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ORIGINAL PAPER

Effect of Deficit Irrigation with Treated Wastewater on Water Use Efficiency, Nutrient Uptake, and Growth of Pistachio Seedlings in an Arid Area

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Abstract

Yazd province is one of the most important centers for pistachio and seedling production in Iran due to its geographical location and climate. However, this province is also one of the arid and semi-arid regions, facing the serious problem of water shortage. The use of wastewater and deficit irrigation techniques is, therefore, very important for irrigating pistachio seedlings in this arid region. For this purpose, this study was conducted to investigate the effect of deficit irrigation with treated wastewater on water use efficiency, leaf nutrient uptake, and growth of 1-year-old pistachio seedlings. This study was performed as factorial experiment based on a completely randomized design with three repetitions; irrigation water quality was addressed in four levels of treated wastewater (W1), groundwater (W2), 50% treated wastewater and 50% groundwater (W3), and intermittent irrigation with treated wastewater and groundwater (W4). Also, four irrigation levels including deficit irrigation based on 100% (S1), 80% (S2), 60% (S3), and 40% (S4) field capacity were considered. At the end of the experiment, some morphological and physiological traits, such as SPAD in the leaves, relative water content (RWC), electrolyte leakage (EL), stem height and diameter, number of green leaves and leaf area, root fresh and dry weight, water use efficiency (WUE) and the leaf nutrient uptake, were evaluated. Statistical analyses showed that all morphological parameters were higher when irrigation was done with treated wastewater rather than groundwater. The results also suggested that water quality was more effective than deficit irrigation levels on the morphological traits. Also, while SPAD was affected by water quality, RWC and WUE were more under the influence of deficit irrigation levels. Further, physiological growth was higher in those seedlings irrigated on W1S1, whereas the highest WUE was obtained in W1S3. The analysis of variance also showed that the main effects of irrigation water quality and different levels of deficit irrigation, as well as the interaction of these treatments, were statistically significant at the level of 1% on all nutrients uptake in the investigated pistachio seedlings. According to the obtained results, wastewater could compensate for the negative effects of deficit irrigation in the moderate levels of deficit irrigation. The use of wastewater, along with the application of deficit irrigation techniques, can be, therefore, recommended as an important step to solve water shortage problems and increase water use efficiency in arid areas. The results of this study could provide information helpful for establishing orchards by using wastewater under water shortage conditions, especially in arid zones.

Keywords Deficit irrigation · Nutrient uptake · Pistachio seedlings · Treated wastewater

1 Introduction

In arid and semi-arid regions, wastewater treatment and reuse play an important role in water resources planning. This is important due to the lack of fresh water, the high cost of chemical fertilizers, and remarkable nutrients in wastewater. Iran is a country with an arid and semi-arid climate; an average long-term annual rainfall of 240 mm with inadequate distribution has limited water for agricultural activities in many parts of the country, especially when needed (Mousavi et al. 2010; Soltani-Gerdefaramarzi et al. 2021). In such a situation, crop

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production during summer depends on irrigation; on the other hand, water supply is a factor limiting production. So, due to the growing need for water, the reliability of wastewater as a source of water in dry and low rainy years (Chaganti et al. 2020), especially in arid and semi-arid regions of Iran, and no direct release of wastewater into the environment, application of wastewater in agriculture can reduce the environmental pollution. Also, high nutrients such as nitrogen, phosphorus and potassium are becoming more and more important for the plant growth (Kamran et al. 2020; Tabatabaei et al. 2017). In addition to the reduction of water consumption and the presence of nutrients in the effluent, using wastewater and mixing it with other available water sources such as groundwater can improve the quality of crops and crop yields (Al Khamisi et al. 2013). The results of a study conducted by Chaganti et al. (2020) highlighted that treated wastewater can be successfully used to grow bioenergy sorghum in arid regions. However, appropriate soil management practices should be in place to counter the effects of high sodium in wastewater. Tsigoida and Argyrokastritis (2020) also reported that the use of wastewater increased calcium carbonate in the sandy loam soil, while there was decrease in the loamy sand one. Concentrations of phosphorus and sodium were increased with the use of wastewater in both soils. The maximum concentration of phosphorus was obtained in the sandy loam soil by irrigation with the raw effluent; meanwhile, in the loamy sand soil, this was achieved by the treatment treating the treated wastewater.

Due to the level of acceptance and also the need to use urban wastewater and unconventional water in agriculture, most wastewater treatment plants in Iran are currently designed and implemented with the aim of reusing wastewater in agriculture (Abedi-Koupai et al. 2006). However, since wastewater is one of the unconventional sources of water, its use in agriculture requires special management, while using it optimally, there should be no environmental and adverse health effects on soil, plants, and surface and groundwater resources (Mendes Reis et al. 2020). If wastewater application can be integrated with deficit irrigation methods, an important step can be taken to address both problems of water crisis and water use efficiency. Zare et al. (2018) showed that treated wastewater and deficit irrigation had a significant effect on the corn diameter and height, fresh and dry weight of roots, and fresh and dry weight of shoots. The fresh and dry weight of roots and shoots was increased with the use of wastewater; with decreasing the amount of the irrigation water, the fresh and dry weight of the shoots was decreased, which was more in the treatments involving irrigation with well water rather than wastewater. Hirich et al. (2014) also reported that the application of controlled irrigation with treated wastewater during the vegetative growth phase developed the roots, leading to the increase of the uptake of water and nutrients, consequently increasing the plant yield. Tabatabaei et al. (2017) compared the traditional and modern deficit irrigation techniques in corn cultivation using treated municipal wastewater. The result showed that dry and fresh weight, leaf area index, dry biomass percentage, height plant, and WUE were affected by water requirement and water quality was affected on all the study indicators of corn plant expect of WUE.

Demir and Sahin (2017) investigated effects of different irrigation practices using treated wastewater on tomato yields, quality, water productivity, and soil and fruit mineral contents. The treated municipal wastewater significantly increased marketable yield, WUE, titratable acidity, vitamin C contents, surface soil, and fruit mineral contents compared to the fresh water.

Abadía et al. (2021) investigated interactions between soil microbial communities and agronomic behavior in a mandarin crop subjected to water deficit and irrigated with reclaimed water. Their results demonstrate that deficit irrigation had not drastic negative impacts on crop yield when reclaimed water is used and that there may be some positive effects in soil microbial communities when fresh water is used for irrigation.

To the best of our knowledge, there is no similar information regarding the simultaneous effect of wastewater and deficit irrigation on the growth of pistachio seedlings. In other words, deficit irrigation is a practice generally implemented in mature trees; the simultaneous effect of deficit irrigation and treated wastewater as a source of irrigation water on young seedlings has not yet been investigated. The results of this study would produce potentially useful information to establish orchards using wastewater under water shortage conditions, especially in arid zones. On the other hand, Iran has been the largest producer and exporter of pistachios in the world for many years. Yazd province is one of the important centers of pistachio production in Iran due to its geographical location and climate. This province is, however, one of the arid and semi-arid regions of the country; as a result, there is a problem of water shortage in this region and the use of wastewater in agriculture, especially irrigation of pistachio seedlings, is very important.

2 Materials and Methods

2.1 Experimental Treatments

This study was conducted in a greenhouse located in Mehriz city, Yazd province (31.5778° N, 54.4452° E), as an arid region with an average annual rainfall of 71.9 mm and an altitude of 1480 m above sea level; the study, done in the 2019 season, was a factorial experiment based on a completely randomized design with three repetitions on 1-year-old potted seedlings. Treatments included the type of irrigation water at four levels of treated wastewater (W1), groundwater (W2), 50% treated wastewater and 50% groundwater (W3), and intermittent irrigation with treated wastewater and groundwater (W4); also, the four levels of irrigation consisted of deficit irrigation based on 100% (S1), 80% (S2), 60% (S3), and 40% (S4) field capacity. The treated wastewater was collected from the output of the last stage of treatment in the Wastewater Treatment Plant of Yazd City. The chemical properties of the treated wastewater and groundwater used are presented in Table 1. Three soil samples were taken from below and above the soil; after mixing, a soil sample was prepared, dried in air, passed through a 2-mm sieve and analyzed. Phosphorus (P) concentrations were determined by flame photometry (Olsen 1982); carbon (C) was investigated by the method presented by Walkley and Black (Nelson and Sommers 1982). Sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chlorine (Cl), lime ($CaCO_3$), and bicarbonate (HCO_3^-) were determined by the titration method (USDA 1972). Finally, the total nitrogen (N) was measured by the Kjeldahl method (Bremner 1996), and Ca_2SO_4 was checked using the Stone method (USDA 1972).

2.2 Experiment Management

In June, 2019, pistachio seedlings were planted in pots; all pots were filled with soil to a specific weight. Some physical and chemical characteristics of the soil are presented in Table 2. All treatments received the same amount of water for 20 days in the initial stage after transferring the seedlings to the pots. Irrigation at this stage was necessary to ensure the growth of the crop and enable it to cope with the lack of irrigation after that. Weight method (using a digital scale with an accuracy of 0.001 g) was then used to apply drought stress. Thus, several soil samples were randomly taken and the weight soil moisture content was determined at the point of permanent wilting (15.2%) and field capacity (28.7%) in the laboratory using a pressure plate with a pressure of 15 and 0.3 bar, respectively. To ensure soil moisture at the potting field capacity point, 3 pots with exactly the same weight and size were saturated and gravity water was allowed to escape from them. In this case, the weight of a given indicated the weight of the dry soil, the weight of the pot itself, and the weight of water within the field capacity. Thus, rapidly available water was obtained from the difference between the weight moisture content of the field capacity and the permanent wilting point. At each irrigation cycle (constant irrigation cycle 3 times a day), the soil moisture deficit, relative to field capacity, was eliminated by irrigation. So, every 3 days, the pots were weighed, and based on the difference between the weight of the pot and its weight in the field capacity, the amount of water required was determined in terms of kilograms. Then, according to the experimental treatments, different levels of deficit irrigation (100%, 80%, 60%, and 40% of field capacity) were determined; then, different types and amounts of the treated irrigation water were applied for 5 months.

2.3 Measurement and Analysis of Data

At the end of the period, SPAD reading was done in the leaves; electrolyte leakage (EL) was done by applying the method developed by Blum and Ebercon (1981). Further, relative leaf water content (RWC) was checked by Ritchie et al. (1990); stem height and diameter, number of green leaves, leaf area, root length, and fresh and dry weight of the roots were investigated as well. To measure the concentration of the mineral nutrients in the leaves, a number of fully developed leaves of plants in each treatment and repetition were selected. After washing the samples with distilled water, they were dried in the oven at 70 °C for 48 h; this was followed by ashing and digesting in 1 M hydrochloric acid. Finally, they were ready to be measured (Mills et al. 1996). Nutrient concentrations in the leaves, including Na and K, were determined with a flame photometer. P was determined by colorimetrical determinations, using a spectrophotometer, and Ca and Mg were checked by titration; further, the total nitrogen (N) was measured by the Kjeldahl method (Bremner 1996). To calculate the irrigation water use efficiency (WUE), the ratio of plant dry weight to the total amount of water consumed during the treatment was considered. Statistically significant differences between the means of the applied treatments were tested using a one-way analysis of variance (ANOVA) followed by a post

Table 1 Some chemical properties of applied irrigation water

Irrigation water	pH	EC (dS m^{-1})	BOD (mg l^{-1})	COD	TDS	TSS	$CaCO_3$	Ca	Mg	P	NH_4^+	NO_3^-
Treated wastewater	848	1.27	23	51	653	21	230	154	75	3.68	14.1	12.8
Groundwater	7.7	0.82	–	–	495	–	187	43	15.2	0	0	9.8
Standard*	6–8.5	3	100	200	–	100	–	–	100			

EC, electrical conductivity; *BOD*, biological oxygen demand; *COD*, chemical oxygen demand; *TDS*, total dissolved solids; *TSS*, total suspended solids

*Wastewater output standard for agricultural and irrigation purposes (Environment Organization of Iran)

Table 2 Physical and chemical characteristics of soil

A) Physical characteristics

Texture	Ca_2SO_4 (mg kg^{-1})	$CaCO_3$ (g kg^{-1})	Clay (%)	Silt (%)	Sand (%)	Bulk density (g cm^{-3})
Sandy loam	110.7	240	16	9	75	1.41

(B) Chemical characteristics

EC (dS m^{-1})	pH	C (mg kg^{-1})	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	HCO_3 (meq l^{-1})	Cl (meq l^{-1})	Ca (meq l^{-1})	Mg (meq l^{-1})	Na (meq l^{-1})
2.1	7.19	578	51	58	175	2.8	23.75	40.08	15.2	27

EC electrical conductivity

hoc Duncan's test at a probability level of 5%; this was done by applying SPSS package, version 23.0, for Windows.

3 Results

3.1 Morphological Traits

According to the results of the analysis of variance (Table 3), the effect of the interaction of deficit irrigation and quality of the irrigation water was significant on the leaf area, root length, and plant height at the probability level of 5%; this was observed at a probability level of 1% on the stem diameter, root and dry weight, and the number of green leaves. Deficit irrigation was statistically significant on all measured traits at 1% level. Also, all physiological parameters were affected by irrigation water quality at 1% significance level.

A statistical analysis of the experimental treatments showed that all measured morphological traits were significantly affected at the 5% significance level by deficit irrigation levels and water quality (Table 4). The statistical analysis also showed that all morphological parameters were higher when irrigation was done with treated wastewater (plant height, 60 cm; stem diameter, 8.38 mm; root length, 8.09 cm; root wet weight, 5.44 g; root dry weight, 3.39 g; leaf area, 867.94 mm^2; and the number of green leaves, 97) rather than with groundwater; this difference was statistically significant. The pots irrigated with 100% field capacity also showed the highest morphological traits. The results also suggested that water quality was more effective than deficit irrigation levels on the morphological traits.

Based on the obtained results, the use of W1, W3, and W4 caused the increase in the plant height (50.64%, 32.24%, and 14.86%, respectively), as compared to W2. Also, S2, S3, and S4 showed the reduction of almost 8.73%, 13.25%, and 43.17%, as compared with the control (59.25 cm), respectively; however, no difference was observed between S2 and S3 (Table 4). According to the results related to the interaction effect of the treatments (Fig. 1a), the highest and shortest plant height was obtained in W1S1 (76.67 cm) and W4S4 (30 cm), respectively.

Application of W1, W3, and W4 increased the stem diameter by approximately 45%, 10%, and 22%, as compared to the control, respectively. Also, the deficit irrigation levels of S2, S3, and S4 decreased the stem diameter by 5%, 9.8%, and 35.7%, as compared to the control, respectively. Comparing the mean interaction of the treatments showed that the maximum and minimum stem diameters were related to W1S1 (9.93 mm) and W2S4 (4.55 mm) treatments, respectively (Fig. 1b).

In regard to the comparison of water quality, Table 4 also shows that the root length was stimulated by 29%, 16.6%, and 10% when seedlings were irrigated with W1, W3, and W4,

Table 3 Results of analysis of variance show the effect of deficit irrigation and water quality treatments on the morphological traits

		Mean squares						
SOV	df	Plant height	Stem diameter	Root length	Root wet weight	Root dry weight	Leaf area	Number of green leaves
Deficit irrigation (S)	3	1479.2**	9.18**	15.8**	229.7**	54.2**	514,400.6**	1790**
Water quality (W)	3	911.1**	15.1**	7.03**	144.8**	34.2**	303,869.8**	1589.5**
S*W	9	56.2*	0.86**	0.1**	4.4**	0.9**	12,273.2*	111.8**
Error	32	18.4	0.01	0.03	0.2	0.3	4487.95	3.6
CV%	–	18.6	11.5	12.6	13.2	16.7	20.0	12.3
SE	–	1.33	0.11	0.13	0.07	0.06	19.24	1.45

SOV, source of variation; *df*, degrees of freedom; *CV*, coefficient of variation; *SE*, standard error; *, significant at 5% level; **, significant at 1% level; *ns*, not significant

respectively, as compared to those irrigated by W2. Table 4 also indicates that the application of S2, S3, and S4 significantly decreased the root length (by 4%, 6% and 31.7% respectively), as compared to S1. The maximum and minimum root length were related to W1S1 (9.21 cm) and W2S4 (4.37 cm) treatments, respectively (Fig. 1c).

Results also suggested that the root wet weight was increased by 78.3%, 21%, and 42.6%, respectively, when W1, W3, and W4 were used for irrigation, as compared to W2. The impact of deficit irrigation levels was highly significant, and the root wet weight in the pots irrigated with S2, S3, and S4 was diminished approximately by 12%, 18%, and 51%, respectively, as compared to S2. Root wet weight reached its maximum and minimum values when plants were irrigated with W1S1 and W2S4, respectively (Fig. 1d). Root dry weight was also significantly affected by water quality and deficit irrigation levels, showing 75.6%, 22.2%, and 39.3% increase when W1, W3, and W4 were applied. The highest root dry weight was recorded when W1 was applied with S1, promoting the root dry weight by 75%, as compared with W2S4 (Fig. 1e).

In regard to the comparison of water quality, Table 4 also indicates that the leaf area was stimulated by 76%, 42.5%, and 23% when the pots were irrigated with W1, W3, and W4, as compared to those irrigated by W2. Table 4 also suggests that the application of S2, S3, and S4 significantly decreased the leaf area (by 10%, 15.5%, and 56% respectively), as compared to S1. Application of W1S1 and W3S1 treatments could increase the leaf area by 90% and 35.67%, respectively, when compared to the control (Fig. 1f).

So, the use of W1, W3, and W4 increased the number of green leaves by 38.6%, 20%, and 8.5%, respectively, as compared to the control. Also, S2, S3, and S4 were decreased by 7.5%, 10.7%, and 31.2%, as compared to S1, respectively (Table 4). According to the results related to the comparison of the average interaction of treatments, the highest and lowest

Table 4 Mean comparisons of single effects of water quality or deficit irrigation levels on morphological traits

	Plant height (cm)	Stem diameter (mm)	Root length (cm)	Root wet weight (g)	Root dry weight (g)	Leaf area (mm^2)	Number of green leaves
Water quality							
W1	60.00a	8.38a	8.09a	5.44a	3.39a	867.94a	97a
W2	39.83d	5.78d	6.27d	3.05d	1.93d	491.95d	70d
W3	52.67b	6.36c	7.31b	3.7c	2.36c	701.12b	84b
W4	45.75c	7.05b	6.89c	4.35b	2.69b	605.47c	76c
Deficit irrigation							
S1	59.25a	7.89a	7.97a	5.18a	3.20a	837.61a	93a
S2	54.08b	7.49b	7.68b	4.57b	2.88b	754.22b	86b
S3	51.25b	7.11c	7.48c	4.26c	2.64c	707.99b	83c
S4	33.67c	5.07d	5.44d	2.55d	1.65d	366.66c	64d

Each mean values followed by the same letters are not significantly different for $P \leq 0.05$ according to the Duncan's test; W1, treated wastewater; W2, groundwater; W3, 50% treated wastewater and 50% groundwater; and W4, intermittent irrigation with treated wastewater and groundwater; deficit irrigation based on *S1* 100%, *S2* 80%, *S3* 60%, and *S4* 40% of field capacity

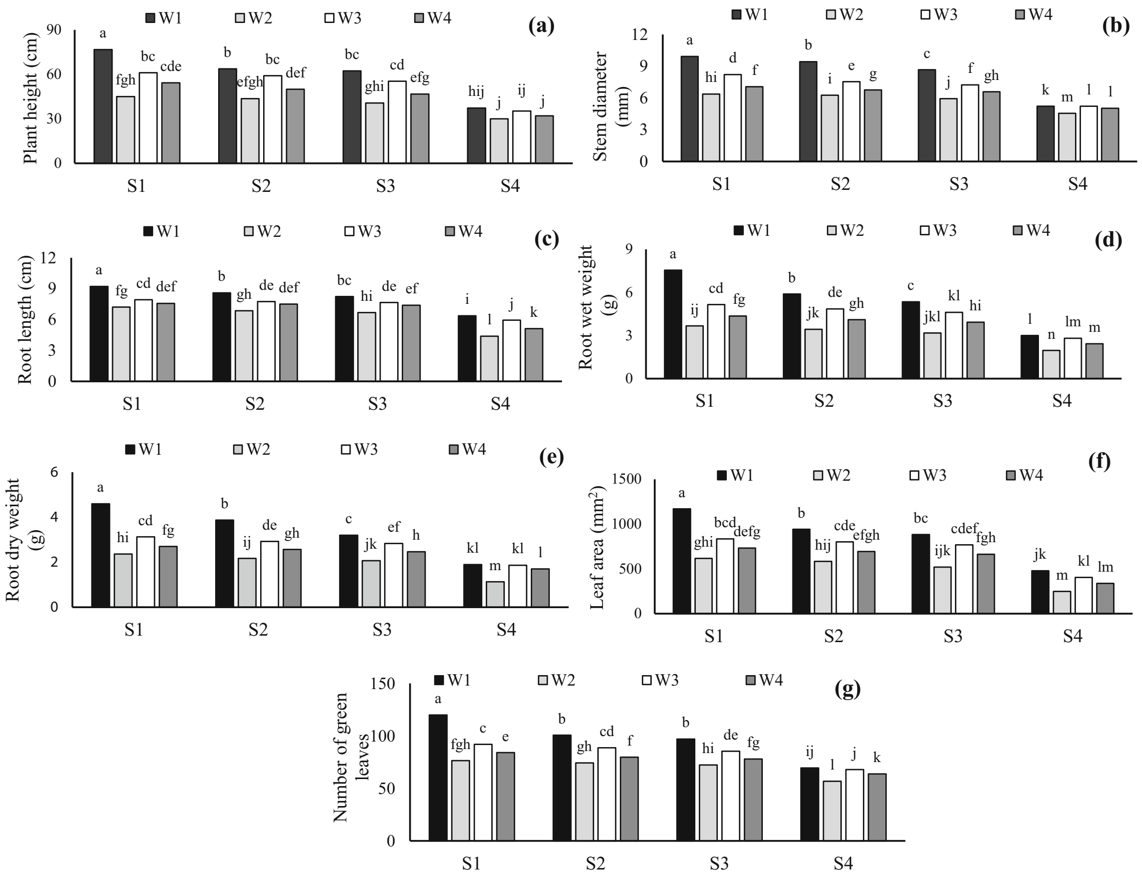

Fig. 1 Mean comparisons of interaction effects of deficit irrigation levels and water quality on morphological traits; W1 treated wastewater, W2 groundwater, W3 50% treated wastewater and 50% groundwater, and W4 intermittent irrigation with treated wastewater and groundwater; deficit irrigation based on S1 100%, S2 80%, S3 60%, and S4 40% of field capacity

number of green leaves belonged to W1S1 (120) and W2S4 (57), respectively (Fig. 1g).

3.2 Physiological Traits

According to the results of the analysis of variance, the effect of the interaction between deficit irrigation and type of irrigation water, and the main effects of deficit irrigation, at the 1% level of probability, were significant on the SPAD index, EL, RWC, and WUE (Table 5). The main effect of irrigation water quality on all physiological traits was observed at the 1% significance level, except EL.

Table 6 shows how the physiological properties of the seedlings were significantly affected at the 5% significance level by deficit irrigation levels or water quality. While SPAD was affected by water quality, RWC and WUE were more under the influence of deficit irrigation levels (Table 4); most of them were observed in different levels of deficit irrigation (RWC = 90.49% in S1 and WUE = 1.00 kg m^{-3} in S3 treatments).

Pots irrigated with treatment wastewater had more SPAD and WUE (by approx. 36% and 204%, respectively), as compared to those irrigated with groundwater. Comparison of the means of the single effects of the treatments on SPAD showed the application of W1, W3, and W4 enhanced the SPAD reading in the leaves by 36.15%, 22.11%, and 14.48%, respectively, as compared to the control. Also, the drought levels of S2, S3, and S4 were reduced by 4.56%, 9%, and 32%, respectively, as compared to S1 (Table 6). According to the results of the interaction effects of water quality and deficit irrigation levels, the highest and lowest SPAD was obtained in W1S1 (65.33%) and W2S4 (27.08%) treatments, respectively (Fig. 2a).

In regard to water quality, Table 6 also shows that RWC was diminished by 13%, 8%, and 5.3% when the seedlings were irrigated with W1, W3, and W4, as compared to those irrigated by W2. It could also be seen from Table 6 that the application of S2, S3, and S4 significantly decreased RWC (by 2.4%, 7.6%, and 24.4%, respectively), as compared to S1. The highest and lowest RWC was obtained in W1S1 (97.64%) and W1S4 (54.35%) treatments, respectively (Fig. 2b).

Mean comparisons of the single effects of water quality or deficit irrigation levels on EL indicated that this parameter was significantly affected by different levels of experimental treatments. The highest and lowest EL was obtained in irrigated groundwater and wastewater treatments, respectively.

Table 5 Results of analysis of variance show the effect of deficit irrigation and water quality treatments on physiological traits and leaf nutrient uptake

		Mean squares									
SOV	df	SPAD	EL	RWC	WUE	Na	K	Ca	Mg	P	N
Deficit irrigation (S)	3	701**	288**	1190.6**	1.6**	0.5**	1.1**	3.7**	12.1**	15.06**	21.3**
Water quality (W)	3	422.1**	3.5^{ns}	261.8**	0.5**	0.4**	1**	3.5**	7.9**	23**	12.1**
S*W	9	20.1**	191.4**	60.3**	0.15**	0.03**	0.09**	0.3**	0.38**	4.3**	18.3**
Error	32	3.8	44.5	4.4	0.005	0.0009	0.002	0.1	0.04	0.1	22.2
CV%	–	14.1	18.8	12.5	24.7	15.0	14.1	19.9	20.7	16.9	15.4
SE	–	0.97	2.33	1.49	0.021	0.013	0.023	0.057	0.044	0.039	27.79

SOV, source of variation; *df*, degrees of freedom; *CV*, coefficient of variation; *SE*, standard error; *, significant at 5% level; **, significant at 1% level; *ns*, not significant; *RWC*, relative water content; *EL*, electrolyte leakage; WUE, water use efficiency; *SPAD*, Soil Plant Analysis Development is an index to show total chlorophyll content in leaf

Also, at the highest level of water stress, most EL was obtained. (Table 6). Comparing the average interaction of the treatments showed that, in S2 and S3 levels, irrigation water types could not make a significant difference in regard to EL, which reached its peak in W4S4 treatments (Fig. 2c).

As far as WUE is concerned, both water quality and deficit irrigation levels improved it, except for S4, which was due to the low dry weight of the plant in this treatment; thus, the minimum value of WUE was obtained (Table 6). W1, W3, and W4 significantly increased WUE (by 204%, 152%, and 95%, respectively). Plants irrigated with S2 and S3 levels tended to have a 42% and 203% higher WUE. In general, the highest WUE was recorded when W1 was applied via S3 (Fig. 2d).

3.3 Leaf Mineral Nutrient Concentrations

The results of the analysis of variance showed that the main effects of irrigation water quality and different levels of deficit irrigation, as well as the interaction of these treatments, were statistically significant, at the 1% level, on all nutrients uptake in pistachio seedlings (Table 5).

As shown in Table 6, all nutrients concentrations in the leaves were influenced by water quality or deficit irrigation levels. The highest concentrations in the leaves were recorded when the seedlings were irrigated with treatment wastewater. The results, as presented in Table 6, showed that the uptake of Na, K, Ca, Mg, P, and N was increased around 102%, 25.5%, 29.3%, 31%, 24.3%, and 55%, respectively, by using W1, as compared to W2. Then, the W3 treatment was the second in terms of the nutrient uptake. Comparing the deficit irrigation levels also showed that all nutrients concentrations were decreased under S2 to S4, the lowest one was observed in S4. According to the obtained results, it was not possible to show explicitly which parameter was the most affected by the nutrients concentrations, because no specific pattern was observed. The results did not follow a regular pattern when the interactions were investigated; these are not, however,

Table 6 Mean comparisons of single effects of water quality or deficit irrigation levels on physiological traits and leaf nutrient uptake

	SPAD	EL (%)	RWC (%)	WUE (kg m^{-3})	Na (mg g^{-1})	K (mg g^{-1})	Ca (mg g^{-1})	Mg (mg g^{-1})	P (mg g^{-1})	N (mg g^{-1})
Water quality										
W1	54.80a	71.42d	77.17d	0.70a	0.85a	2.56a	3.84a	3.94a	2.56a	3.35a
W2	40.25d	79.24a	88.40a	0.23d	0.42d	2.04 cd	2.97c	3.01d	2.06c	2.16d
W3	49.15b	74.54c	81.54c	0.58b	0.65b	2.34b	3.21b	3.41b	2.39b	2.87b
W4	46.08c	76.47b	83.72b	0.45c	0.54c	2.19c	3.17b	3.23c	2.12c	2.31c
Deficit irrigation										
S1	53.54a	63.91d	90.49a	0.33c	0.79a	2.34a	3.73a	3.97a	2.51a	3.28a
S2	51.10b	72.47c	88.32b	0.47b	0.69b	2.28ab	3.04b	3.38b	2.28b	2.75b
S3	49.21c	77.78b	83.61c	1.00a	0.64c	2.14c	3.18b	3.46b	2.22b	2.25c
S4	36.42d	87.51a	68.40d	0.15d	0.32d	2.07 cd	2.83c	3.20c	2.08c	2.10d

Each mean values followed by the same letters are not significantly different for P ≤ 0.05 according to the Duncan's test

RWC, relative water content; *EL*, electrolyte leakage; *WUE*, water use efficiency; *SPAD*, Soil Plant Analysis Development is an index to show total chlorophyll content in leaf; *W1*, treated wastewater; *W2*, groundwater; *W3*, 50% treated wastewater and 50% groundwater; *W4*, intermittent irrigation with treated wastewater and groundwater; deficit irrigation based on *S1* 100%, *S2* 80%, *S3* 60%, and *S4* 40% of field capacity

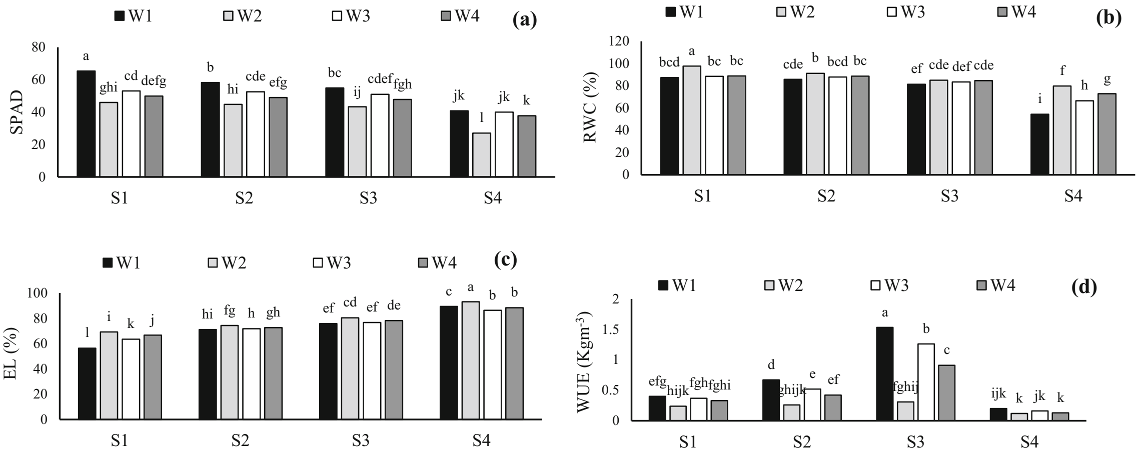

Fig. 2 Mean comparisons of interaction effects of deficit irrigation levels and water quality on physiological traits; RWC relative water content, EL electrolyte leakage, WUE water use efficiency, SPAD Soil Plant Analysis Development is an index to show total chlorophyll content in leaf; W1 treated wastewater, W2 groundwater, W3 50% treated wastewater and 50% groundwater, and W4 intermittent irrigation with treated wastewater and groundwater; deficit irrigation based on S1 100%, S2 80%, S3 60%, and S4 40% of field capacity

presented here. However, the use of wastewater was able to reduce the negative impact of deficit irrigation.

4 Discussion

Based on the results of this experiment, the growth was improved in pistachio seedlings receiving treatment wastewater, thus indicating the positive effect of wastewater on the plant growth and water use efficiency. Generally speaking, treated wastewater can be regarded as a rich source of nutrients required for the plant growth (Ali et al. 2019; Ashrafi et al. 2017; Chaganti et al. 2020; Mendes Reis et al. 2020; Tabatabaei et al. 2017). The increased growth may be due to the availability of nutrients and the adequacy of soil water to meet the plant water demand. However, in some studies, the application of untreated or the wastewater contains high levels of salts and heavy metals resulted in reduced plant growth (Hajihashemi et al. 2020; Hassena et al. 2021; Kamran et al. 2020; Mallhi et al. 2020; Tabatabaei et al. 2017).

Our finding also suggests that the application of deficit irrigation significantly decreased the leaf area. Reducing leaves' number and size is a result of cell behavior sensitive to water shortage. This could be due to transmitted signal from the roots to the shoots ordering them to decrease leaf growth and finally to close leaf stomata (Tabatabaei et al. 2017). Leaf area was larger in treatments involving irrigation with wastewater. Large leaf area is very important for light interception in plants, leading to the enhanced photosynthesis and growth (Ali et al. 2019; Ashrafi et al. 2017). Also, the use of wastewater for the irrigation of garden plants is proposed because it is a rich source of N, P, and K, thus helping to increase the leaf area and biomass production (Guo and Sims 2000; Leonel and Tonetti 2021; Nagi et al. 2020). Some researchers have reported that the use of wastewater could increase chlorophyll concentration in the leaves. On the other hand, N and Mg are known to be the essential nutrients for chlorophyll synthesis (Ali et al. 2019; Ashrafi et al. 2015; Egbuikwem et al. 2020; Herteman et al. 2011); these nutrients are abundant in wastewater. Application of wastewater, as compared with groundwater, significantly increased Na, K, Ca, Mg, P, and N concentrations in the leaves. These findings are completely consistent with the results obtained by Aghabarati et al. (2008), Ashrafi et al. (2015), Demir and Sahin (2017), Egbuikwem et al. (2020), Hirich et al. (2014), and Ohtake et al. (2020). However, Samarah et al. (2004) reported that the occurrence of drought stress led to a decrease in the concentration of nitrogen, potassium, calcium, and phosphorus in soybeans. Demir and Sahin (2017) also reported that mineral contents declined with reduction in irrigation water. That is completely consistent with the results of this research.

As the amount of the irrigation water was decreased, RWC and EL of the leaves were also decreased. These results were in line with that of Akhtar et al. (2014) and Demir and Sahin (2017) who reported that increasing water stress could reduce the RWC of leaves due to the decrease of water uptake by cells and tissues in plants. When water stress applied to the plant is increased, the cell membrane may be severely damaged, reducing the cell's ability to control the entry and exit of substances from the cell membrane (Akhtar et al. 2014). Furthermore, RWC was diminished when the seedlings were irrigated with wastewater as compared to those irrigated by groundwater. This result is completely consistent with the achievement of Acosta-Motos et al. (2014) and Hassena et al. (2021) that indicated the treated wastewater irrigation caused a significant decrease in RWC, although water qualities had no statistical effect on RWC as reported by Demir and Sahin (2017). However, in this study, the application of wastewater in irrigation water was found to improve the effect of water stress on EL.

With decreasing water consumption up to 80% field capacity, WUE was increased, as compared to the control; however, this parameter was decreased at the lowest deficit irrigation level, as compared to the control, so, the highest and lowest WUE was observed in 60% and 40% field capacity, respectively. Similar results were observed by Demir and Sahin (2017) in plants irrigated with effluent compared to fresh water, and also, Tabatabaei et al. (2017) observed that the maximum WUE belonged to partial rootzone drying with 60% of plant water requirement compared to the minimum WUE in full irrigation treatment. Yang et al. (2015) also stated that with the reduction of irrigation water, WUE was increased. Under drought stress, the plant feeds on water stored in the soil; thus, while saving water consumption, it leads to enhanced water efficiency. However, Tabatabaei et al. (2017) illustrated that water quality had no effect on WUE while deficit irrigation showed a significant positive effect. However, in this study, the highest WUE was recorded when irrigation at 60% of field capacity was done with wastewater because wastewater has high amount of essential nutrients like N and P, which are useful for plant growing. Similarly, Demir and Sahin (2017) determined that higher WUE values obtained under treated wastewater application conditions comparing with freshwater application conditions.

In comparison to complete irrigation, deficit irrigation did not decrease nutrients uptake in the leaves when wastewater was used and even improved it. Our study results are compatible with findings of study conducted by Hirich et al. (2014). They indicated that deficit irrigation with treated wastewater when applied during vegetative growth stage could increase water and nutrient uptake and subsequently increase the yield. In line with this, Demir and Sahin (2017) expressed that the soluble solid content in tomato fruits was significantly higher in deficit irrigations than in full irrigation when wastewater was used as irrigation water.

Application of treated wastewater under full irrigation conditions has greater potential for increasing the risk of existing heavy metals (Demir and Sahin 2017). Overall, deficit irrigation practices in hot and dry areas with limited irrigation water resources could be a practical and effective strategy to improve water use efficiency and reduce metal contamination in plants irrigated with wastewater.

5 Conclusion

In many countries, potential use of treated wastewater for irrigation is being explored, a fact that is confirmed by our study. Results of this study can be used for irrigation management of pistachio orchards in the dry province of Yazd, which is the third (24,200 ton) largest producer of pistachios in Iran. According to the results, it seems that pistachio seedlings can be well established under deficit treated wastewater irrigation as 40% less than field capacity, because, they had the maximum WUE in these conditions. Our results also confirmed the fact that nutrients in the treated wastewater can compensate the adverse effect of moderate level of deficit irrigation with treated wastewater.

At the moment, approximately 10.7 million m^3 treated wastewater is annually produced in Yazd province which can be used to irrigate pistachio seedlings orchards. Instead, groundwater abstraction is reduced by the same amount in the province which is seriously facing limited irrigation water resources. Furthermore, the treated wastewater was a rich source of nutrients, since the lack of nutrients was not observed. Therefore, the nutrients in this amount of treated wastewater can save up 136,960 kg N, 39376 kg P which is equivalent to $17,351 annually.

To the best of our knowledge, there is no similar study providing information on the simultaneous effect of wastewater and deficit irrigation on the growth of pistachio seedlings. However, more research still needs to be conducted to address the long-term impact of the treated wastewater on the growth characteristics of pistachio seedlings, the amount of fertilizer required, and the soil microbial communities.

Author Contribution SS-G: conceptualization, writing—original draft preparation; VB-K: methodology, data curation; AA: performed the analysis; NY: writing—reviewing and editing.

Declarations

Conflict of Interest The authors declare no competing interests.

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