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Utilization of reclaimed wastewater for olive irrigation: Effect on soil properties, tree growth, yield and oil content

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ABSTRACT

The experiment was conducted over four successive years (2008, 2009, 2010 and 2011) on 'Nabali Muhassan' olive cultivar at a private olive orchard located in the northern part of Jordan (Ramtha area). Experimental treatments applied were irrigation with fresh water (underground well water) and reclaimed wastewater to be compared with the rain-fed (non-irrigated) treatment. Total quantity of fresh water and reclaimed wastewater applied were similar during the irrigation period. Analysis of irrigation water showed higher EC value for reclaimed wastewater as compared to fresh water. Average values of pH, EC, TSS, cations, anions, N, NO3, B, heavy metals, BOD5, COD and fecal coliform in reclaimed wastewater were within the Jordanian standard for water use in irrigation of fruit trees, however, the values of SAR, Cl and Na were higher than the standard limits. Results of soil analysis indicated that soil chemical properties (pH, EC, Ca, Na, SAR, ESP, P, K, Cu, Mn, Pb and B) in soil irrigated with reclaimed wastewater were significantly higher than in soil irrigated with fresh water. The application of reclaimed wastewater or fresh water showed significant increase in annual shoot length as compared to rain-fed treatment. Average olive tree yield was significantly higher for fresh water treatment than the rain-fed treatment, which was not significantly different from the reclaimed wastewater treatment. Fruit oil content based on fresh weight and dry weight basis were significantly higher in rain-fed treatment than freshwater and reclaimed wastewater treatments.

1. Introduction

The olive (*Olea europaea* L.) is one of the most important fruit trees grown in the Middle-East region. Olive tree has been traditionally grown under rain-fed conditions and is considered as one of the best-adapted species to the semi-arid environment (Gimenez et al., 1997). Area under olive cultivation in Jordan is around 131,000 ha with an annual production of about 175,000 t of olive fruits (Ministry of Agriculture, 2013).

Water availability is a worldwide spread problem, especially in arid regions, which are characterized by low rainfall. Jordan is considered as one of the four poorest countries worldwide in water resources. The scarcity of water resources is one of the major challenges for Jordan and a limiting factor for economic development particularly for agriculture sector (Denny et al., 2008; Ministry of Water and Irrigation, 2009). Therefore, one of the strategies to be adopted to alleviate the water shortage problem in the country is to use treated municipal wastewater for irrigation purposes. Olive is considered moderately tolerant to salinity (Mass, 1990; Gucci and Tattini, 1997; Chartzoulakis et al., 2002) and therefore treated wastewater may be a useful option (Palese et al., 2008; Petousi et al., 2015).

Use of treated wastewater for irrigation of cultivated crops has grown considerably in recent years, especially in areas suffering from shortage in fresh water. With this increased necessity to use treated wastewater, farmers are faced with problems among which is the possible degradation in soil structure and stability (Petousi et al., 2015). Probable risks of adverse changes in the structure and stability of soils and their hydraulic properties following irrigation with treated wastewater, may arise from the higher levels of dissolved organic matter, suspended solids, sodium adsorption ratio (SAR) and salinity in the treated wastewater as compared with its fresh water of origin (Levy, 2013). In Jordan, Batarseh et al. (2011) investigated the effect of treated wastewater on soil physical and chemical properties, heavy metals and main nutrients translocation in olive leaves and fruits. Results showed that much smaller quantities of heavy metals compared to essential elements were accumulated in olive leaves and fruits.

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In a series of studies, it has been demonstrated that introduction of irrigation to rain-fed olive orchards, dramatically increases yields (Cruz Conde and Fuentes, 1984; Patumi et al., 2002). However, fresh water in these areas is scarce and only resources of low-quality water (saline and reclaimed wastewater) are available for olive irrigation. It is well established that the quantity of water used in irrigation of olive trees affects fruit yield, oil content and the quality of olive oil (Mailer and Ayton, 2011).

It was reported that treated wastewater available for irrigation is commonly characterized by high salinity, excess levels of B and significant but non-uniform concentrations of both potential plant nutrients (N, P, K and micronutrients) and environmental contaminants including heavy metals, COD and BOD_5 (Pescod, 1992). Little information is available regarding the effect of the reclaimed wastewater on olive tree yield and oil quality. Palese et al. (2006) reported that the irrigation of olive trees with treated wastewater during six crop seasons in southern Italy enhanced olive productivity, limited alternate bearing and allowed producing safe high value yields and did not affect significantly the quality parameters of the obtained olive oil. In a study conducted in Jordan, it was reported that olive oil produced from trees irrigated with reclaimed wastewater was not inferior in terms of chemical and sensory properties to oil produced from rain-fed or fresh water irrigated trees (Ayoub et al., 2013).

A Tunisian study demonstrated that the use of treated wastewater increased vegetative growth and olive yield in comparison to non-irrigated regime (Charfi et al., 1999). Another Tunisian study showed that irrigation of olive trees with treated wastewater caused limited vegetative growth retardation but a highly significant increase in the yield. The application of treated wastewater significantly increased concentration of total N, P and K in the leaves, also caused an increase of Zn and Mn in soil and leaves but within the usual range noticed in plants (Bedbabis et al., 2010). Furthermore, the effect of irrigation with saline water on olive tree was reported. Irrigation of olive trees with moderate saline water (EC 4.2 $dS\,m^{-1}$) led to significant increase in tree productivity and oil yield as compared to the high salinity and the control treatments (Wiesman et al., 2004). High salinity of irrigation water generally reduces olive yield, fruit weight and oil content and increasing the moisture content of the fruits (Chartzoulakis, 2011).

The aim of this research was to study the effect of using treated wastewater for irrigation of 'Nabali Muhassan' olive trees on soil chemical properties, tree growth and yield in comparison to irrigation with fresh water and rain-fed conditions.

2. Materials and methods

The experiment was conducted on four successive years 2008, 2009, 2010 and 2011 on 'Nabali Muhassan' olive cultivar grown at a private olive orchard located in the northern part of Jordan (Ramtha area) (altitude 484 m, latitude 32°35′ N and longitude 35°59′ E), with an average annual rainfall of about 275 mm, the textural class of the soil was silty clay.

Fourteen-year-old 'Nabali Muhassan' olive trees spaced 6×6 m were selected for the experiment. A randomized complete block design with five replications and three treatments was used. Each experimental plot consisted of nine trees for each treatment providing one "inner" tree for monitoring and for data collection and surrounded by border trees receiving the same treatment. Experimental treatments were carried out to compare between rain-fed trees (not irrigated), and irrigation with fresh water and with reclaimed wastewater.

Reclaimed wastewater was supplied from Ramtha wastewater secondary treatment plant located near the experiment orchard. It was pumped from the treatment plant through a main pipeline to the drip irrigation system at the olive orchard. Underground well water (fresh water treatment) was brought by tanker vehicle and reserved in tanks at the experiment location, and then it was pumped through the drip irrigation system. Rain-fed olive trees at the same orchard were taken as the control treatment.

Quantity of irrigation water was determined according to the maximum crop evapotranspiration (ETc), using the FAO method (Doorenbos and Pruitt, 1997; Allen et al., 1998) based on reference crop evapotranspiration (ETo) multiplied by crop coefficient (Kc) and a plant cover factor measured as percentage of surface covered by trees in the orchard and determined by measuring shaded area at solar noon. Irrigation water (fresh and reclaimed) was provided 2 days per week by drip irrigation method (7 emitters per tree; 8 L/h). Distances between emitters were 40 cm and were equally spaced around the Tree 50 cm from the main trunk. Irrigation scheduling and monitoring was controlled manually through opened valves according to a time schedule. Irrigation was started on April and finished on October for each growing season.

Total quantity of fresh water and reclaimed wastewater applied were similar during the irrigation period. The total quantity of applied water for each type of irrigation water was 3820, 3080, 2950 and 2880 $m^3\,ha^{-1}\,year^{-1}$ for 2008, 2009, 2010 and 2011 seasons, respectively. Samples of fresh water and reclaimed wastewater were taken each year during the irrigation period and analyzed for chemical characteristics and for biochemical oxygen demand (BOD) and chemical oxygen demand (COD) according to standard methods (American Public Health Association, 1998).

Soil samples were taken at two depths (0–25 cm and 25–50 cm), air-dried at room temperature and grounded to pass a 2-mm sieve. Soil samples were analyzed for pH, EC, Ca, Mg Na, Cl, SO_4, SAR, ESP, N, P, K, Fe, Cu, Mn, Zn, B, Cd, Pb, As, organic matter, fecal coliform and soil texture according to standard methods of soil analysis (Klute, 1994).

Composite olive leaf samples were collected in July from the periphery of each tree in the plot. Olive leaf contents of specific elements and heavy metals were analyzed according to official methods of analysis of AOAC (Horwitz, 2000).

Seasonal shoot growth was measured during April and September. Four shoots per each tested tree was labeled and measured for the increase in shoot length. Fruit set level was monitored using labeled inflorescence two months after flowering.

Olive fruits were harvested by hand during November of each growing season at a maturity index around 4. Each inner tree from the experimental plot was harvested separately. Oil extraction was performed within 2 days using small-scale olive mill (two- phase centrifugal system, Model BuonOlio Campagnola, Italy). Fruit samples were taken from each tree in the plot for measurement of fruit weight, stone weight, flesh/stone ratio, fruit moisture content and oil content. Fruit oil content was measured as fresh and dry weight bases using Soxhlet extraction method.

Data were analyzed using two-way analysis of variance (ANOVA) using SAS statistical software. Means were compared using Duncan's multiple range tests at ($p \leq 0.05$) probability level.

3. Results and discussion

3.1. Characteristics of irrigation water

Analysis of irrigation water showed higher electric conductivity (EC) value for reclaimed wastewater (2.6 $dS\,m^{-1}$) as compared to fresh water (1.22 $dS\,m^{-1}$) (Table 1). The mean values of pH, TSS, cations, anions, N, NO_3, B, heavy metals, BOD_5, COD and fecal coliform in reclaimed wastewater were within the Jordanian standard for treated wastewater use in irrigation of fruit trees. However, values of EC, Sodium adsorption ratio (SAR), Cl and Na, were higher

Table 1
Characteristics of fresh water and wastewater used in irrigation of olive trees as compared to Jordanian standard for treated wastewater used for irrigation of fruit trees.

Parameter	Type of irrigation water		Maximum limit (Jordanian standard, No. 893/2006)[a]
	Reclaimed wastewater	Fresh water	
pH	7.98 ± 0.25	8.25 ± 0.13[b]	6.0–9.0
EC (dS m^{-1})	2.71 ± 0.31	1.20 ± 0.10	<2.5
TSS (ppm)	39.00 ± 22.82	17.75 ± 3.86	150
SAR	11.45 ± 2.59	3.16 ± 0.58	9
Ca (ppm)	71 ± 0.32	75.8 ± 0.44	230
Mg (ppm)	41.28 ± 0.21	35.52 ± 0.36	96
Na (ppm)	492.66 ± 4.67	132.94 ± 0.97	230
Cl (ppm)	694.38 ± 3.15	210.87 ± 0.66	390
K (ppm)	53.82 ± 0.12	10.53 ± 0.04	–
T-PO_4 (ppm)	0.68 ± 0.62	0.00 ± 0.00	30
SO_4 (ppm)	325.44 ± 2.47	231.36 ± 0.57	480
T-N (ppm)	45.48 ± 18.76	29.18 ± 9.48	70
NO_3 (ppm)	22.73 ± 15.20	14.15 ± 12.52	45
B (ppm)	0.40 ± 0.37	0.25 ± 0.11	1.0
As (ppb)	<0.002	<0.002	100
Cd (ppm)	<0.002	<0.002	0.01
Pb (ppm)	<0.01	<0.01	5
COD (ppm)	49.25 ± 27.11	16.50 ± 16.34	500
BOD_5 (ppm)	24.90 ± 21.48	6.25 ± 5.19	200
Fecal coliform (CFU 100 mL^{-1})	51.00 ± 26.41	<2	1000

[a] Jordanian standard for reclaimed wastewater, Ministry of Water and Irrigation, 893/2006.
[b] Each value is the mean of eight samples ± standard deviation.

Table 2
Effect of rain-fed and irrigation treatments on soil properties at two soil depths for 2008 and 2009 seasons.

Parameter	Unit	2008						2009					
		Soil depth/0–25 cm			Soil depth/25–50 cm			Soil depth/0–25 cm			Soil depth/25–50 cm		
		Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater
pH	–	7.98 a	8.08 a	8.08 a	8.10 a	8.02 ab	7.90 b	8.04 a	8.00 a	8.02 a	7.98a	7.86 a	7.88 a
EC	dS m^{-1}	0.78 b	2.97 ab	3.66 a	0.92 b	1.42 b	4.81 a	0.81 b	0.98 b	3.49 a	1.26b	2.22 b	4.49 a
Na	meqL^{-1}	4.39 a	10.77 a	17.22 a	5.64 b	7.57 b	22.19 a	3.72 b	5.59 b	22.51 a	5.42b	11.51 b	27.01 a
Ca		3.22 a	12.55 a	8.08 a	3.90 b	5.18 b	14.58 a	2.94 a	3.46 a	8.58 a	3.54b	7.32 a	10.10 a
Mg		2.18 b	7.8 ab	10.3 a	2.60 b	3.70 b	9.72 a	2.76 a	2.34 a	6.1 a	4.66a	5.4 a	7.04 a
CL		4.06 b	18.12 ab	22.12 a	2.50 b	9.38 b	35.62 a	7.00 b	8.00 b	23.00 a	7b	14 b	33.5 a
SO_4		3.57 a	10.81 a	12.03 a	7.42 a	4.79 a	8.73 a	1.37 a	2.4 a	13.6 a	5.53a	9.14 a	9.96 a
N	%	0.02 a	0.02 a	0.02 a	0.04 a	0.03 a	0.02 a	0.118 b	0.117 b	0.133 a	0.12a	0.11 b	0.10 b
SAR	–	2.66 a	3.82 a	5.58 a	3.12 b	3.49 ab	6.17 a	2.1 b	3.33 b	8.31 a	2.53b	4.4 b	9.21 a
ESP	–	2.52 a	4.03 a	5.79 a	3.14 b	3.65 ab	7.04 a	1.75 b	3.43 b	9.40 a	2.34b	4.81 b	10.66 a
P	ppm	4.78 b	5.58 ab	6.68 a	4.98 a	5.45 a	5.75 a	5.56 a	7.12a	13.24a	4.9 b	4.88 b	13.4 a
K		380.28 a	288.35 a	350.32 a	305.75 a	288.38 a	392.70 a	432.3 b	465.5 b	1070 a	330.6 b	334.8 b	768.5 a
Fe		1.27 a	1.24 a	1.24 a	1.46 a	1.39 a	0.93 a	2.45 a	2.33 a	2.6 a	2.24 a	2.34 a	2.31 a
Cu		2.22 b	2.96 a	2.35 ab	2.32 a	2.53 a	2.23 a	1.91a b	2.21 a	1.57 b	1.63 a	2.19 a	1.72 a
Mn		13.74 a	10.87 a	12.64 a	15.27 a	6.83 a	7.04 a	7.08 a	6.82 a	9.77 a	6.56 a	16.03 a	10.59 a
Zn		4.11 a	4.64 a	2.53 a	0.81 b	5.26 a	0.57 b	0.689 b	7.07 a	0.92 b	1.09a b	5.58 a	0.61 b
B		0.65 a	0.69 a	0.77 a	0.66 a	0.72 a	0.67 a	1.62 a	1.03 a	1.37 a	1.22 a	1.08 a	1.47 a
Cd		0.01 a	0.01 a	0.01 a	0.01 a	0.01 a	0.01 a	0.013 a	0.011 a	0.017 a	0.01 a	0.01 a	0.01 a
Pb		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.18 a	0.24 a	0.21 a	0.18 a	0.2 a	0.21 a
As	ppb	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Organic matter	%	1.27 a	1.00 a	1.01 a	1.06 a	1.34 a	0.93 a	1.35 a	1.10 a	1.21 a	1.02 a	1.26 a	0.84 a
Fecal coliform	*E. coli*/g	<2	<2	8×10^2	<2	<2	8×10^2	0.0	0.0	>1600	0.0	0.0	>1600

Means within rows for each parameter, year and soil depth having the same letters are not significantly different at 5% probability level according to Duncan's multiple-range test.

than the Jordanian standard limits (Table 1). Although the EC value of the reclaimed wastewater was relatively high, olive trees can tolerate irrigation water salinity of up to 5 dS m^{-1} with a SAR of 18 and can produce new growth at leaf Na levels of 0.4–0.5% dry weight (Tattini et al., 1992). Furthermore, the olive tree is considered a moderately salt tolerant plant (Mass and Hoffman, 1977; Rugini and Fedeli 1990).

3.2. Soil analysis

Results of soil analysis for 2008 season at 0–25 cm depth indicated that EC, P, CL, Mg values in soil irrigated with reclaimed wastewater was significantly higher than in the rain-fed soil. Soil pH value for rain-fed treatment was significantly higher than soil irrigated with reclaimed wastewater at 25–50 cm soil depth; however, EC, Cl, Na, Mg and Ca values were significantly higher in soil irrigated with reclaimed wastewater at the same depth compared to rain-fed and fresh water treatments. No significant differences were found in soil SAR and ESP values between fresh water and reclaimed wastewater treatments. Microbiological tests indicated normal levels soil samples (Table 2). Results of soil analysis for 2009 season at 0–25 cm and 25–50 cm depths indicated that EC, Na, CL, K, SAR and ESP values in soil irrigated with reclaimed wastewater was significantly higher than in soil irrigated with fresh water and

Table 3
Effect of rain-fed and irrigation treatments on soil properties at two soil depths for 2010 and 2011 seasons.

Parameter	Unit	2010						2011					
		Soil depth/0–25 cm			Soil depth/25–50 cm			Soil depth/0–25 cm			Soil depth/25–50 cm		
		Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater
pH	–	7.78 c	7.98 b	8.06 a	7.82 c	8.00 b	8.10 a	7.92 a	7.86 a	7.94 a	7.84 a	7.82 a	7.89 a
EC	dSm^{-1}	1.10 c	2.52 b	3.81 a	1.23 c	3.59 b	5.85 a	0.52 c	2.49 b	4.98 a	0.62c	2.58 b	5.51 a
Na	$meqL^{-1}$	2.68 c	3.32 b	11.40 a	1.38 c	13.08 b	13.10 a	2.13 b	8.16 a	8.38 a	1.72 b	6.12 a	7.67 a
Ca		2.24 b	6.98 a	7.59 a	2.80 c	11.20 a	8.992 b	2.46 b	6.88 a	5.3 a	2.42 b	4.4 b	9.56 a
Mg		1.39 c	9.31 b	13.82 a	1.33 c	13.65 b	25.56 a	2.03 c	10.87 b	41.10 a	2.07 c	14.17 b	43.13 a
CL		3.46 c	9.60 b	19.37 a	4.41 b	20.40 a	21.13 a	2.45 c	8.60 b	22.00 a	4.52 b	16.2 a	18.5 a
SO_4		6.28 b	8.76 ab	12.19 a	6.65 c	28.92 b	44.35 a	3.06 b	2.4 b	13.66 a	2.45 b	9.14 a	12.88 a
N	%	1.65 c	4.87 b	5.81 a	1.59 c	5.75 b	9.60 a	1.75 c	4.43 b	7.40 a	1.34 c	5.81 b	10.66 a
SAR	–	21.36 c	31.61 b	57.45 a	22.29 c	41.44 b	66.24 a	27.2 c	37.97 b	59.99 a	29.32 c	42.94 b	54.79 a
ESP	–	0.132 c	0.142 b	0.156 a	0.116 a	0.120 a	0.122 a	0.10 b	0.12 ab	0.14 a	0.11 b	0.13 ab	0.15 b
P	ppm	9.92 c	23.23 b	41.34 a	6.72 c	12.20 b	25.48 a	6.56 b	9.12 b	23.24 a	5.9 b	5.88 b	24.4 a
K		233.3 c	410 b	775.5 a	318.1 c	493 b	743.9 a	432.3 b	465.5 b	758.8 a	330.6 b	412.8 b	814.5 a
Fe		3.85 b	3.87 b	4.36 a	4.106 b	4.196 ab	4.430 a	0.96 a	2.23 a	1.87 a	1.09 a	2.06 a	1.91 a
Cu		2.43 b	2.55 b	3.20 a	2.462 b	2.560 ab	2.714 a	1.41 a	1.53 a	1.67 a	1.63 a	2.01 a	1.92 a
Mn		7.02 c	9.23 b	14.98 a	7.380 c	11.15 b	13.00 a	3.08 a	4.82 a	6.77 a	3.56 a	4.03 a	6.59 a
Zn		0.942 b	9.362 a	1.086 b	0.674 c	1.198 a	0.870 b	0.68 a	0.97 a	0.82 a	1.09 b	2.48 a	3.61 a
B		0.112 b	0.116 ab	0.130 a	0.110a	0.1120 a	0.1240 a	0.013 a	0.011 a	0.017 a	0.01 a	0.01 a	0.01 a
Cd		1.156 c	1.256 b	1.336 a	1.044 b	1.136 b	1.252 a	0.18 a	0.24 a	0.21 a	0.18 a	0.2 a	0.21 a
Pb		0.568 c	0.898 b	1.524 a	0.600 c	0.918 b	1.612 a	1.62 a	1.03 a	1.37 a	1.22 a	1.08 a	1.47 a
As	ppb	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Organic matter	%	1.15 c	1.28 b	1.37 a	0.91 a	0.97 a	1.05 a	1.43 a	2.10 a	1.84 a	0.92 a	1.87 a	1.66 a
Fecal coliform	*E. coli*/g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	>1600	0.0	0.0	>1600

Means within rows for each parameter, year and soil depth having the same letters are not significantly different at 5% probability level according to Duncan's multiple-range test.

rain-fed soil. No significant differences were observed between the three treatments regarding the levels of pH, Ca, Mg, HCO_3, SO_4, P, Fe, Mn, B, Cd, Pb and organic matter. Microbiological tests indicated high levels of fecal coliform bacteria in soil irrigated with reclaimed wastewater compared to fresh water irrigated soil and rain-fed soil (Table 2). Soil analysis for 2010 season indicated that pH, EC, Ca, Na, SAR, ESP, P, K, Cu, Mn, Pb and B values in soil irrigated with reclaimed wastewater was significantly higher than in soil irrigated with fresh water and the rain-fed soil at both soil depths. No significant differences were found in soil Cd and As values between well water and reclaimed wastewater treatments. Microbiological tests indicated that fecal coliform was not detected in all soil samples (Table 3). Results of soil analysis for 2011 season indicated that pH, EC, Na, K, P, SAR and ESP values in soil irrigated with reclaimed wastewater was significantly higher than in soil irrigated with fresh water and the rain-fed soil at both soil depths. No significant differences were found in soil organic matter content, Boron and heavy metals (Cd, As and Pb) values between fresh water and reclaimed wastewater treatments (Table 3).

According to Al-Shdiefat et al. (2009), irrigation of olive trees with reclaimed wastewater significantly increases soil K and P concentrations as compared to fresh water irrigation. Bedbabis et al. (2015) reported that irrigation with treated wastewater increased soil pH, EC, OM, main elements, salts and heavy metals contents.

In general, our results indicated that irrigation with reclaimed wastewater may affect negatively some soil properties particularly soil EC, Na and SAR values. According to Levy (2013) there is growing evidence toward the possible build-up of undesired sodicity levels, especially in clay soils, at depths >30 cm in orchards subjected to long term irrigation with treated wastewater. These preliminary findings suggest that long-term irrigation with treated wastewater may not be a sustainable practice. Attention should be given to developing irrigation practices that will alleviate subsoil sodification following irrigation with treated wastewater.

3.3. Diagnosis of olive leaves

Macro and micronutrients and heavy metals concentrations in the leaves measured during the experiment are presented in (Table 4). Olive leaf analysis for 2008 season showed no significant differences in element concentrations between the three treatments. No consistent effect of treatment on elements level was observed. Leaf analysis for 2009 season showed no significant differences between the three treatments in all elements analyzed except for Fe, which was significantly higher in olive leaves from rain-fed treatment as compared to fresh water treatment and for Mn, which was significantly higher in olive leaves from reclaimed wastewater treatment, compared to fresh water treatment (Table 4). Olive leaf analysis for 2010 season showed no significant differences in element concentrations between the three treatments except for Fe, which was significantly higher in the leaves of reclaimed wastewater treatment compared to fresh water treatment (Table 4). Olive leaf analysis for 2011 season showed no significant differences in element concentrations between the three treatments except for N, which was significantly higher in the leaves of reclaimed wastewater treatment and fresh water treatment compared to the rain-fed treatment (Table 4). Our results agree partially with the finding of Al-Shdiefat et al. (2009) who reported higher N, P and K concentrations in olive leaves from trees irrigated with reclaimed wastewater compared to fresh water irrigated trees. However, Fe and Mn concentrations were higher in olive leaves from the fresh water irrigated trees. Petousi et al. (2015) reported that no significant differences between irrigation with reclaimed wastewater and fresh water in macronutrients and heavy metals in olive leaves. However, Bedbabis et al. (2010) found that irrigation of olive trees with treated wastewater significantly increased concentration of N, P and K in the leaves, whereas heavy metals (Zn and Mn) showed a significant increase only after the second year of irrigation.

Table 4
Olive leaf nutrient content of 'Nabali Muhassan' olive trees grown under rain-fed and irrigated conditions.

Parameter	Unit	2008			2009			2010			2011			Critical levels of nutrients
		Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	
N	%	1.24 a	1.13 a	1.19 a	1.36 a	1.36 a	1.34 a	1.83 a	1.718 a	1.724 a	1.43 b	1.76 a	1.79 a	1.5–2.0
P	%	0.09 a	0.14 a	0.09 a	0.26 a	0.10 a	0.11 a	0.063 a	0.014 a	0.063 a	0.05 a	0.05 a	0.06 a	0.1–0.3
K	%	1.13 a	1.10 a	0.97 a	0.64 a	0.74 a	0.77 a	0.848 a	0.772 a	0.854 a	0.24 a	0.25 a	0.28 a	>0.8
Na	%	0.04 a	0.04 a	0.05 a	0.04 a	0.03 a	0.04 a	0.024 a	0.022 a	0.028 a	0.11 a	0.12 a	0.14 a	Toxic > 0.2
CL	%	0.09 a	0.06 a	0.06 a	0.11 a	0.18 a	0.11 a	0.43 a	0.424 a	0.43 a	0.04 a	0.05 a	0.06 a	Toxic > 0.5
Ca	%	2.59 a	2.69 a	2.43 a	2.18 a	2.71 a	2.55 a	2.556 a	2.626 a	2.5 a	2.33 a	2.54 a	2.40 a	>1.0
Mg	%	0.24 a	0.26 a	0.34 a	0.28 a	0.28 a	0.29 a	0.23 a	0.23 a	0.24 a	0.31 a	0.31 a	0.29 a	>0.1
Fe	ppm	200.99 a	227.19 a	203.26 a	408.4 a	269.5 b	316.6 ab	203.2 a	149.6 b	216.3 a	238.6 a	232.4 a	206.5 b	100–400
Mn	ppm	55.56 a	51.49 a	46.78 a	49.25 ab	44.13 b	49.93 a	51.8 a	50.63 a	49.92 a	48.16 a	44.77 b	46.20 ab	>20
Zn	ppm	22.45 a	22.55 a	22.08 a	18.69 a	18.19 a	18.54 a	17.18 a	19.97 a	21.66 a	15.71 a	16.02 a	16.10 a	–
Cu	ppm	4.48 a	4.63 a	4.36 a	6.62 a	7.54 a	8.19 a	3.6 a	4.458 a	5.07 a	3.65 a	3.12 a	5.02 a	>40
Pb	ppm	<IDL[1]	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	–
Cd	ppm	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	<IDL	–

Means within rows for each parameter and year having the same letters are not significantly different at 5% probability level according to Duncan's multiple-range test.
[1] Instrumental Detection Limit (IDL).

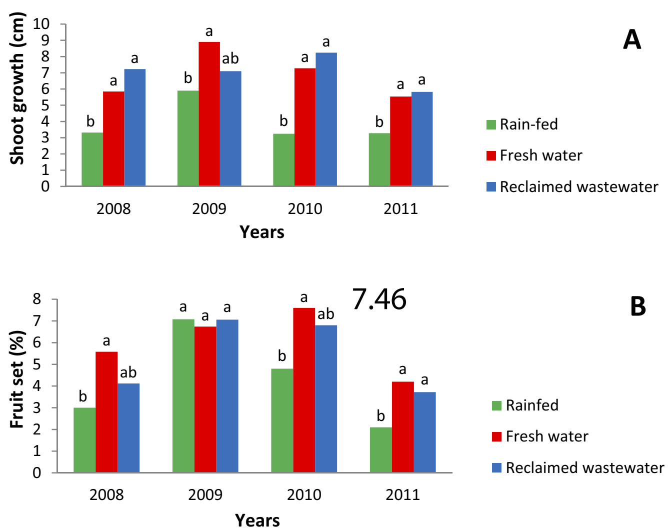

Fig. 1. Shoot growth (A) and fruit set (B) of 'Nabali Muhassan' olive trees grown under rain-fed and irrigated conditions. Means with the same letters for each year are not significantly different at 5% probability level.

3.4. *Shoot growth, fruit set, yield, fruit measurements, fruit moisture and oil content*

Fresh water and reclaimed wastewater treatments gave significantly higher increase in shoot length compared to rain-fed treatment over the four seasons, however, no significant differences were observed between reclaimed wastewater and rain-fed treatments (Fig. 1A).

Fruit set results showed significantly higher percent of fruit set for fresh water treatment compared to the rain-fed treatment for 2008, 2010 and 2011 seasons, however, no significant differences in fruit set were observed between the three treatments for 2009 season. On the other hand, no significant differences were observed in percent of fruit set between the fresh water and reclaimed wastewater treatments over the four years (Fig. 1B). Average tree yield was significantly higher for fresh water treatment than reclaimed wastewater and rain-fed treatments for 2008 season. Tree yield was significantly higher for fresh water and wastewater treatments compared to rain-fed treatment for 2009, 2010 and 2011 seasons, however, no significant difference was observed between fresh water and wastewater treatments (Fig. 2A). Our results are in agreement with the finding of other researchers who reported

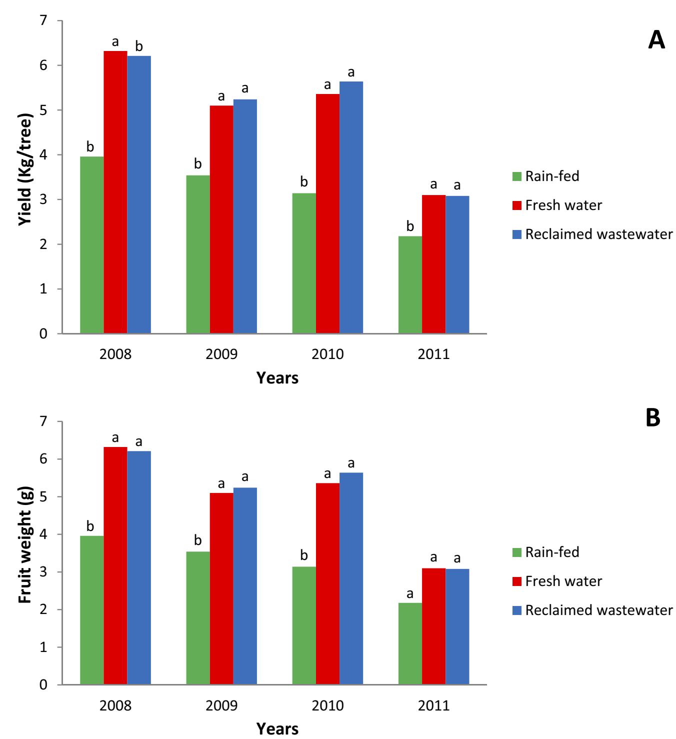

Fig. 2. Tree yield (A) and fruit weight (B) of 'Nabali Muhassan' olive trees grown under rain-fed and irrigated conditions. Means with the same letters for each year are not significantly different at 5% probability level.

that irrigation of olive trees with treated wastewater significantly increased the tree yield (Palese et al., 2006; Bedbabis et al., 2010). On the other hand, it was reported that saline water might reduce the yield compared to control conditions (Chartzoulakis, 2011).

Average fruit and stone weight were significantly higher for trees irrigated with fresh and reclaimed wastewater compared to rain-fed trees for 2008, 2009 and 2010 seasons, however, no significant difference was observed between the three treatments for fruit weight for 2011 season (Fig. 2B) and (Fig. 3A). On the other hand reclaimed wastewater treatment gave significantly higher stone weight compared to rain-fed treatment for 2011 season (Fig. 3A).

Fruit flesh/stone ratio values were significantly higher for trees irrigated with fresh and reclaimed wastewater compared to rain-

Table 5
Fruit moisture content and fruit oil content of 'Nabali Muhassan' olive trees grown under rain-fed and irrigated conditions.

Parameter	2008			2009			2010			2011		
	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Fresh water	Reclaimed wastewater	Rain-fed	Well water	Reclaimed wastewater
Fruit moisture content (%)	41.19 b	49.17 a	51.10 a	50.69 b	58.77 a	57.14 a	47.06 b	52.51 a	53.50 a	47.07 b	64.69 a	62.66 a
Oil content based on fresh weight basis (%)	20.68 a	15.15 b	17.94 ab	16.54 a	15.22 a	15.56 a	16.11 a	13.18 b	12.93 b	18.96 a	11.83 b	13.56 b
Oil content based on dry weight basis (%)	42.14 a	34.03 a	37.36 a	37.45 a	36.41 a	35.98 a	32.46 a	27.95 b	26.24 b	38.78 a	33.63 a	36.44 a

Means within rows for each parameter and year having the same letters are not significantly different at 5% probability level according to Duncan's multiple-range test.

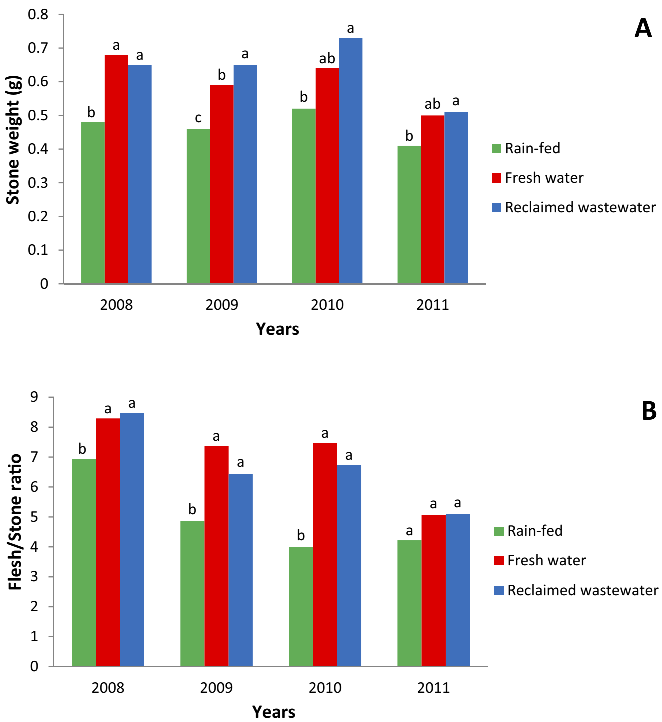

Fig. 3. Stone weight (A) and flesh/stone ratio (B) of 'Nabali Muhassan' olive trees grown under rain-fed and irrigated conditions. Means with the same letters for each year are not significantly different at 5% probability level.

fed trees for the 2008, 2009, 2010 seasons, however the difference was not significant for 2011 season (Fig. 3B).

Fruit moisture content was significantly higher for trees irrigated with fresh and reclaimed wastewater compared to rain-fed trees over the four seasons (Table 5). Fruit oil content on fresh weight basis was significantly higher in rain-fed treatment than fresh water treatment for 2008 season. Fruit oil content on fresh weight basis for 2010 and 2011 season was significantly higher in rain-fed treatment than fresh water treatment and reclaimed wastewater treatment. However, no significant differences were observed between the three treatments in terms of fruit oil content on dry weight basis for 2008, 2009 and 2011 seasons (Table 5).

4. Conclusions

Irrigation with reclaimed wastewater may negatively affect some soil chemical properties particularly EC, Na% and SAR values, which requires continues monitoring of these parameters on the long run. Olive tree shoot growth, fruit set fruit weight and yield were significantly improved by irrigation with reclaimed wastewater or fresh water compared to rain-fed conditions.

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