# Effect of Irrigation with Reclaimed Wastewater on Soil Properties and Olive Oil Quality

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## ABSTRACT

A number of Mediterranean countries have experienced severe imbalances of water supply and demand. Due to water scarcity, Jordan has very limited fresh water resources and the demand on water is ever increasing. Reclaimed wastewater is considered one of the alternative sources of irrigation water in these countries. A two consecutive year monitoring study was conducted in 2002 and 2003 to evaluate the effect of reclaimed wastewater (from Al-Samra Treatment Plant (STP)) on soil chemical properties, leaf mineral composition and olive oil quality. A reference olive orchard irrigated with fresh water of comparable age located near the STP was chosen for this comparative study using the local olive cultivar 'Nabali Baladi' in both locations. Soil, water, olive leaves, fruits and olive oil samples were analyzed according to standard methods. Irrigation with reclaimed wastewater significantly increases K and P concentrations in the soil of the STP olive orchard as compared to the reference orchard; while irrigation water indicated no significant differences in pH values between the two sources of irrigation water. Water salinity and $Na^+$ were much higher in reclaimed wastewater as compared to fresh water. However, $Cl^-$, $SO_4^{2-}$ and heavy metal concentration remain within the standard limits in both water sources except for Mo which exceeds the standard limit.

Olive leaf tissue showed higher N, P and K concentrations from orchard irrigated with reclaimed wastewater. However, Fe and Mn concentrations were higher in olive leaves from the reference orchard. Results also showed no trend of increasing heavy metal concentrations in the leaves of olive trees in both orchards. Percent of olive oil content, expressed as dry matter, was significantly higher in fruits from the STP orchard as compared to the reference orchard. Olive oil quality parameters indicated no significant differences in moisture content, specific gravity, refractive index, free acidity and iodine value extracted from olive fruits at both locations. Trace elements (Fe, Cu) and heavy metals (Pb, Cd) in olive oil were below the detectable level for both olive orchards. This indicated that there was no residual effect of RWW irrigation on the concentrations of trace elements and heavy metals in olive leaves during the study period.


**Keywords**: Olive, Olive oil quality, Fresh water, Reclaimed wastewater.

## INTRODUCTION

Olive (*Olea europaea* L.) cultivation was developed by ancient civilizations around the Mediterranean Basin. Today, olive remains one of the most important crops in the region and holds enormous economical and agricultural importance. Olive is the most important tree crop in Jordan with an annual production of 243,000 tons of olive fruits cultivated on about 126,000 ha (Ministry of Agriculture, 2006). Jordan places tenth on the list of the world's nations in olive oil production (IOOC, 2005).

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Land areas available for agricultural development in the Middle-East are located in arid and semi-arid zones, where cultivation compels utilization of large amounts of irrigation water and where good quality water sources are particularly scarce. Among various water conservation practices, the use of non-conventional water resources, such as treated wastewater must be probed (Mahasneh et al., 1989; Al-Lahlam et al., 2003). Jordan's 19 wastewater treatment plants generate more that 80 million cubic meters of treated wastewater per year. This volume is significant and will play an important role in meeting future demands for water in Jordan. Wastewater reuse for agriculture offers the greatest scope for application because it usually has the potential to meet growing water demands, conserve potable supplies, reduce disposal of pollution effluent into surface water bodies, allow lower treatment costs and enhance the economic benefits for growers due to reduced application rates for fertilizers.

Irrigation allows cultivation of olive in semi-arid and arid geographic locations, where rain-fed olive orchards are unfeasible (average annual rainfall of less than 300 mm per year). Fresh water in these dry areas is scarce and only low-quality (saline and reclaimed wastewater) sources of water are available for olive irrigation. There is little information regarding the effect of reclaimed wastewater (RWW) on olive trees. There is also no information available today considering the effect of reclaimed wastewater (effluent) irrigation on oil quality.

A number of studies during the past decades have demonstrated that irrigation may dramatically increase olive yield under typical Mediterranean climatic conditions (Cruz-Conde and Fuentes, 1984; Patumi *et al*., 2002). Olive is considered moderately tolerant to salinity (Maas, 1990; Gucci and Tattini, 1997; Chartzoulakis *et al*., 2002), and therefore low-quality water sources including treated wastewater may be a useful option. It was reported that RWW 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 (Pescod, 1992). The few publications available on the use of RWW for irrigation of olive trees are limited mostly to water from olive industry; table olive industry (Murillo *et al*., 2000) or mills. A study from Tunisia demonstrated that the use of treated chloride-sodic wastewater increased vegetative growth and olive yield in comparison to non-irrigation regime (Charfi *et al*., 1999). Reclaimed wastewater is often characterized by relatively high concentrations of nutrients including K (Pescod, 1992) which should be beneficial for the olive plant. This is complicated by the fact that recycled water is also characterized by high levels of $Na^+$ and $NH_4^+$ that may cause reduction in K level in leaves through antagonistic effects of these cations on uptake and transport of K (Tattini *et al*., 1995; Dag *et al*., 2004; Al-Absi *et al*., 2003).

There is little to no literature regarding the effect of RWW on olive oil quality, despite the fact that it is already used in some countries (Tsagarakis *et al*., 2001). Regarding the relatively high salinity of reclaimed wastewater, Wiesman *et al*. (2004) found no effect of saline water irrigation (comparing to fresh water) on fatty acid composition, especially peroxide value and fatty acid profile. Saline water increased the level of certain antioxidant components (polyphenols and Vitamin E), which might indicate an advantage to the reclaimed wastewater.

The main objective of this study was to investigate the effect of RWW irrigation on soil properties, leaf mineral composition and olive oil quality.

## MATERIALS AND METHODS

A two-year monitoring study was conducted in 2002 and 2003 to investigate the effect of RWW irrigation from Al-Samra Treatment Plant (STP) on soil chemical properties, olive leaf composition and oil quality. A reference site was chosen to assess the extent of pollution induced by irrigation with RWW in comparison to fresh water. The reference site is a private olive orchard irrigated with fresh water and located nearly 5 km north-west of the STP site.

The planted orchards, both at STP and reference orchard, were divided into four plots, each consisting of four olive trees of 'Nabali Baladi' cultivar. Olive trees at the STP orchard were subjected to surface irrigation (Basins) with reclaimed wastewater since 1986. Soil samples were randomly collected from each plot in September for two successive seasons at three depths (0-30, 30-60 and 60-90 cm). Soil samples were air-dried at room temperature and ground to pass a 2-mm sieve. Saturated paste extracts of soil samples were analyzed for pH, EC, Na, Ca, Mg, $HCO_3$, Cl, $SO_4$, N, SAR, P, K, Fe, Cu, Mn, Cd, Pb, Ni, Zn, Mo, Se and As, according to methods of soil analysis (Anonymous, 1994). Plant available P was analyzed by the ascorbic acid molybdenum blue method after sodium bicarbonate extraction (Olsen and Sommers, 1982). Exchangeable K was analyzed by flame photometery after neutral 1.0 N ammonium acetate extraction (Knudsen and Peterson, 1982).

Water samples were collected each season in September from the STP irrigation water and from the reference irrigation well. Water samples were analyzed for pH, EC, TDS, Na, Ca, Mg, $HCO_3$, Cl, $SO_4$, SAR, P, K, Fe, Cu, Mn, Zn, Cd, Pb, Ni, Mo, Se and As, according to standard methods for water and wastewater analysis (Anonymous, 1998).

Composite olive leaf samples were collected in July from the periphery of each tree in the plot. Olive leaves were washed with 0.1% neutral detergent, dried at room temperature in the shade for 24 hours and then in the oven at 70°C for 48 hours and electrically ground using a Molinex blender mixer to pass a 20-mesh screen. The resulting powder was wet-digested using, preferentially, a 1:4 acid mixture of $HClO_4$ and $H_2SO_4$ for trace element analysis (Cajuste *et al*., 1991). Olive leaf contents of specific elements and heavy metals were analyzed according to official methods of analysis of AOAC (Horwitz, 2000).

Olive fruits were harvested in November and sent directly to olive mill for oil extraction. Fruit samples were taken for determination of oil and moisture content. After pit removal, fruits were crushed and dried at 105°C for 3 hours. The dried matter was weighed, moisture content recorded and the total oil was extracted using Soxhlet apparatus with petroleum ether as solvent. The oil content was calculated on a dry weight basis (Paquot, 1997).

Analysis of olive oil quality parameters including moisture content, specific gravity, refractive index, free acidity, peroxide value, iodine value, trace metals and heavy metals was performed according to the methods described in the International Standard Organization (ISO) and the International Olive Oil Council standards (IOOC, 2003).

Statistical analysis was performed using SPSS program (version 10, 1999). Means were calculated for the four replicates of each sampling site in both studied orchards and compared using Student's *t*-test (Little and Hills, 1978).

## RESULTS AND DISCUSSION

### Analysis of Irrigation Water

Reclaimed wastewater analysis showed significantly higher salt concentrations, $Na^+$, $HCO_3^-$, $SO_4^{2-}$, SAR, P, K, Fe, Mn, Se and As for the 2002 season as compared to fresh water used in the reference orchard (Table 1). However, during the 2003 season, RWW analysis showed significantly higher salt concentrations, $Na^+$, $HCO_3^-$, $Cl^-$, SAR, P, K, Fe and As, as compared to fresh water used in the reference orchard. In addition, Pb, Ni and Mo concentrations were below detection. The average concentrations of most cations, anions, trace elements and heavy metals in RWW were within the Jordanian standard for water use in irrigation of fruit trees (Table 1).

Reference well water was found to have EC values of 1.23 and 1.26 dS/m and SAR values of 1.86 and 8.44 in 2002 and 2003 seasons, respectively. According to Rhoades *et al.* (1992), this type of water is classified as slightly saline. However, STP effluent water is classified as moderately saline for the 2002 and 2003 seasons based on available EC and SAR values (Table 1).

**Soil Analysis**

Soil analysis for both STP and reference orchards indicated that soil texture was silty clay. There was no effect of irrigation with RWW on soil pH as compared to soil irrigated with fresh water for the 2002 and 2003 seasons (Tables 2 and 3). Results revealed no variation in soil solution pH over the two seasons, which may be explained by the fact that our studied soils are high in $CaCO_3$ which buffers soils in the pH range of 7.14 to 8.5 (Lindsay and Schwab, 1982). Soil EC was negatively affected by irrigation with RWW as compared to soil irrigated with fresh water. In general, soil EC increased by irrigation with RWW. Soil EC was 3.26, 5.05 and 1.83 dS/m for depths 0-30, 30-60 and 60-90cm, respectively for soil which received RWW, while soil EC was 1.38, 1.73 and 3.40 dS/m at the same depths, respectively for soil which received fresh water for the year 2002 (Table 2). The same trend was observed also for the 2003 season (Table 3). Fardous and Jamjoum (1996) reported EC values of 5.67 dS/m at 10-20cm depth for STP soil profile.

Irrigation with RWW increased the concentration of soil exchangeable K and available P at all soil depths as compared to soil which received fresh water for both 2002 and 2003 seasons (Tables 2 and 3). For example, soil P content was 159.59, 156.72 and 143.59 ppm for depths 0-30, 30-60 and 60-90cm, respectively for soil which received RWW, while soil P was 49.72, 46.97 and 38.14 ppm at the same depths for soil which received fresh water for the year 2002 (Table 2).

The concentrations of Fe, Mn, Zn and Mo in STP soil solution were not significantly different from those of the reference orchard for the 2002 and 2003 seasons. However, Cu concentration was significantly higher in the reference orchard compared to STP orchard (Tables 2 and 3). Irrigation with RWW showed no significant addition of heavy metals (Pb, Cd, Ni and Se) to soil at all depths. These results may be attributed to low contents of trace elements and heavy metals in RWW used, since the influents of STP is almost exclusively of domestic origin, with little industrial contribution. In general, our results are in harmony with the findings of Khattari and Jamjoum (1988) who conducted a study on the effect of effluent irrigation on quality and yield of sweet corn and some soil properties, and concluded that effluent irrigation raised soil $EC_e$ and increased concentrations of extractable P, K and to a lesser extent micronutrient cations; while no contribution to heavy metal input to soil was observed. However, Al-Gazzaz (1999) reported that reclaimed wastewater irrigation from STP increased soil solution $K^+$, extractable P and extractable Fe and Pb, while extractable Cd was below detection.

**Olive Leaves Analysis**

In general, olive leaf analysis showed higher concentrations of N, P and K for olive trees irrigated with RWW as compared to those irrigated with fresh water in the reference orchard. However, the difference was significant only for N and K for the 2003 season (Table 4). Olive leaves of the reference orchard accumulated higher concentrations of Ca, Mg, Fe and Mn for the two sampling years, even though the difference was significant for only Mg and Mn elements. Olive leaf analysis showed no trend of increasing heavy metal concentrations for trees irrigated with treated wastewater compared to those irrigated with fresh water (Table 4). These results may be explained by the relative low concentrations of trace elements and heavy metals in the STP orchard soil. Al-Gazzaz (1999) reported that olive irrigated with reclaimed wastewater results in higher olive leaf concentrations of Cu, Fe, Mn, Cd and Pb. Fardous and Jamjoum (1996) reported high K concentration in corn leaves in response to irrigation with reclaimed wastewater. However, the level of micronutrients in corn leaves was not affected by reclaimed wastewater irrigation. Furthermore, Khattari and Jamjoum (1988) reported that effluent irrigation caused an increase in sweet corn leaf N, P and K and thus in the total dry matter yield.

For diagnosis of the nutritional status of olive trees in our study, results of olive leaf chemical analysis were compared with documented standards. Olive trees from STP and reference orchard proved to be both deficient in Cu while exhibiting sufficient supplies of N, P, K, Ca, Mg, Fe and Mn (Jones, Jr. *et al*., 1991; Reuter and Robinson, 1986). On the other hand, olive leaf Na and Cl were normal at both sites (Reuter and Robinson, 1986). In addition, leaf Cd and Pb were normal at both sites (Chaney, 1983, cited by Cajuste, 1991).

**Effect of RWW on Oil Content and Quality Parameters**

Olive fruit moisture content for trees irrigated with reclaimed wastewater was not significantly different from trees irrigated with fresh water in the reference orchard. Oil content of the olive fruits, expressed as percent of dry matter, was significantly higher in the fruits harvested from the STP orchard compared to reference orchard (Table 5). Higher oil content in fruits from STP orchard may be explained by higher P and K levels in soil solution and in olive leaf tissue, in addition to differences in soil salinity of both orchards. Cimato (1990) reported a positive correlation between potassium build-up in the olive fruit and its oil content. Inglese *et al*. (1996) attributed higher oil content in irrigated olives compared with non-irrigated ones, to higher K concentrations in the olive fruits. Al-Gazzaz (1999) reported that fruits of olive trees irrigated with recycled wastewater exhibited higher oil content compared with fresh water irrigated trees. Loupassaki *et al*. (1993) found that soil application of N fertilizer depressed olive flesh oil percentage by 4.18% in comparison with unfertilized control due mostly to the enhancement of vegetative growth and hence delayed fruit ripening.

In general, all olive oil quality parameters fall within the standard limit values (Tables 6 and 7). Results showed that moisture content, specific gravity, refractive index, free acidity and iodine value for olive oil extracted from fruits of the STP orchard were not significantly different from those in the reference orchard. However, peroxide value was significantly higher for olive oil extracted from fruits of the reference orchard, even though its value remains below the standard limit. Trace elements (Fe, Cu) and heavy metals (Pb, Cd) were below the detectable levels for both olive orchards (Table 6). Analysis of fatty acid composition revealed no significant differences between olive oil extracted from olive trees grown in the STP and the reference orchards except for palmitic acid and linoleic acid which were significantly lower for oil extracted from the STP orchard compared with the reference one (Table 7). There is little to no literature regarding the effect of reclaimed wastewater on olive oil quality, despite the fact that it is already used in some countries (Tsagarakis *et al.,* 2001). According to Kiritsakis (1998), nitrogen is considered essential for lipogenesis. It has been observed that nitrogen-fertilizer increases the oleic and stearic acid content of olive oil.

Dag *et al*. (2004) reported that olive oil produced under saline irrigation do not differ significantly in terms of quality parameters from other oil produced from rain-fed and fresh-water irrigated orchards. Cresti *et al*. (1994) reported that salinity increased olive oil linoleic-linolenic acid ratio and decreased the oleic-linolenic acid ratio.

## CONCLUSIONS

Results of the current study indicated that there was no residual effects of RWW irrigation on the concentration of trace elements and heavy metals in olive leaves during the study period.

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**Table (1):Physical and chemical analysis of reclaimed wastewater from Al-Samra Treatment Plant (STP) and the reference orchard irrigation water for the years 2002 and 2003 as compared to Jordanian standard (JS-893/2002) for reclaimed wastewater used for fruit trees.**

| Parameter | Unit | 2002 | | 2003 | | JS** |
|---|---|---|---|---|---|---|
| | | STP | Reference Orchard | STP | Reference Orchard | |
| **pH** | **-** | 8.32 a* | 8.15 a | 8.18 a | 8.00 a | 6-9 |
| **EC** | **$dSm^{-1}$** | 2.61 a | 1.23 b | 2.62 a | 1.26 b | 2.5 |
| **TDS** | **ppm** | 1681.60 a | 808.75 b | 1148.50 a | 584.25 b | 1500 |
| **$Na^+$** | **$meq\ L^{-1}$** | 10.91 a | 3.62 b | 23.24 a | 16.21 b | 10 |
| **$Ca^{2+}$** | | 3.18 a | 3.18 a | 3.26 a | 3.39 b | 11.5 |
| **$Mg^{2+}$** | | 3.32 a | 4.39 b | 3.86 a | 4.12 a | 8 |
| **$HCO_3^-$** | | 7.25 a | 1.08 b | 7.15 a | 0.71 b | 6.5 |
| **$Cl^-$** | | 6.62 a | 8.04 b | 12.48 a | 7.82 b | 11 |
| **$SO_4^{2-}$** | | 2.50 a | 1.97 b | 12.67 a | 15.53 b | 10 |
| **SAR** | **-** | 6.04 a | 1.86 b | 12.29 a | 8.44 b | 9 |
| **P** | **ppm** | 13.53 a | 3.34 b | 13.65 a | 2.52 b | 30 |
| **K** | | 48.50 a | 7.75 b | 52.20 a | 5.71 b | - |
| **Fe** | | 0.17 a | 0.02 b | 0.17 a | 0.02 b | 5 |
| **Cu** | | 0.02 a | 0.01 a | 0.02 a | 0.02 a | 0.2 |
| **Mn** | | 0.11 a | 0.02 b | 0.03 a | 0.02 a | 0.2 |
| **Zn** | | 0.05 a | 0.06 a | 0.04 a | 0.03 a | 5 |
| **Cd** | | 0.02 a | 0.02 a | 0.01 a | 0.02 a | 0.01 |
| **Pb** | | 0.04 a | 0.14 b | bd[1] | bd | 5 |
| **Ni** | | 0.02 a | 0.01 a | bd | bd | 0.2 |
| **Mo** | | 0.06 a | 0.04 a | bd | bd | 0.01 |
| **Se** | **ppb** | 1.88 a | 0.54 b | 0.52 a | 0.51 a | 50 |
| **As** | | 4.68 a | 0.64 b | 5.35 a | 0.66 b | 100 |

*Means within rows for each year having the same letter are not significantly different at 5% probability level according to Studant's *t*-test.

** Jordan Standard for Reclaimed Waste Water (Ministry of Water and Irrigation, 893/2002.

[1] bd: Below detection level.

**Table (2): Soil physical and chemical properties of collected soil samples from Al-Samra Treatment Plant area (STP) and the reference orchard area at three depths for the year 2002.**

| Parameter | Unit | STP | | | Reference Orchard | | |
|---|---|---|---|---|---|---|---|
| **Soil depth (cm)** | | **0-30** | **30-60** | **60-90** | **0-30** | **30-60** | **60-90** |
| **pH** | - | 7.70 | 7.78 | 7.90 | 7.95 | 7.90 | 7.85 |
| **EC** | $dSm^{-1}$ | 3.26 | 5.05 | 1.83 | 1.38 | 1.73 | 3.40 |
| $Na^{+}$ | $meqL^{-1}$ | 9.98 | 8.69 | 7.54 | 5.63 | 6.72 | 12.32 |
| $Ca^{2+}$ | | 9.75 | 7.00 | 5.25 | 2.50 | 2.75 | 4.62 |
| $Mg^{2+}$ | | 10.25 | 7.25 | 5.00 | 5.00 | 6.25 | 10.62 |
| $HCO_3^{-}$ | | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| $Cl^{-}$ | | 6.25 | 4.38 | 5.62 | 8.75 | 9.38 | 13.12 |
| $SO_4^{2-}$ | | 21.23 | 16.07 | 9.92 | 1.88 | 3.84 | 11.95 |
| **Na** | % | 33.34 | 39.88 | 43.01 | 44.76 | 45.63 | 47.95 |
| **N** | % | 0.11 | 0.82 | 0.05 | 0.10 | 0.80 | 0.07 |
| **SAR** | - | 3.15 | 3.38 | 3.34 | 2.97 | 3.18 | 4.04 |
| **P** | ppm | 195.59 | 156.72 | 143.59 | 49.72 | 46.97 | 38.14 |
| **K** | | 983.92 | 894.62 | 833.25 | 503.12 | 451.20 | 425.85 |
| **Fe** | | 5.40 | 4.38 | 5.19 | 4.77 | 3.67 | 4.16 |
| **Cu** | | 0.99 | 0.89 | 0.85 | 1.33 | 1.24 | 1.24 |
| **Mn** | | 19.26 | 20.05 | 15.79 | 18.89 | 16.54 | 17.24 |
| **Cd** | | 0.09 | 0.06 | 0.05 | 0.07 | 0.06 | 0.06 |
| **Pb** | | 0.21 | 0.18 | 0.20 | 0.12 | 0.10 | 0.08 |
| **Ni** | | 0.76 | 0.73 | 0.63 | 0.57 | 0.55 | 0.53 |
| **Zn** | | 2.63 | 3.79 | 1.71 | 2.25 | 1.10 | 1.47 |
| **Mo** | | 0.48 | 0.65 | 0.68 | 0.46 | 0.62 | 0.53 |
| **Se** | ppb | 0.74 | 1.30 | 1.77 | 0.38 | 0.39 | 0.58 |
| **As** | | 9.66 | 14.89 | 22.10 | 19.27 | 16.19 | 19.75 |
| **Soil texture** | | Silty clay loam | Silty clay | Silty clay | Silty clay loam | Silty clay | Silty clay |

**Table (3): Soil physical and chemical properties of collected soil samples from Al-Samra Treatment Plant area and the reference orchard area at three depths for the year 2003.**

| Parameter | Unit | STP | | | Reference | | |
|---|---|---|---|---|---|---|---|
| Soil depth (cm) | | 0-30 | 30-60 | 60-90 | 0-30 | 30-60 | 60-90 |
| **pH** | - | 7.62 | 7.55 | 7.72 | 7.80 | 7.80 | 7.70 |
| **EC** | $dSm^{-1}$ | 2.36 | 2.72 | 1.96 | 1.24 | 1.68 | 3.92 |
| $Na^{+}$ | $meqL^{-1}$ | 8.87 | 13.77 | 7.48 | 4.08 | 21.77 | 21.07 |
| $Ca^{2+}$ | $meqL^{-1}$ | 8.75 | 18.75 | 7.00 | 5.50 | 7.75 | 11.00 |
| $Mg^{2+}$ | $meqL^{-1}$ | 5.50 | 12.00 | 6.50 | 4.62 | 10.25 | 8.00 |
| $HCO_3^-$ | $meqL^{-1}$ | 5.62 | 6.25 | 5.50 | 6.00 | 6.25 | 6.00 |
| $Cl^-$ | $meqL^{-1}$ | 11.88 | 23.75 | 13.12 | 6.75 | 27.25 | 31.62 |
| $SO_4^{2-}$ | $meqL^{-1}$ | 5.62 | 14.52 | 2.35 | 1.46 | 6.02 | 2.44 |
| **Na** | % | 38.61 | 34.21 | 37.06 | 28.26 | 36.54 | 39.79 |
| **N** | % | 0.44 | 0.09 | 0.07 | 0.42 | 0.06 | 0.06 |
| **SAR** | | 3.17 | 3.61 | 2.96 | 1.79 | 5.49 | 6.78 |
| **P** | ppm | 124.08 | 98.08 | 93.38 | 10.81 | 13.68 | 13.09 |
| **K** | ppm | 873.88 | 806.31 | 648.65 | 357.66 | 303.60 | 233.79 |
| $Fe^{2+}$ | ppm | 8.36 | 7.32 | 7.69 | 6.67 | 6.40 | 7.31 |
| $Cu^{2+}$ | ppm | 0.89 | 0.84 | 0.75 | 1.09 | 0.97 | 0.86 |
| $Mn^{2+}$ | ppm | 10.04 | 10.04 | 10.02 | 16.35 | 13.39 | 11.58 |
| $Cd^{2+}$ | ppm | 0.06 | 0.08 | 0.07 | 0.09 | 0.06 | 0.05 |
| $Pb^{2+}$ | ppm | 0.41 | 0.41 | 0.43 | 0.50 | 0.48 | 0.42 |
| **Ni** | ppm | 0.44 | 0.45 | 0.42 | 0.42 | 0.34 | 0.29 |
| **Zn** | ppm | 5.32 | 4.36 | 2.56 | 5.10 | 6.43 | 16.91 |
| **Mo** | ppm | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Se** | ppb | 3.37 | 3.84 | 4.46 | 1.99 | 2.92 | 2.67 |
| **As** | ppb | 26.38 | 27.60 | 34.16 | 7.14 | 11.20 | 8.03 |
| **Soil texture** | | Silty clay loam | Silty clay | Silty clay | Silty clay loam | Silty clay | Silty clay |

**Table (4): Average olive leaf content of elements at Al-Samra Treatment Plant and the reference orchard for the years 2002 and 2003.**

| Parameter | Unit | 2002 | | 2003 | | Standard olive leaf nutrient content** |
|---|---|---|---|---|---|---|
| | | STP | Reference | STP | Reference | |
| **N** | **%** | 1.94±0.16 a * | 1.36±0.06 a | 2.32±0.12 a | 1.31±0.11 b | 1.5-2.0 |
| **P** | **%** | 0.10±0.01 a | 0.10±0.00 a | 0.14±0.01 a | 0.12±0.01 a | 0.1-0.3 |
| **K** | **%** | 0.94±0.04 a | 0.86±0.05 a | 1.40±0.04 a | 0.75±0.09 b | >0.8 |
| **$Na^+$** | **%** | 0.04±0.00 a | 0.04±0.01 a | 0.17±0.01 a | 0.10±0.01 b | - |
| **$Cl^-$** | **%** | 0.08±0.00 a | 0.08±0.00 a | 0.05±0.00 a | 0.02±0.00 a | - |
| **Ca** | **%** | 1.21±0.03 a | 1.26±0.06 a | 1.18±0.03 a | 1.26±0.04 a | >1.0 |
| **Mg** | **%** | 0.15±0.01 a | 0.20±0.01 b | 0.17±0.01 a | 0.26±0.02 b | >0.1 |
| **Fe** | **ppm** | 289.50±34.64 a | 389.00±74.02 a | 389.75±40.47 a | 524.00±70.57 a | - |
| **Mn** | **ppm** | 37.00±1.22 a | 65.50±4.86 b | 47.75±1.25 a | 60.75±2.93 b | >20 |
| **Cu** | **ppm** | 2.25±0.25 a | 1.50±0.29 a | 4.25±0.25 a | 3.50±0.50 a | >40 |
| **Pb** | **ppm** | 1.25±0.32 a | 0.69±0.16 a | <0.01 | <0.01 | 2-5 |
| **Cd** | **ppm** | <0.2 | <0.2 | 0.09±0.02 a | 0.26±0.04 b | 0.1-1.0 |
| **Cr** | **ppm** | 0.65±0.14 a | 0.70±0.11 a | 0.76±0.11 a | 0.97±0.17 a | - |
| **Ni** | **ppm** | 1.95±0.25 a | 2.00±0.15 a | 2.08±0.05 a | 2.20±0.11 a | - |

*Mean ± SE of four replications. Mean separation, by Studant's *t* test. Means within rows for each year having the same letter are not significantly different at 5% probability level.

** Source: (Reuter and Robinson, 1986).

**Table (5): Percent of oil and moisture content in 'Nabali' olive fruits grown at Al-Samra Treatment Plant and the reference orchard for the season 2003.**

| Parameter | STP | Reference |
|---|---|---|
| **Moisture content (%)** | 50.89 a* | 51.06 a |
| **Oil content (%) (Dry weight basis)** | 52.06 a | 47.52 b |

* Means within each row having the same letter are not significantly different at 5% probability level according to Student's t-test.

**Table (6): Quality characteristics of olive oil extracted from 'Nabali' cultivar grown at Al-Samra Treatment Plant and the reference orchard for the season 2003.**

| Parameter | Unit | STP | Reference Orchard | Limit value** |
|---|---|---|---|---|
| **Moisture content** | % | 0.12 a* | 0.14 a | Max 0.2 |
| **Specific gravity at 20°C** | $gcm^{-3}$ | 0.912 a | 0.912 a | 0.910-0.916 |
| **Refractive index at 20°C** | - | 1.469 a | 1.469 a | 1.467-1.470 |
| **Free acidity as oleic acid** | % | 0.50 a | 0.52 a | Max 3.3 |
| **Peroxide value** | meq $O_2$ $kg^{-1}$ oil | 12.62 a | 17.48 b | Max 20 |
| **Iodine value** | g/100g | 84.27 a | 81.24 a | 75-94 |
| **Iron (Fe)** | mg/kg | NIL[1] | NIL | Max 3.0 |
| **Copper (Cu)** | mg/kg | NIL | NIL | Max 0.1 |
| **Lead (Pb)** | mg/kg | NIL | NIL | Max 0.1 |
| **Cadmium (Cd)** | mg/kg | NIL | NIL | Max 0.1 |

*Means within each row having the same letter are not significantly different at 5% probability level according to Studant's *t*-test.

[1]NIL: non-identifiable level.

**Source: (IOOC, 2006). Trade standard applying to olive oils and olive-pomace oils. International Olive Oil Council, (COI/T.15/NC no.3/Rev. 2) Madrid, Spain.

**Table (7): Fatty acid composition of olive oil extracted from 'Nabali' cultivar grown at Al-Samra Treatment Plant and the reference orchard for the season 2003.**

| Fatty acids (% m/m methyl esters) | STP | Reference Orchard | Limit value** |
|---|---|---|---|
| **Palmitic acid C16:0** | 13.01 a* | 14.01 b | 7.5-20.0 |
| **Palmitoleic acid C16:1** | 1.09 a | 1.21 a | 0.3-3.5 |
| **Stearic acid C18:0** | 2.74 a | 2.65 a | 0.5-5.0 |
| **Oleic acid C18:1** | 68.06 a | 67.24 a | 55.0-83.0 |
| **Linoleic acid C18:2** | 13.06 a | 13.73 b | 3.5-21.0 |
| **Linolenic acid C18:3** | 0.95 a | 0.80 a | Max 1 |
| **Arachidic acid C20:0** | 0.58 a | 0.44 a | Max 0.6 |
| **Behenic acid C22:0** | 0.15 a | 0.14 a | Max 0.2 |

*Means within each row having the same letter are not significantly different at 5% probability level according to Studant's *t*-test.

**Source: (IOOC, 2006), Trade standard applying to olive oils and olive-pomace oils. International Olive Oil Council, (COI/T.15/NC no.3/Rev. 2) Madrid, Spain.

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# تأثير الري بمياه الصرف الصحي المستصلحة على خواص التربة وجودة زيت الزيتون

***صالح الشديفات* ، سلام أيوب** و خليل جمجوم*****

## ملخـص


يعاني عدد من بلدان البحر الأبيض المتوسط من اختلالات حادة في إمدادات المياه والطلب عليها. ونظرا لندرة المياه، فإن الأردن يعاني من محدودية موارد المياه العذبة والطلب المتزايد عليها أكثر من اي وقت مضى. وتعتبر مياه الصرف الصحي المعالجة من المصادر البديلة لمياه الري في هذه البلدان. اجريت هذه الدراسة في العامين المتتاليين 2002 و 2003 لتقييم تأثير مياه الصرف الصحي المعالجة (من محطة السمرا) على خصائص التربة الكيميائية، ومحتوى الأوراق من العناصر الغذائية، وجودة زيت الزيتون. تم اختيار بستان زيتون بنفس العمر مروي بالمياه العذبة يقع بالقرب من محطة السمرا، وتم استخدام صنف الزيتون " النبالي البلدي" في كلا الموقعين. وقد تم تحليل عينات التربة والمياه وأوراق الزيتون وزيت الزيتون حسب الطرق الفنية المتبعة.

أدى الري بمياه الصرف المستصلحة في محطة السمرا إلى زيادة تركيز البوتاسيوم والفسفور في تربة بستان الزيتون وبشكل معنوي بالمقارنة مع المزرعة الشاهد. ولم يكن هناك أي تباين في درجة حموضة مياه الري (pH) بين مياه الري المستصلحة والعذبة في كلا الموقعين. أما ملوحة المياه وتركيز الصوديوم فكانا أكبر في مياه الري المستصلحة، وبقي تركيز الكلورين والكبريتات والعناصر الثقيلة من كلا المصدرين ضمن حدود المواصفة القياسية لمياه الري ما عدا عنصر الملبدينوم (Mo) الذي زاد تركيزه عن المواصفة القياسية الأردنية لمياه الري المستصلحة. أدى الري بالمياه المستصلحة إلى زيادة تركيز النيتروجين والفسفور والبوتاسيوم في أوراق صنف الزيتون المروي بهذه المياه، بينما كان تركيز الحديد والمنغنيز في الأوراق أعلى في أوراق الأشجار المروية بالمياه العذبة في المزرعة الشاهد. كما لم تلاحظ أي زيادة في تركيز العناصر الثقيلة في الأوراق في كلا الموقعين .

نسبة الزيت في ثمار الزيتون على أساس الوزن الجاف كانت أعلى في الثمار المأخوذة من الأشجار المروية بالمياه المستصلحة مقارنة مع تلك المروية بالمياه العذبة في المزرعة الشاهد. كما أشارت نتائج فحص جودة الزيت إلى عدم وجود تباين في الزيت المستخاص من الثمار في كلا الموقعين فيما يتعلق بنسبة الرطوبة والكثافة النوعية ومعامل الانكسار والحموضة الحرة والرقم اليودي. كما لم يكن هناك وجود لعنصري الحديد والنحاس والعناصر الثقيلة الرصاص والكادميوم في الزيت المستخاص من كلا الموقعين، وهذا يشير إلى عدم وجود آثار متبقية نتيجة الري بالمياه المستصلحة على مستوى العناصر الصغرى والثقيلة في أوراق النبات خلال فترة الدراسة.


**الكلمات الدالة**: مياه عذبة، زيتون، جودة زيت الزيتون، مياه الصرف الصحي المستصلحة.

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