.9	Clay	1.19	37	18

Table 2 Chemical analysis of pretreated municipal wastewater and water sources using as irrigation water

Sources	EC (dS/m)	pH	TDS (mg/l)	TSS (mg/l)	SAR (mol/l)$^{1/2}$	BOD (mg/l)	N–NO_3^- (mg/l)	K (mg/l)	PO_4^{-3} (mg/l)
Wastewater	0.75	7.8	450	30	2.2	18.75	16	14	30.5
Water	0.3	7.45	38	0	0.13	3.96	2.61	0.21	15

on the soil tests. Each treatment was designed in the format of furrow irrigation style. Experimental plot size was 3 × 4 m with 1 m distance between each plot. The distance between the planting rows was 75 cm and the distance between corn plants was 10 cm (Fig. 1). Research was implemented based on the factorial (split plot) design in three replicates and fifteen treatments. Quality and water management were the two factors, so that three water quality levels made up the main plots (Table 3). Water used for irrigation contained three quality levels: fresh water (FW), a mixture of 50% fresh water and 50% wastewater (5050), and finally 100% wastewater (WW).

Water management was the third factor determined in three levels: full irrigation (FI), partial root-zone drying (PRD) and the traditional deficit irrigation (TDI). Three levels of water application factor were implemented in 100, 80 and 60 percent of estimated crop water requirement (creating water stress of zero, 20 and 40 percentages, respectively). The reference evapotranspiration (ET_0) (mm/day) was estimated using the FAO Penman–Monteith equation and employing daily data from a nearby automatic weather station. Crop water requirements were calculated by multiplying the ET_0 values with the corn crop coefficients (K_c) given by Kheirabi et al. (2009) and E_{pan} as 5–8.5 mm/day. Concerning irrigation system, drip irrigation (T-tape) was used and was conducted 8 days after planting in late July. Corn crops were irrigated every three days. After the growth period, the plant physiological parameters such as shoot's fresh and dry weight and leaf area index

Table 3 Fifteen treatments applied in this study

Treatments		
WW-FI_{100}	5050-FI_{100}	FW-FI_{100}
WW-PRD_{80}	5050-PRD_{80}	FW-PRD_{80}
WW-TDI_{80}	5050-TDI_{80}	FW-TDI_{80}
WW-PRD_{60}	5050-PRD_{60}	FW-PRD_{60}
WW-TDI_{60}	5050-TDI_{60}	FW-TDI_{60}

FW 100% fresh water, *5050* 50% fresh water plus 50% wastewater, *WW* 100% wastewater, *FI* full irrigation, *PRD* partial root-zone drying, *TDI* traditional deficit irrigation, *60 AND 80* 80 and 60 percent of the estimated crop water requirement

(LAI) were measured. Plant height was measured in each treatment using a meter scale and the biomass (the above part of the ground). Thereafter, it was cut into small pieces and dried at 70 °C to reach a constant weight for the estimation of dry matter. Dry biomass percentage (DBP) was calculated using the following equation.

$$\text{DBP} = (\text{Sample total dry weight}/\text{Sample total fresh weight}) \times 100$$

Soil samples were collected from 0 to 45 cm soil depth. Air-dried soil samples were sieved through a 2-mm sieve to determinate physicochemical soil properties. Electrical conductivity (EC) and acidity of soil (pH), wastewater and water were identified by Jenway EC and pH meters (Page et al. 1991), respectively. Cation like as Ca and Mg was determined by titration method with 0.01 N EDTA (Klute 1986) and sodium (Na) and potassium (K) were measured

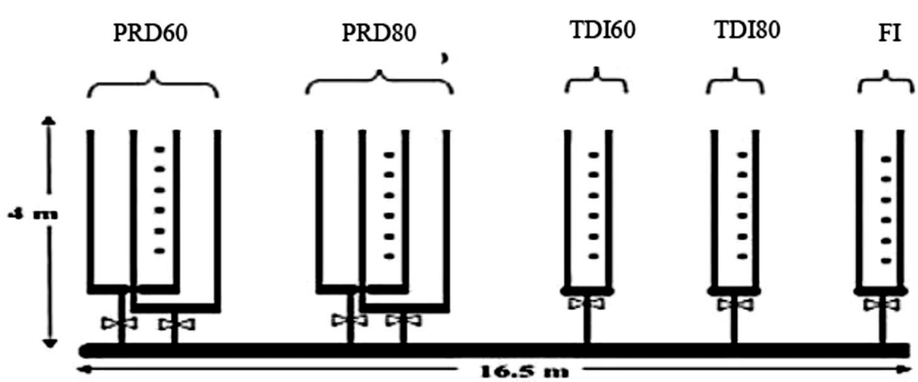

Fig. 1 Layout of the system. *PRD* partial root-zone drying, *TDI* traditional deficit irrigation, *FI* full irrigation. ⋈ Valve; *asterisks* corns; ▬ lateral

by flame photometry. Sodium adsorption ratio (SAR) was defined by the relation.

Soil's phosphor was measured using the method described by Olsen et al. (1954), soil texture was determined by hydrometer (Lee and Bauder 1986), total nitration by Kjeldahl digestion (Page et al. 1991), bulk density by clod and particle density by pycnometer (Klute 1986), total suspended solids (TSS) by gravimetric analysis (APHA 1975), total dissolved solids' (TDS) by Canadian Council of Ministers of the Environment (2011).

Afterwards, analysis of variance was performed and treatments' averages were compared with the least significant difference test (LSD) with 5% probability level. Statistical analysis was performed using "Statistical software" and also "Excel software" was applied for data management.

Results and discussions

Dry and fresh weight of corn shoots

The results showed that fresh weight of corn shoots in different treatments had significant difference at 5% level of probability. Fresh weight' mean of crop that irrigated by FI (5940 g/plant) was significantly higher than the fresh weight' mean of crop planted under TDI_{60} irrigation treatment (492.33 g) (Fig. 2). Water stress in TDI was the main reason to reduce shoot' fresh weight at 5% probability level. Although, wet and dry weight of corn plans of TDI_{60} plus PRD_{60} and TDI_{80} plus PRD_{80} together in each group were in the same probability level. Although, both PRD treatments (PRD_{60} and PRD_{80}) were higher than TDI treatments (TDI_{60} and TDI_{80}) (Fig. 2).

Nagaz et al. (2013) indicated that shoot lost its fresh weight rapidly in water stress situation. On the other hand, the corn plants irrigated with PRD had greater fresh weight in comparison with traditional irrigation system (Li et al. 2010); nevertheless, it was not significant at 5% probability level.

More dry weight of the corn shoots (119.7 g/plant) were observed in FI comparing TDI_{60} (91.44 g/plant). Also, dry weight of TDI_{80} with 108. 65 g/plant decreased to 91.44 (g/plant) in TDI_{60} (Fig. 2). Water deficiency primarily affects crops by reduction of dry matter accumulation (Karam et al. 2003) in which happens through TDI diminishing dry matter development (Lopez et al. 1996) because of water tension, stomata conductance and photosynthesis rate (Nazemosadat and Kazemini 2008). In this experiment, irrigation with 5050-treatment reached a peak of 556.3 g fresh weight/plant. It was then followed by WW-treatment used as irrigation water. FW irrigation treatment with 505.33 g fresh weight/plant was applied at the end of grouping (Fig. 3). The rate of fresh weight was raised from 4 to 10% using 5050-treatment as the first treatment and using WW-treatment as the second treatment, respectively ($p < 0.01$). Also, it was seen that 5050-treatment and WW-treatments resulted in 30.3 and 17.2% increase in dry weight ($p < 0.01$).

Also, Rousan et al. (2008) reported that dry weight was increased more under FI with fresh water and wastewater than deficit irrigation. This trend was perceived to be similar in the yield response of Dorjia et al. (2004). In another study implemented by Fulai et al. (2006), the results showed that deficit irrigation method reduced leaves' dry matter and in contrast increased roots' dry matter of potato' stems. Dorjia et al. (2004) in the course of their research on hot pepper find that total fruit's fresh mass per plant in PRD was 586.5 g higher than its amount in TDI; whereas it was 724.1 g lower than its amount in control irrigation treatment. However, there was no considerable difference in total fruit' dry mass among the treatments. These results were consistent with our findings as well. The ratio of $N–NO_3$ (mg/l) in wastewater was six times bigger than their volumes in FW-treatment; therefore, using WW-treatment as irrigation water increased more $N–NO_3$ concentration of corn' shoots. On the other

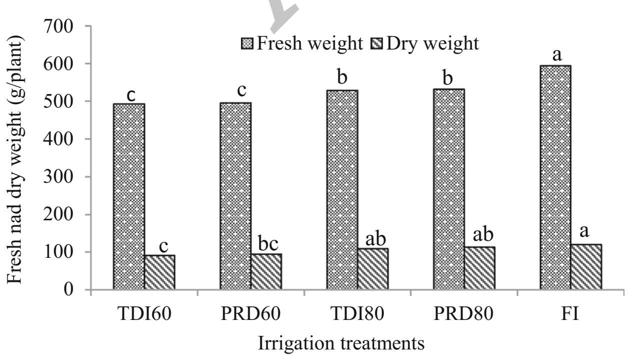

Fig. 2 Effect of irrigation treatments on dry and fresh weight of corn shoots ($p < 0.05$)

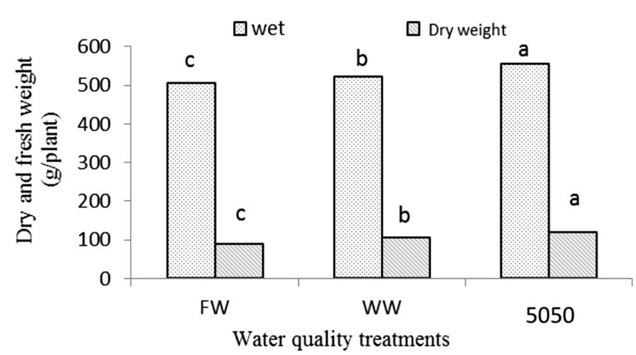

Fig. 3 Effect of water quality on dry and fresh weight of corn shots ($p < 0.01$)

hand, analysis of variance shoots' fresh weight demonstrated that interaction between water quality and TDI method was significant at 1% probability level. The results uncovered that the least and the most of yield were achieved using TDI_{60} (585.3 g) and 5050-FI (468.7 g) treatments, respectively. Also, WW-FI reduced two percent of yield in comparison with FW-FI due to nutrient toxicity. However, there was a slight rise in yield of WW-PRD_{80} and WW-PRD_{60} treatments.

Overall, PRD irrigation method using wastewater as irrigation water brought about greater yield than using FW-TDI method. Unlike fresh weight, irrigation with wastewater did not have any significant difference in dry weight instead; it indicated that there was only an increase in water percentage. Findings showed that the biggest dry weight was occurred in 5050-FI. FW-TDI_{60} was located at the end of grouping. Available nutrients of wastewater transmitted a signal from roots to shoots for strengthening of plant stomata (Li et al. 2010).

Dry biomass percentage (DBP)

In this study, the ratio of samples' total dry weight to samples' total fresh weight of samples is DBP. The amounts of DBP in all treatments were significantly different at 1% probability level. Concerning this parameter, PRD_{80} had the biggest DBP (21.29%) and TDI_{80} (with 18.51%) was placed at the end of this category (Fig. 4) because of its soil moisture stress and photosynthesis rate. Also, the DBP of TDI_{80} and FI treatments were 20.56 and 20.23 and there was no significant difference with the maximum DBP in PRD_{60} (Fig. 4). As it was already said, water deficiency primarily affects crops through prevention of dry matter accumulation (Karam et al. 2003) due to reduced dry matter development (Lopez et al. 1996). Dorjia et al. (2004) represented that the DBP to roots was equal among all different treatments; nevertheless, a higher allocation was revealed in stems and leaves in TDI and PRD plants comparing the control plants. In addition, wastewater irrigation might have an impact on the dissolution of the nutrient may be due to reduce the microbial activity in the soil and resulting in slower release of plant available nutrients (Shammi et al. 2016). In this research, applying lower irrigation water amount by TDI than FI techniques cause to increase more DBP.

In addition, analysis of variance showed that DBP had a significant difference at 5% probability level based on different irrigation water methods (Fig. 5).

The DBP means the ratio of total dry weight to total fresh weight of samples. The highest and lowest rates were reported applying 5050-WW with 21.47% and FW-treatment with 18.01%, respectively.

Rousan et al. (2008) illustrated that regardless of the water quality, TDI results in lower DBP. In their view, the reason was that amount of applied irrigation water was significantly less than the tomato crop's water requirement. Other researchers attributed improved plant growth with wastewater to improved soil condition, and in particular to enhanced soil organic matter content (Mohammad and Mazahreh 2003; Yonts 2010).

Leaf area index (LAI)

Leaf area is greatly changed with soil water availability. The effect of soil dryness on physiological indices was small over a certain range of soil water deficit started from 0 to approximately 40% (Patanè 2011). Reducing leaves' number and size are a result of cell behavior sensitive to water shortage (Sawia et al. 2002; Atti et al. 2004).

The findings indicated that water irrigation volume had a significant impact on LAI at 5% probability level (Fig. 6). According to the graph, a reduction of 20 and 40% in irrigation water happened as a result of TDI consequently diminished 9.3 and 25% of LAI. In addition, statistics demonstrate that PRD_{60} method decrease more effectively the LAI than the TDI_{60} method (Fig. 6). This could be due to transmitted signal from the roots to the shoots ordering them to decrease leaf growth and increase production of abscisic acid (ABA), and finally to close leaf stomata.

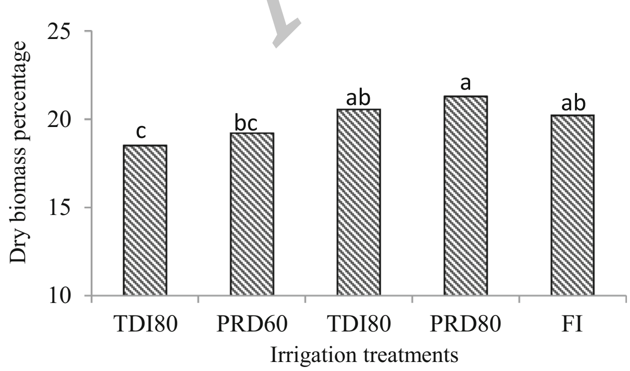

Fig. 4 Effect of irrigation treatments on dry biomass percentage ($p < 0.05$)

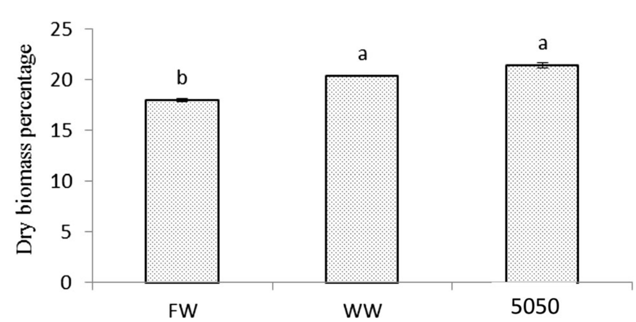

Fig. 5 Effect of water quality on dry biomass percentage ($p < 0.05$)

Similar results were reported by Liu et al. (2006) and Shahnazari et al. (2008). The findings also represented that in FI treatment the maximum and minimum LAI across the period were 7.17 and 5.2, respectively.

According to the research and based on the statistical comparison, water quality did not have any special effect on LAI. Nonetheless, the largest and least LAI belonged to 5050-treatment and FW-treatment with 6.24 and 6.13, respectively (Fig. 7).

Also, this finding is similar to the results of Hirich et al. (2011) in which a local variety of chickpea was planted under TDI (50% full irrigation) with treated domestic wastewater. The TDI applied for corn plants during vegetative growth lead to a greater proportion of its root systems developed deeper in the soil profile, which could lead to better use of stored soil water. Corn responded to drier soil conditions by increasing the proportion of roots deeper in the soil (Benjamin and Nielsen 2006). On the other hand, terminal water stress decreased the total plant dry matter including LAI and leaf weight (Sharma et al. 2007; Labidi et al. 2009; Behboudian et al. 2001).

Based on the results, a decrease in LAI was seen in all treatments expect FW-FI. This result similar to Yonts (2010) results that indicated the leaf area index of sugar beet planted under TDI was approximately 14% less than FI.

Also, the most and least LAI were distinguished in 5050-FI (7.5) and 5050-PRD$_{60}$ treatments (4.8).

Plant height

One of the growth indexes that are affected strongly by water shortage is plant height (Atti et al. 2004; Sawia et al. 2002). In this research, plant height was measured three times (stages) but the results of two stages of height of corn plants were showed in Fig. 8.

Analysis of variance showed that height of corn plants had a significant difference at 1% probability level based on the irrigation methods. The TDI$_{60}$ and PRD$_{60}$ were at the same statistical level in the end of experiment.

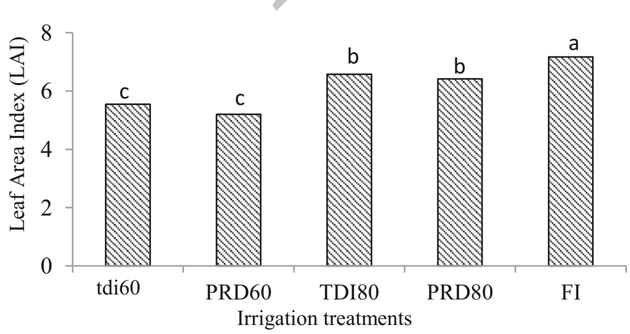

Fig. 6 Effect of irrigation treatments on leaf area index (LAI) ($p < 0.05$)

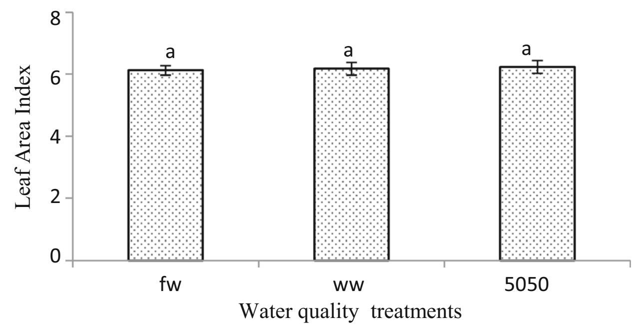

Fig. 7 Effect of water quality on leaf area index (LAI)

Although there is significant difference between these treatments on height of corn plants on 15 days before applied irrigation treatments (Fig. 8). On the other hand, three treatments included TDI$_{80}$, PRD$_{80}$ and FI did not have significant difference in the first stage of measuring height of corn plants but using FI method caused to increase height of corn plants than TDI and PRD irrigation techniques.

Full irrigation had the maximum height of corn plants among irrigation treatments (Fig. 8). Also, PRD$_{80}$, TDI$_{80}$, PRD$_{60}$ and TDI$_{60}$ caused 7.1, 6.4, 12.8 and 12% of height reduction, respectively, in comparison with FI. The reduced plant height in all irrigation treatments was significant expect TDI$_{80}$ at 1% probability level. However, there was not seen any significant difference between PRD and TDI irrigation methods. This outcome is similar to the results of Du et al. (2006) on cotton plants. It seems there is a genetic correlation between yield and plant height, cultivated plants with water stress resistance is able to maintain against reduced plant height.

Yonts (2010) reported that sugar beet plant height was 127–305 mm less in deficit irrigation method than full irrigation treatments. Also, variance analysis of interactive effects between water quality and water quantity of Yonts' study showed that there was no significant difference at 5% probability level.

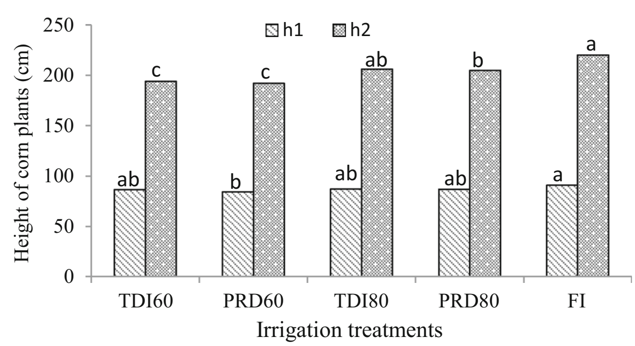

Fig. 8 Effect of irrigation treatments on height of corn plants ($p < 0.01$). h1: 15 days before applied irrigation treatments. h2: 50 days in the end of experiment

The analysis of variance showed that height of corn plants had a significant difference at the 5% probability level based on water quality. The results indicate that using 5050-FI was the best composition of irrigation water to increasing height of corn plant (Fig. 9).

Chemura (2014) showed in the research on coffee, irrigation water amounts in terms of height have significant effect ($p < 0.05$). Coffee plants were tallest and thickest plant stems when supplied the more irrigation water levels (1000 ml) and shortest and thinnest under the lowest irrigation amounts (500 ml) because of inorganic fertilizers are the most effective at high irrigation levels while organic manure performs better than inorganic fertilizers under low irrigation water amount.

Water use efficiency (WUE)

Water use efficiency, if defined as the biomass accumulation over water consumed may be fairly constant for a given species in given climate. WUE can be enhanced by less irrigation. However, such enhancement is largely a trade-off against lower biomass production (Zhang and Yang 2004). The maximum WUE was belonged to PRD_{60} with 3.09 (kg dry matter/m^3 water using) compared to the minimum WUE in FI treatment with 2.47 (kg dry matter/m^3 water using). Sahin et al. (2014) indicated that PRD technique increased by 34.9% WUE compared to FI of sugar beet (*Beta vulgaris* L.) because of increase root yield during 2-year study.

Overall, PRD had the WUE much more than TDI and it was significant at 5% probability level. It was similar to the results of Shahnazari et al. (2008) and Liu et al. (2006) on potato; Gencoglan et al. (2006) on green bean; De la Hera et al. (2006) on fruit quality in field-grown wine grapes. On the other hand, Hu et al. (2009) and Wang et al. (2008) reported that there was a significant rise in WUE for potato plant, when used the PRD to TDI method in pot.

Water use efficiency like other indicators dry and fresh weight shoots; plant height was being more affected by the amount of irrigation water than TDI methods. It is clear from the data that the amount of WUE in TDI_{60} to TDI_{80} and then TDI_{80} to FI were significant at 5% probability level (Table 4).

In other research, WUE was higher in TDI and PRD plants than in control plants (Zegbe-Domínguez et al. 2003). Acar et al. (2014) illustrated by use of DI by drip system average 25% volume of water saving can be made.

The analysis of variance showed that WUE had a significant difference at the 5% probability level based on irrigation water quality (Table 4). The 5050-treatment with 3.17 kg dry matter/m^3 using water was leader in this group. Irrigation with FW-treatment with 2.435 kg dry matter/m^3 water was in the end. The results indicated that irrigation with treatment included WW-treatment than 5050-treatment as another quality irrigation water has a significant decline on fresh water because of two main reasons: first of all, nutrient toxicity using WW-treatment as irrigation water and second, water stress by increasing osmotic potential due to high level of salts in this irrigation water source. The soil conditions such as arid climate and heavy soil texture caused to increase these effects if using wastewater as irrigation water (Table 1). On the other hand, wastewater has high amount of essential nutrients like N and P, while they are useful for plant growing.

It is clear that the minimum WUE belonged to use FW-FI and then irrigation with WW-FI. According to analysis of variance of interactive effects between water quality and water quantity, 5050-PRD_{80} and 5050-PRD_{60} with 3.36 and 3.3 kg/m^3 has the biggest WUE. Whereas FW-FI and FW-TDI_{80} with 2.31 and 2.26 kg/m^3 in contrast to 5050-PRD_{80} and 5050-PRD_{60} had the smaller WUE (Table 4). The results showed that using 5050-treatment caused to compensation of 40% water deficit for WUE because of higher concentration of $N–NO_3$ (16 mg/l) in wastewater in comparison with of $N–NO_3$ lower concentration (2.61 mg/l) in FW-treatment, increased dry matter development.

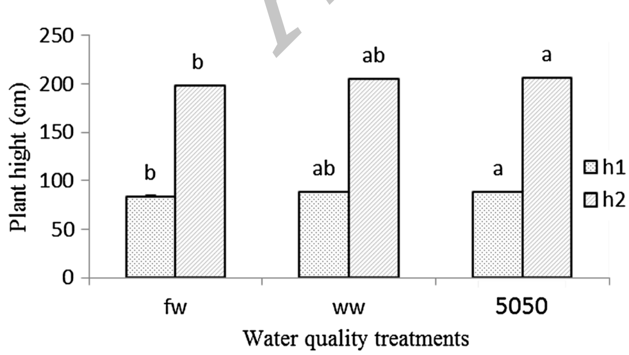

Fig. 9 Effect of water quality on height of corn plant ($p < 0.05$). h1: height of corn plants on 15 days before applied irrigation treatments. h2: height of corn plants on 50 days in the end of experiment

Table 4 Effects of irrigation treatments and water quality on water use efficiency (kg/m^3)

	TDI_{60}	PRD_{60}	TDI_{80}	PRD80	FI
Irrigation treatments	2.97ab	3.1a	2.74c	2.86bc	2.47d
	FW		WW		5050
Water quality	2.44c		2.88b		3.17a

FW 100% fresh water, *5050* 50% fresh water plus 50% wastewater, *WW* 100% wastewater, *FI* full irrigation, *PRD* partial root-zone drying, *TDI* deficit irrigation; 80 and 60 percent of the estimated crop water requirement

Conclusions

This experiment was done to assess TDI and PRD as water-saving irrigation techniques. In both TDI and PRD treatments than FI, dry and, fresh weight, height of plant and LAI of plants were reduced because of water stress but PRD and TDI method were caused to increase WUE and DBP. Using PRD_{80} method is more suitable than TDI method. After FI technique, corn plant that irrigated by PRD_{80} method has the bigger dry and fresh weight, DBP and WUE than TDI. So, it outcome in PRD_{80}, we can store irrigation water during study with less effects on corn plants yield because of better water distribution in hemispheric wetted volume than TDI as other water-saving irrigation technique. It seems transmitted signal from roots to shoots to decline the rate of leaf growth and increasing to produce ABA and to close stomata. The height of corn plants was more affected by declining the volume of irrigation water, therefore $FI > PRD_{80} > TDI_{80} > PRD_{60} > TDI_{60}$. WUE as the main aim was the maximum by PRD_{60} to FI as the minimum WUE. Based on the results, it was parented that applying PRD method has higher performance than TDI. Also, in comparison of three water qualities, using 5050-treatment caused to compensation of water deficit for WUE, LAI, and yield indices but irrigation with WW-treatment alone had unsuitable effects because of nutrient toxicity and undesirable effects of increasing osmotic potential due to high level of salts. Changing of water quality has significant difference on dry and fresh weight, DBP, height of plant and WUE expect LAI. Although PRD and TDI methods were found to be feasible for corn cultivation but using PRD system was considered as a better strategy for water-saving than TDI.

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References

Acar B, Topak R, Yavu D, Kalender MA (2014) Is Drip irrigation technique sustainable solution in agriculture for semi-arid regions? A case study of Middle Anatolian region. Turk Int J Agric Econ Dev 2(2):1–8

APHA (1975) Method 208 D. Total non-filterable residue dried at 103–105 °C (total suspended matter) in standard methods for the examination of water and wastewater, 14th edn. American Public Health Association, Washington, DC, p 460

Atti S, Bonnell R, Smith DL, Prasher S (2004) Response of an indeterminate soybean to chronic water deficit during reproductive development under greenhouse conditions. Can Water Resour J 29(4):209–224

Behboudian H, Ma MQ, Palta CNT, Jairo A (2001) Reactions of chickpea to water stress: yield and seed composition. Sci Food Agric J 81(13):1288–1291

Benjamin JG, Nielsen DC (2006) Water deficit effects on root distribution of soybean, field pea and chickpea. Field Crops Res J 97:248–253

Canadian Council of Ministers of the Environment (2011) Protocol manual for water quality sampling in Canada. Canadian Council of Ministers of the Environment, P 180

Cantore V, Wassar F, Yamaç SS, Sellami MH, Albrizio R, Stellacci AM, Todorovic M (2014) Yield and water use efficiency of early potato grown under different irrigation regimes. Int J Plant Prod 8(3):409–428

Chemura A (2014) The growth response of coffee (*Coffea arabica* L.) plants to organic manure, inorganic fertilizers and integrated soil fertility management under different irrigation water supply levels. Int J Recycl Org Waste Agric 3:59

De la Hera ML, Romero P, Gomez-Plaza E, Martinez A (2006) Is partial root-zone drying an effective irrigation technique to improve water use efficiency and fruit quality in field-grown wine grapes under semi-arid conditions? Agric Water Manag J 87:261–274

Dorjia K, Behboudiana MH, Zegbe-Dominguez JA (2004) Water relations, growth, yield, and fruit quality of hot pepper under deficit irrigation and partial root-zone drying. Sci Hortic J 104:137–149

Du T, Kang SH, Zhang J, Li F, Hu X (2006) Yield and physiological responses of cotton to partial root-zone irrigation in the oasis field of northwest China. Agric Water Manag J 84:41–52

English M, James L (1990) Deficit irrigation. II: Observation in Colombia basin. J Irrig Drain Eng 116(3):413–426

Fulai L, Shahnazari A, Andersen MN, Jacobsen SE, Jensen CR (2006) Physiological responses of potato (*Solanum tuberosum* L.) to partial root-zone drying: ABA signaling leaf gas exchange and water use efficiency. Exp Bot J 57:3727–3735

Gallardo M, Jackson LE, Schulbach K, Snyder RL, Thompson RB, Wyland LJ (1996) Production and water use in lettuces under variable water supply. Irrig Sci J 16:125–137

Geerts S, Raes D (2009) Review: deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agric Water Manag J 96:1275–1284

Geerts S, Raes D, Garcia M, Condori O, Mamani J, Miranda R, Cusicanqui J, Taboada C, Yucra E, Vacher J (2008) Could deficit irrigation be a sustainable practice for quinoa (*Chenopodium quinoa* Willd.) in the Southern Bolivian Altiplano? Agric Water Manag J 95:909–917

Gencoglan C, Altunbey H, Gencoglan S (2006) Response of green bean (*P. vulgaris* L.) to subsurface drip irrigation and partial root-zone-drying irrigation. Agric Water Manag J 84:274–280

Grant OM, Stoll M, Jones HG (2004) Partial rootzone drying does not affect fruit yield of raspberries. J Hortic Sci Biotechnol 79(1):125–130

Hirich A, Choukr-Allah R, Jacobsen Sven-Erik, Hamdy A, Youssfi L, El-Omari H (2011) Improving water productivity of chickpea by the use of deficit irrigation with treated domestic wastewater. World Acad Sci Eng Technol 59:1352–1357

Hu T, Kang S, Li F, Zhang F (2009) Effects of partial root-zone drying irrigation on the nitrogen absorption and utilization of maize. Agric Water Manag J 96:208–214

Karam F, Breidy J, Stephan C, Rouphael J (2003) Evapotranspiration, yield and water use efficiency of drip irrigated corn in the Bekaa Valley of Lebanon. Agric Water Manag J 63:125–137

Karizan MM (2011) Use of deficit irrigation techniques (DI and PRD) in irrigated with municipal wastewater branch under drip irrigation (T-tape) on corn silage. M.Sc. thesis, Department of Water Engineering, Faculty of Agriculture, Shahrekord University, Shahrekord, Iran

Kham-chin Moghadam F, Rezaei Pajand H (2009) Realize maximum daily rainfall by using De Martonne method and compare by linear combination method. Tech Eng J Islam Azad Univ Mashhad Branch 2:93–103

Kheirabi J, Darbandi S, Entesari M, Salamat A, Moghadesi F (2009) Evaluation and comparison Penman–Monteith equation with 24-FAO methods in Iran. Iranian National Committee on Irrigation and Drainage Publication. Tehran, Iran, p 208

Klute A (1986) Physical and mineralogical methods In: Methods of soil analysis. Part 1. American Society of Agronomy-Soil Science Society of America pubication, 2nd edn. p 1189

Labidi N, Henda M, Messedi D, Slama I, Chedly A (2009) Assessment of intervarietal differences in drought tolerance in chickpea using both nodule and plant traits as indicators. Plant Breed Crop Sci J 1:80–86

Lee GW, Bauder JW (1986) Particle size analysis. In: Klute A (ed) Methods of soil analysis, Part 1. American Society of Agronomy-Soil Science Society of America publication, pp 383–411

Li F, Yu J, Nong M, Kang S, Zhang J (2010) Partial root-zone irrigation enhanced soil enzyme activities and water use of maize under different ratios of inorganic to organic nitrogen fertilizers. Agric Water Manag J 97:231–239

Liu F, Shahnazari A, Andersen MN, Jacobsen SE, Jensen CR (2006) Effects of deficit irrigation (DI) and partial root drying (PRD) on gas exchange, biomass partitioning, and water use efficiency in potato. Sci Hortic J 109:113–117

Lopez FB, Johansen C, Chauhan YS (1996) Effects of timing of drought stress on phenology, yield and yield components of short-duration pigeonpea. Agron Crop Sci J 177:311–320

Mohammad MJ, Mazahreh N (2003) Changes in soil fertility parameters in response to irrigation of forage crops with secondary treated wastewater. Soil Sci Plant Anal J 34:1281–1294

Nagaz K, Mokh FE, Masmoudi MM, Mechlia NB (2013) Soil salinity, yield and water productivity of lettuce under irrigation regimes with saline water in arid conditions of Tunisia. Int J Agron Plant Prod 4:892–900

Najafi P, Asgari K, Samadi N (2016) Heavy metal elimination from industrial wastewater using natural substrate on pitcher irrigation. Int J Recycl Org Waste Agric 5:333–337

Nazemosadat SMJ, Kazemini SA (2008) The effects of water stress and photosynthesis active radiation on photosynthesis rate of wheat. Agric Sci Nat Resour J 14(6):34–44

Olsen SR, Cole CV, Watunable FS, Dean LA (1954) Estimation of available P in soil by extraction with Na-bicarbonate. Circular, No.939 USDA. US. Government, Washington DC

Page AL, Miller RH, Keeney DR (1991) Chemical and biological properties. In: Methods of soil analysis, part 2. American Society of Agronomy-Soil Science Society of America publication, 2 edn, p 1159

Patanè C (2011) Leaf area index, leaf transpiration and stomata conductance as affected by soil water deficit and VPD in processing tomato in semi-arid mediterranean. Clim Agron Crop Sci J 197:165–176

Patel N, Rajput TBS (2013) Effect of deficit irrigation on crop growth, yield and quality of onion in subsurface drip irrigation. Plant Prod J 7:417–436

Rousan LM, Rusan MJ, Amayreh J (2008) Irrigation with treated wastewater under full and deficit soil moisture conditions. In: Eds: Al-Mattareneh H, Sidek LM, Youssef MZ (eds) Proceeding of the international conference on construction and building technology (ICCBT): innovations in water resources and environmental engineering, Kuala Lumpour, Malaysia, vol 38, pp 405–416

Sahin U, Ors S, Kiziloglu FM, Kuslu Y (2014) Evaluation of water use and yield responses of drip-irrigated sugar beet with different irrigation techniques. Chil J Agric Res 74:302–310

Sawia M, Omaima U, EL-Beharya A, Abdolhamid AF (2002) Effect of irrigation level and N source on green bean productivity. Egypt Appl Sci J 47:326–347

Shahnazari A, Ahmadi SH, Lærke PE, Liu F, Plauborg F, Jacobsen SE, Jensen CR, Andersen MN (2008) Nitrogen dynamics in the soil-plant system under deficit and partial root-zone drying irrigation strategies in potatoes. Eur J Agric 28:65–73

Shammi M, Abul Kashem M, Mostafizu Rahman Md, Delwar Hossain Md, Rahman R, Khabir Uddin M (2016) Health risk assessment of textile effluent reuses as irrigation water in leafy vegetable Basella alba. Int J Recycl Org Waste Agric 5:113–123

Sharma KD, Pannu RK, Tyagi PK, Chaudhary BD, Singh DP (2007) Response of chickpea genotypes to plant water relations and yield under soil moisture stress. Agrometeo J 9:42–48

Tabatabaei SH, Najafi P, Mirzaei SMJ, Nazem Z, Heidarpour M, Hajrasoliha S, Afyuni M, Beigi Harchegani H, Landi E, Akasheh L, Zamanian M, Barani M, Amini H (2012) Compost' leachate recycling through land treatment and application of natural Zeolite. Int J Recycl Org Waste Agric 1:2. doi:10.1186/2251-7715-1-2. http://www.ijrowa.com/content/1/1/2

Wang J, Kang S, Li F, Zhang F, Li Z, Zhang J (2008) Effects of controlled alternate partial root-zone drying irrigation on soil microorganism and growth of maize. Plant Soil J 302:45–52

Yazar A, Gokgel F, Sezen MS (2009) Corn yield response to partial root zone drying and deficit irrigation strategies applied with drip system. Plant Soil Environ J 55:494–503

Yonts CD (2010) Development of season long deficit irrigation strategies for Suger-beets. The University of Nebraska Panhandle Research and Extension Center, Scottsbluff, p 69361

Zegbe-Domínguez J, Behboudian A, Lang MHA, Clothier BB (2003) Deficit irrigation and partial root zone drying maintain fruit dry mass and enhance fruit quality in 'Petopride' processing tomato (*Lycopersicon esculentum*, Mill.). Sci Hortic J 98:505–510

Zhang H, Oweis T (1999) Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agric Water Manag J 38:195–211

Zhang J, Yang J (2004) Crop yield and water use efficiency. In: Bacon MA (ed) Water use efficiency in plant biology. Blackwell Publishing, Oxford, pp 189–218