Long-Term Effect of Khirbet El-Samra Treatment Water Irrigation on Soil and Olive Quality

By

Nabeel M. Al-Gazzaz

Supervisor

Prof. T. M. Abu-Sharar

Co-Supervisor

Prof. Gilani Abdel Gawad

Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in
Environmental Sciences and Management

Faculty of Graduate Studies
University of Jordan

August 1999

This Thesis was successfully defended and approved on the 3rd of August, 1999 by:

Examination Committee	Signature
1. **Dr. T. M. Abu-Sharar, Chairman** (Prof. of Soil Chemistry)	
2. **Dr. Gilani Abdel Gawad, Member** (Prof. of Soil Chemistry)	a. Gilani
3. **Dr. Anwar Battikhi, Member** (Prof. of Soil Physics)	A. M. Battikhi
4. **Dr. Deifallah M. Badarneh, Member** (Assoc. Prof. of Soil Microbiology)	
5. **Dr. Abdel Nabi Fardous, Member** (Soil Physics Specialist)	

Dedication

To all those who do so very short-sightedly think that by bubbling balloons here and there in the sky they can obstruct falcons from flying high, hanging the sky, hanging the summits and resting there, I present this piece of my striving effort as a special dedication.

Acknowledgment

To each and every one who knows well and for sure that he did, in a way or another, contribute something, material and/or immaterial, to releasing this work, I owe a great debt of gratitude.

List of Contents

Subject **Page**

List of Tables

Table **Page**

List of Appendices

Abstract

Long-Term Effect of Khirbet El-Samra Treatment Water Irrigation on Soil and Olive Quality

By
Nabeel M. Al-Gazzaz
Supervisor
Prof. T. M. Abu-Sharar
Co-Supervisor
Prof. Gilani Abdel Gawad

A two-year study was started in 1996 in an effort to investigate the long-term effect of effluent irrigation on soil chemical properties and olive yield and quality, with particular emphasis on accumulation of B and heavy metals, especially Pb and Cd, in the soil profile and plant tissue.

Local olive varieties have been surface-irrigated with Khirbit es-Samra Treatment Plant (STP) effluent since 1986. A fresh water-irrigated olive orchard of comparable age in the vicinity of STP was selected for comparison purposes.

Soil and plant leaf and fruit samples were collected late in November coinciding with fruit collection period, in two successive seasons (1996/1997 and 1997/1998). Collected samples were subjected to complete chemical analysis according to standard methods.

Irrigation with STP effluent increased soil solution B, K^+, NH_4OAc-extractable K, $NaHCO_3$-extractable P, and DTPA-extractable Fe and Pb while under both types of irrigation water, DTPA-extractable Cd was below detection. The soil of the reference orchard had higher electrical conductivity of saturation extract (EC_e), total soluble ion concentrations (Na^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, NO_3^- and SO_4^{2-}), organic matter (OM), total N, and DTPA-extractable Cu, Zn and Mn concentrations. As to olive trees, higher leaf concentrations of B, Cu, Fe, Mn, Cd and Pb, and higher aqueous leaf extract Na^+, K^+, SO_4^{2-}, and PO_4^{3-} concentrations were affected by effluent irrigation. Olive fruits responded to effluent irrigation by exhibiting higher fat content (fat %), and N, P, K, Ca, Mg, B, Fe, Mn, Cd, and Pb concentrations.

1. INTRODUCTION

Water resources in Jordan are almost exclusively dependent on rainfall. Precipitation rates range from 50 to 600mm year^{-1}. Nearly 90% of Jordan receive less than 200mm of annual precipitation. Average annual precipitation is estimated at 8.5×10^9 m^3 of which about 85% is lost via evaporation. Total annual rainfall amounts to approximately 6.0×10^9 and 11.5×10^9 m^3 in dry and wet years, respectively (Tuffaha, 1996). It has been estimated by the Water Authority of Jordan that available annual surface and ground water totals 1.1×10^9 m^3 (Sahouri, 1988). The average annual surface water resources of the country are estimated to be of the order of 880×10^6 m^3. In addition, some 220×10^6 m^3 can be extracted annually from underground (Nasser, 1988). Agricultural demand of water was also estimated at 70% of total water consumption in Jordan (Sahouri, 1988). As agriculture competes strongly with other sectors, covering a certain fraction of its water demand through wastewater reuse releases pressure off potable water supplies.

Wastewater renovation and reuse, as a means of conserving and augmenting water sources, is gaining more and more weight and momentum all over the world. It derives its importance from the fact that it guarantees a continuous water supply throughout the whole year, reduces the cost of treatment and energy inputs, supplies the soil with nutrients required for normal plant growth, and increases the amount of organic matter (OM) in the irrigated soil, thus reducing reliance on synthetic fertilizers. Land application of effluent is considered an advanced wastewater treatment technique or a tertiary treatment step. The premise underpinning land application of wastewater is that the soil-plant ecosystem has the potential to immobilize and transform applied metals and nutrients so that they will not pollute groundwater or contaminate the food chain. The soil, serving as a living filter, will effectively alternate and thus remove harmful toxic chemicals and microorganisms from applied wastewater as it percolates through soil (United States Environmental Protection Agency, 1981). In addition, when irrigation water is applied to heavy-textured soils of neutral or alkaline pH, or soils with appreciable ($\geq$ 10%) amounts of $CaCO_3$ and organic matter content, significant amounts of most trace metals are retained by the soil, thus rendering them potentially less bioavailable (Hooda and Alloway, 1998; and Page and Chang 1981).

Problems most commonly encountered under effluent irrigation include soil and groundwater pollution. Soil pollution can take the form of either, or a combination of, soil salinity, alkalinity, and accumulation of heavy metals and B in soil. Soil salinity in particular may affect plant growth and development and induce Na^+ and/ or Cl^- and/or B specific toxicity to plants. Deterioration of groundwater may take the form of induced salinization and/or NO_3^- pollution of groundwater reservoirs.

Land application of wastewater is not that recent practice. Day and Tucker (1977) date this practice back in Britain to as early as 1865. Asano and Levine (1996) reported that wastewater reuse has a long and illustrious history as evidenced by the elaborate sewerage systems associated with ancient palaces and cities of the Minoan Civilization. In addition, Jennet and Linnemann (1979) reported that application of raw or treated wastewater to land had been practiced in Europe since Roman times.

In light of the above-mentioned discussion and cons and pros of effluent irrigation, this study sat forth to destinate at the target objective of studying the effect of ten years of Khirbit es-Samra Treatment Plant (STP) effluent water irrigation on:

(1-a) Soil solution chemistry. Properties studied were: pH; EC_e; major soluble ions; and SAR.

(1-b) Macro-nutrients, micro-nutrients, and heavy metals accumulation, movement in the soil profile, and removal by olive trees, with particular emphasis on Cd and Pb.

(1-c) Elemental composition of olive leaves and fruits.

Data obtained will, hopefully, furnish quite adequate information on soil and olive response to prolonged effluent irrigation and aid in assessing future needs to deal with environmental implications of land application of effluent at the site.

2. LITERATURE REVIEW

2.1 Soil

Day *et al.* (1972) found that effluent-irrigated soil had higher pH and concentrations of nitrates, phosphates, and calcium plus magnesium as compared with a field irrigated with well water and fertilized with recommended N, P and K concentrations. In addition, soil receiving wastewater had a lower infiltration rate than the control. John (1974) leached secondary sewage effluent through three columns of two alkaline and one acidic soils. Average soil P attenuation for 22 leachings ranged from 88 to 94% of effluent P for the alkaline soil columns. In addition, besides increasing soil total P content, effluent inputs of P to soil columns supported enhanced levels of P availability in both columns in comparison with controls. As regards Ca and Mg, earlier leachings washed out readily soluble and extractable forms of both metals. Earlier leachates as a consequence contained levels of both metals far in excess of applied effluent and it was not until equilibrium was re-established and soil columns resaturated with Ca and Mg that this trend was reversed. The final collection of leachate from the alkaline soil columns contained 24 to 36% more NO_3^- than added effluent. Sidle and Sopper (1976) concluded that effluent irrigation had no measurable effect on the 0.1N HCl-extractable Cd in the soil. After eleven years of effluent application, concentrations of 0.1N HCl-extractable Cd were only detected at the ppb level ($\leq$ 500ppb). De Jong (1978) found that effluent leaching of slightly acidic to neutral soil columns increased soil pH and the sum of exchangeable Na, K, Ca and Mg. Sommers *et al.* (1979) concluded that the majority of P added to soil during wastewater irrigation remained in the upper 30-cm of soil and that for the 0 to 15-cm depth, wastewater irrigation consistently increased organic-C, total N and P levels, while no definite trends in the parameters traced were observed at 15-30 and 30-60cm in all effluent-irrigated sites.

Jame *et al.* (1984) found that after eight years of effluent irrigation, new steady state salinity profiles developed. At this steady state condition, salt contents in the upper 60cm of the root zone were generally similar; salinity increased with depth towards bottom of the root zone from an initial low EC_e value of 2.5 to 6.0dS m^{-1}. Papadopoulos and Stylianou (1991 and 1988) found that higher EC_e, and hence inputs to soil of the major soluble ions (Na^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}) resulted from fresh, rather than effluent, irrigation water. Sodium adsorption ratio was reduced beneath drippers in the surface 15 and 30cm depths with fresh and effluent water, respectively, and the reverse trend was observed thereafter. In addition, substantial increases in SAR and reductions in soil permeability were observed in fresh, rather than effluent, water-irrigated plots. Nitrate accumulation was higher in plots receiving effluent and the effect of effluent on soil P was particularly greater at the surface 45cm.

Khattari and Jamjoum (1988) concluded that effluent irrigation at Queen Alia International Airport (Jordan) raised soil EC_e and organic matter content and increased the concentrations of extractable P, K and, to a lesser extent, micronutrient cations, while no contribution to heavy metal input to soil was observed (Appendix 1).

Neilsen *et al.* (1991) examined response of sweet cherry orchards to wastewater irrigation. They found that sites receiving wastewater had higher extractable P and K concentrations and lower extractable Ca and Mg than controls. In addition, wastewater irrigation significantly increased extractable Na and hot water soluble B. Nevertheless, soil B ranged from 0.28mg L^{-1} at 0.7 to 0.9m to 0.67mg L^{-1} in the surface 0.1m. As the increase in extractable Na was not paralleled by comparable increases in extractable Ca and Mg, a significant increase in SAR was recorded. Besides, wastewater affected higher soil saturation extract electrical conductivity (EC_e), which under both treatments kept increasing with time, thus reflecting salt accumulation in the profile, particularly at the surface. However, regardless of type of irrigation water, all plots exhibited a temporal pH increase since both types of irrigation water had higher pH values (7.9) compared with the soil (6.94 in 0.01 $CaCl_2$). DTPA-extractable Zn concentrations were extremely low, averaging 0.65 and 0.44mg L^{-1}, respectively throughout the well water and wastewater-irrigated sites.

Hayes *et al.* (1990) found that effluent, as compared with potable water, irrigation at Arizona increased soil EC_e by 0.5dS m^{-1}, NO_3^- by 7.8mg kg^{-1}, P by 31.7mg kg^{-1}, K by 134mg kg^{-1}, Na by 138mg L^{-1}, and exhangeable sodium percentage (ESP) by 6.8. Soil Ca+Mg concentrations were greater under effluent irrigation but decreased during the study period, thus reflecting replacement of these elements with Na at the exchange sites. Meanwhile, soil pH and the levels of DTPA-extractable Cu, Fe, Mn and Zn were not significantly affected by irrigation source and are collectively displayed in Appendix 2. Shatanawi *et al.* (1994) concluded that effluent irrigation induced a slight increase in soil solution pH, EC_e, P, K and NO_3^-, and a reduction in Mg and Cl^-.

Allhands *et al.* (1995) recorded an exponential decrease with soil depth in OM, CEC and available P under effluent water irrigation. Jiménez-Cisneros (1995) reported that wastewater from the Valley of Mexico was a good source of water for irrigation purposes in the arid zone of the Valley of Mezquital. It furnished the soil with OM and nutrients (mainly N and P) required for agriculture. El Hamouri *et al.* (1996) pointed out that under arid and saline conditions, waste stabilization pond effluent had the advantage of attenuating the detrimental effect of irrigation water salinity on crop. In addition to this, effluent irrigation increased the concentrations of the macro-nutrients N, P and K in soil. Smith *et al.* (1996) studied the effect of irrigation with secondary treated municipal effluent on accumulation of heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) in soil. They concluded that effluent irrigation didn't bring about any increases in the concentrations of EDTA-extractable metals at either site. In addition, metal concentrations were still within the normal 'background' ranges reported for Australian soils. Soil pH (0.01 M $CaCl_2$) and EC were significantly decreased in all horizons to a depth of 150cm at a site under 4 years of effluent irrigation and significantly increased at another site under 17 years of effluent irrigation. However, no differences between the site under 17 years of effluent irrigation and the control were observed below 40cm of depth.

2.2 Plant

Day and Tucker (1977) found that wastewater-irrigated sorghum produced higher grain yields than sorghum irrigated with well water plus N, P and K in amounts equal to those present in wastewater. Jame *et al.* (1984) reported various percentages of relative crop yield depression under wastewater irrigation in the various soil types studied. Papadopoulos and Stylianou (1991 and 1988) found that effluent was generally superior to fresh water in increasing yields. With no supplementary N additions, effluent affected higher sunflower and seedcotton yields, and petiole and laminae N concentrations. Khattari and Jamjoum (1988) concluded that effluent irrigation at Queen Alia International Airport (Jordan) affected an increase in the concentrations of N, P and K and thus total dry matter yield of sweet corn, while it had no contribution to heavy metal input to soil or sweet corn (Appendix 1). Neilsen *et al.* (1989) found no major horticultural limitations in the successful establishment and growth of effluent-irrigated apple cultivars which were characterized by improved N, P and K nutrition, increased trunk diameter, and increased yield and fruit number in the first two years of yield measurement. Based on these results, they concluded that wastewater irrigation could be similar in effect to continuous fertigation with dilute concentrations of several important plant nutrients. Neilsen *et al.* (1991) examined response of sweet cherry orchards to wastewater irrigation. They found that ranges of annual sweet cherry leaf micronutrient means for B, Cu, Fe, Mn and Zn were 55-69, 5.9-8.2, 63-100, 42-124 and 4.7-9.4mg kg^{-1}, respectively. Neither soil, nor plant tissue Cd or Pb was included in this study.

Shatanawi *et al.* (1994) reported enhanced eggplant availability of the micronutrient cations (Cu, Fe, Mn and Zn) and the heavy metals Cd, Cr and Pb under effluent irrigation (Appendix 3). In addition, eggplant leaf and fruit concentrations of N, P, K, Na, Ca and Mg proved higher under effluent, rather than under fresh, water irrigation. Under both treatments, plant fruit content of Cu, Fe, Mn, Zn, Pb and Cd was still within normal ranges (Appendix 3). Allhands *et al.* (1995) reported a linear increase in bermudagrass dry matter yield and uptake of N and K with harvest interval under effluent irrigation. Jiménez-Cisneros (1995) found that yields of effluent-irrigated alfalfa and corn were well above the national mean under fresh water irrigation. El Hamouri *et al.* (1996) pointed out that effluent, which had an EC of 2.94dS m^{-1} in comparison with groundwater having an EC of 5.04dS m^{-1}, affected increased yields of the salt sensitive cucumber and turnip as well as yields of the salt tolerant alfalfa, corn, coursettes, beans and tomatoe crops. Fardous and

Jamjoum (1996) studied response of sweet corn to effluent irrigation and found that total sweet corn dry matter, vegetative and grain yields increased with effluent application rate and that no significant differences in N and P concentrations of corn leaves or grains were observed. In addition, no substantial differences in concentrations of heavy metals in leaves or seeds were observed between the various treatments. Concentrations of heavy metals in corn tissue corresponding to the 100% of class A pan evaporation treatment are given by Appendix 4. Soil chemical characteristics after sweet corn crop harvest are presented and discussed in the Discussion chapter.

2.3 Olive Trees (*Olea europaea* L.)

The olive (*Olea europaea* L.) is a broad-leaved evergreen tree in the family Oleaceae. There are about twenty species of Olea found in the tropical and subtropical regions of the world, but edible fruits are produced only by varieties of *Olea europaea* L. Olive trees are adaptable to a wide range of soil types and conditions, including both acid and alkaline soils. In addition, olives are quite tolerant of high salinity conditions and will survive under long periods of very low soil moisture. The olive fruit is a drupe, maturing for table-olive processing from late September through November. Olive fruits to be utilized for oil production are allowed to remain on the tree until winter (late

November) when they have become completely black and have attained their highest oil content. Alternate bearing is one of the chief problems wherever olives are grown. A very high fruit set in one year is followed invariably by little or no crop the next (Childers, 1966).

Supplementary irrigation, distributed during critical stages of fruit growth, particularly during mesocarp cell enlargement, increases fruit weight, percent flesh, overall tree production and oil yield. However, percent oil content in the pericarp usually decreases under fully-irrigated conditions because of a proportionally larger increase in fruit water content (Inglese *et al.*, 1996). Evergreen fruit trees like olives are extremely sensitive to ESP. The range of ESP at which these trees are affected is 2.0 to 10.0 (Follet *et al.*, 1981). In addition, among fruit trees, olive is considered moderately tolerant to salinity (Pescod, 1992; Therios and Misopolinos, 1988; and Ayers and Westcot, 1985). It was reported that olive productivity was only reduced by 10% when EC_e was 4.0-6.0dS m^{-1} and that this value could be as high as 6.0-8.0dS m^{-1} in soils rich in Ca (Therios and Misopolinos, 1988). However, while Follet *et al.* (1981) classify olive trees as tolerant of soil salinity of 6.0 to 8.0dS m^{-1}, olive yield reductions of 10, 25, and 50% have been reported to be induced respectively by EC_e values of 4, 5 and 8dS m^{-1} (Fernández, 1997). Cresti *et al.* (1994) found that salt treatments of 0, 10, and 120mM NaCl (0, 10 and 120me Na^+ L^{-1}) did not affect fruit drop and size while yield of salt-treated plants was decreased with respect to control plants. Therios and Misopolinos (1988) found that no toxicity symptoms (foliar injury) appeared at four tested NaCl concentrations (0, 15, 30 and 45me NaCl L^{-1}) in the growing medium on most of the examined olive cultivars. However, at NaCl concentrations greater than 60me L^{-1}, olive leaf edges turned chlorotic, then died peripherally and subsequently started to drop.

Though regarded as one of the crops most sensitive to B deficiency (Shorrocks, 1997), olive is classified as a fruit crop semitolerant to B where semitolerancy corresponds, by convention, to 2.0mg B L^{-1} in irrigation water and 1.0-5.0mg B L^{-1} in soil saturation extract (Gupta *et al.*, 1985). However, a value higher than 0.33mg kg^{-1} hot water soluble B of soil (i.e. 0.165mg B L^{-1} in saturation extract) was found sufficient for the olive crop. Concentrations of B in olive leaves less than 20mg kg^{-1} of dry matter correspond to insufficient B nutrition and deficiency symptoms become apparent and distinct for concentrations less than 10mg kg^{-1} of dry material (Tsadilas *et al.*, 1994).

One-year old olives of the Manzanillo cultivar were grown in pots and irrigated for 8 months with untreated wastewater (raw sewage). During the study period, growth was enhanced and tissue Ca and N content proved to have been increased. In addition, no toxicity symptoms or any other anomaly were observed (Fernández, 1997).

3. MATERIALS and METHODS

3.1 Study Site

Khirbit Es-Samra is part of the Amman-Zerqa basin which encloses an area approximately 450 km^2 and consists of two other districts besides Samra, namely, Dhuleil and Hallabat (Bajjali, 1997). The subject of our study, Khirbit Es-Samra Treatment Plant lies about 40 km North East of the capital Amman, and was constructed on a basaltic flat upland area in the central lower part of Wadi Dhuleil (El-Sallag, 1996).

3.2 Climate

The microclimate of the study area is arid Mediterranean with cool, moist winters and hot, dry summers. Over a period of 19 years, the average precipitation, evaporation, relative humidity, and average temperature were 150mm year^{-1}, 1500mm year^{-1}, 55%, and 17.4°C, respectively (Bajjali, 1997; El-Sallag, 1996; and RSS, 1995).

3.3 Soil Characteristics

According to Shatanawi *et al.* (1994), the soil of the study site is fine, mixed, thermic family of xerochreptic calciorthids. The upper 20cm of the soil is clay loam (Shatanawi *et al.*, 1994; and Fardous and Jamjoum, 1996) while the textural class of the subsoil is clay with moderately hard calcareous concretions.

3.4 Sample Collection

The planted fields, both at STP and reference, were arbitrarily divided into five plots. Triplicate soil and olive leaf and fruit samples were randomly collected from each for two successive seasons, namely 1996/1997 and 1997/1998. Reference site is a private olive orchard that lies nearly 7km north west of STP and nearly 1km north of Zerqa stream.

Soil samples were collected at 15-cm-depth increments down to 75cm at three sites for each plot at both fields using a local-made auger. Composite olive leaf and fruit samples were collected late in November, during olive fruit collection, from a number of different trees out of each designated site per plot.

Water samples were collected from a reference irrigation well during both years. Chemical characteristics of this well water are given in Table1. No effluent samples were collected due to the availability of pertinent information regarding its chemical characteristics. These were collected from various references and are collectively given in Table 2.

3.5 Sample Analysis

3.5.1 Chemical Analysis of Reference Well Water

Collected reference irrigation water samples were analyzed according to standard methods (American Public Health Association, 1985) and analysis results are displayed in Table 1.

Table 1. Chemical characteristics of reference orchard irrigation water.

Parameter	Unit	Year	
		1996	1997
pH		7.86	7.96
EC	dS m^{-1}	5.56	5.54
Na^+	ppm	294.1	292.3
K^+		14.6	15.2
Ca^{2+}		326.8	326.2
Mg^{2+}		314.5	316.1
CO_3^{2-}		bd $^{(1)}$	bd $^{(1)}$
HCO_3^-		381.4	390.5
Cl^-		1460.3	1438.5
NO_3^-		284.56	238.73
SO_4^{2-}		248.85	261.9
PO_4^{3-}		bd	bd
SAR	$(me\ L^{-1})^{1/2}$	2.78	2.76
Cu^{2+}	ppm	bd	bd
Fe^{2+}		bd	bd
Mn^{2+}		0.027	0.017
Zn^{2+}		bd	bd
Cd^{2+}		bd	bd
Pb^{2+}		bd	bd

(1) Below detection.

3.5.2 Khirbit Es-Samra Treatment Plant Effluent

Table 2. Chemical characteristics of Khirbit es-Samra Treatment Plant (STP) effluent.

Parameter	Unit	91/92 (1)	93 (3)	95/96 (4)	96 (6)	98 (7)
pH		8.0	7.4	7.78	7.8	8.0
EC	dS m^{-1}	2.056	2.5	2.318	1.82	-
DO (8)	ppm	2.2	-	5.1	-	4.0
TSS		153	-	127	-	108
TDS		1236 (2)	-	1220	1166	1134
Total N		95 (2)	-	-	-	88
NH_4^+-N		79	105	81	87.9	70
NO_3^--N		0.4	57	3.9-4.3	0.51	19
Total P		17.5 (2)	-	-	-	19
PO_4^{3-}-P		8.88 (2)	28	42-49 (5)	18.8	14
Na^+		220 (2)	268	218	-	-
K^+		-	1.1	-	-	-
Ca^{2+}		107 (2)	251	103	100	92
Mg^{2+}		28 (2)	45	25	-	-
Cl^-		339 (2)	355	342	355	373
HCO_3^-		-	920	851	854	787
SO_4^{2-}		40	49	25	23.9	24
SAR	$(me\ L^{-1})^{1/2}$	4.84	5.6	4.96	-	8.0

Table 2. Chemical characteristics of STP effluent (Continued).

Parameter	Unit	91/92 (1)	93 (3)	95/96 (4)	96 (6)	98 (7)
B	ppm	0.69 (2)	-	0.53	0.52	1.0
Cu		-	0.013	0.03	-	-
Fe		-	0.333	0.42-0.23 (5)	-	-
Mn		-	0.067	0.07-0.16 (5)	-	-
Zn		0.042 (2)	0.035	0-0.002 (5)	-	-
Cd		< 0.01	0.006	0.04-0.008 (5)	-	-
Pb		< 0.05	-	0.01-0.012 (5)	-	-

(1) Tabulated data are average readings of at least nine samples collected on a monthly basis (RSS, 1995).

(2) Source: RSS, 1994.

(3) Source: Shatanawi *et al.*, 1994 (Tabulated data are average readings of three samples).

(4) Source: RSS, 1996. Tabulatd data are averages of at least 6 measurements covering the period March, 1995 through February, 1996.

(5) Source: Gedeon, 1996. Given ranges correspond respectively to the lower and higher detected concentrations in the years 1995 and 1996.

(6) Source: Fardous and Jamjoum, 1996.

(7) Source: Water Authority of Jordan, 1998.

(8) Dissolved Oxygen.

3.5.3 Soil Analysis

Soil samples were air-dried at room temperature and ground to pass a 2-mm sieve. Plant available trace elements (Cu, Fe, Mn, Zn, Cd and Pb) were determined by Atomic Absorption Spectrophotometry (AAS) after Diethylene Triamine Pentaacetic Acid (DTPA) extraction (Lindsay and Norvel, 1978).

Soil solution was analyzed for pH, EC_e, and major soluble ions (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, B, Na^+, K^+, Ca^{2+}, Mg^{2+} and NO_3^-) using the saturated paste extract (Rhoades, 1982). 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 1.0N ammonium acetate extraction (Knudsen and Peterson, 1982). Soil OM content was determined using wet oxidation of dichromate according to the Walkley-Black procedure (Nelson and Sommers, 1982) and CEC by NH_4^+ saturation and Na^+ displacement (Chapman, 1965).

The salicylic acid-thiosulfate modification of the regular Kjeldahl method was adopted both for soil and plant total N determination (Bremner and Mulvaney, 1982).

Tabulated EC_e values have been standardized to 25 °C using the equation $EC_{298.15} = EC_t \times (f_t)$, where f_t is a temperature coefficient that can be determined from the relation $f_t = 1 + 0.019\,(t - 298.15)$ and t is the temperature, in degrees Kelvin, at which experimental measurement was made (United States Salinity Laboratory Staff, 1954).

3.5.4. Plant Analysis

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 Moulinex blender mixer to pass a 20-mesh screen. The resultant powder was wet-digested using, preferentially, a 1:4 acid mixture of $HClO_4$ and H_2SO_4 acids for trace element analysis (Cajuste *et al.*, 1991). This allows for the simultaneous AAS determination of the micronutrients and heavy metals.

The anions Na^+, K^+, NO_3^-, SO_4^{2-}, PO_4^{3-} and Cl^- were analysed according to the method of Bradfield and Cooke (1985). In this method, oven-dried and finely-ground plant leaves were extracted with distilled water at a ratio of 0.1g: 5ml for 30 minutes at 70°C, filtered through Whatman 541 paper and washed with further 5ml of water.

B in plant leaf and fruit tissue was determined according to the carmine method after dry ashing at 450°C and dissolving the ash in 6N HCl (Jones *et al.*, 1991; and Hamzé *et al*, 1984).

Olive fruits were analyzed for fruit mass and oil percentage as reflectives of yield and for elemental content as an indicator of plant uptake. Fruit fresh weight was determined on 100 fruits per sampling site. Tabulated data correspond to average fresh weight of the single fruit after pit removal (fruit fresh flesh weight). After pit removal, fruits were dried at 105°C for 3 hours and the dry material was electrically ground (using a Moulinex blender mixer) to assure sample homogeneity before subsequent analysis. Apart from fruit fat percentage (dwb) which was determined after soxhlet extraction with a mixture of 1:1 diethyl and petroleum ethers (Paquot, 1979), all other fruit parameters were analyzed following the same procedures used in leaf analysis. In order to further ascertain edibility of olive oil produced from both fields, ether-extracted olive oil from both fields was digested as mentioned above and analyzed for Pb and Cd.

With the exception of Na^+ and K^+, standards for each metal studied (Ca, Mg, Cd, Cu, Fe, Mn, Pb and Zn) were prepared from purchased certified 1000mg L^{-1} element standards (High Purity Analytical Reagent; Gainland Chemical Company (GCC), UK). Standards of a given metal were prepared in a matrix containing fixed quantities of the other metals. Sodium and potassium ions were determined by flame photometry, and Ca, Mg, Cu, Fe, Mn, Zn, Cd and Pb by AAS. Lanthanum, and Li solutions were added as suppressant solutions in the analysis of Ca^{2+} and Mg^{2+}, and Na^{+} and K^{+}, respectively (Rhoades, 1982). Chloride was determined by $AgNO_3$ titration (Mohr method). B was determined spectrophotometrically using the carmine procedure (Bingham, 1982), and SO_4^{2-} was determined by difference between sum of total soluble cations and anions.

3.5.5 Statistical Data Analysis

Soil and plant analysis results were statistically treated as follows:

(1) averages and standard deviations were calculated for the three replicates of each sampling site of both studied fields, and

(2) resultant averages for each of the five sampling sites of each field were treated as replicates and hence subjected to average and standard deviation calculation. Accordingly, tabulated overall averages and standard deviations of each and every parameter correspond to those of 15 individual measurements at each field.

4. RESULTS and DISCUSSION

4.1 Irrigation Water

4.1.1 Reference Well Water

No detectable concentrations of B, Cu, Fe, Zn, Cd, Pb, PO_4^{3-} and CO_3^{2-} in reference well water were found (Table 1). This well water had EC values of 5.56 and 5.54dS m^{-1}, and SAR values of 2.78 and 2.76 (me $L^{-1})^{1/2}$ in 1996 and 1997 irrigation seasons, respectively. While according to Rhoades *et al.* (1992), this water is classified as moderately saline, it reflects very high salinity and low sodium hazards once subdued to irrigation water quality classification (USSL, 1954). No P was detected in this well water. Shallow groundwater normally has low concentrations of P, with values ranging from 0.005 to 0.1mg P L^{-1} and typical concentrations of < 0.005mg P L^{-1} (Reneau *et al.*, 1989).

Reference well water had a NO_3^- concentration more than 5 times the WHO upper limit of 45mg NO_3^- L^{-1} for drinking water (WHO, 1984), and more than 7.5 times the 30mg NO_3^- L^{-1} corresponding, according to Ayers and Westcot (1985), to severe restriction on use for irrigation purposes. Extremely high NO_3^- concentrations are nothing rare or unusual downstream of STP where our reference field is located. Bajjali (1997) reported NO_3^- concentrations as high as 324mg L^{-1} in one of the downstream wells. Chloride ion concentration of this water was in excess of 1400mg L^{-1} (1460.3 and 1438.5mg L^{-1} respectively in 1996 and 1997). Such elevated concentrations are nothing uncommon in the study area and are ascribed mainly to dissolution of Cl^--type minerals accumulating either in the surface soil or deposited in subsurface geological formation (Bajjali, 1997). Royal Scientific Society (1996) reported 6 out of 7 monitoring wells downstream of STP to have Cl^- concentrations in excess of 1000mg L^{-1} while the remainder well had a Cl^- content of 964mg L^{-1}. Additional support of these findings was delivered by Bajjali (1997) who reported Cl^- concentrations to range from 1000 to 2000mg L^{-1} in wells of Dhuleil, Hallabat and Khirbit Es-Samra areas where agricultural activities are widespread.

If we combine the effects of reference well water EC and SAR values, we reach to the conclusion that no water infiltration problems are due to be forced upon soil by such irrigation water. Contrariwise, however, severe restriction on irrigation use of this water is imposed by the individual effects of its EC and extremely elevated concentrations of Na^+, Cl^-, HCO_3^- and NO_3^-.

In light of the discussion thus far, it turns out that reference well water deviates sharply from suitability for drinking and irrigation uses.

4.1.2 Khirbit Es-Samra Treatment Plant Effluent

While reference well water scored higher values than STP effluent of EC and Na^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, and SO_4^{2-} concentrations, available data on STP effluent chemical characteristics reveal higher values of all other tested parameters than this reference well water.

According to Rhoades *et al.* (1992) and based on EC values, (Table 2), Khirbit Es-Samra Treatment Plant effluent water used to fall in the moderate salinity classification. An exception was in 1996 when a shift towards slight salinity was reported. If the USSL (1954) classification of irrigation water was adopted, Khirbit Es-Samra Treatment Plant effluent would be classified as an irrigation water of high salinity and low sodium hazards.

However, if we decide to examine compliance of STP effluent characteristics with the local effluent irrigation guideline 893/ 1995 (Appendix 5), we come to the conclusion that:

1. Effluent pH and SAR values, and DO, TSS, TDS, N, Ca^{2+}, Mg^{2+}, SO_4^{2-}, B, Cu, Fe, Mn, Zn and Cd concentrations fit use for irrigation of all types of crops.

2. Nitrate concentrations reflected slight deviation from suitability for irrigation purposes in the years 1993 and 1996. The high NH_4^+ concentration of STP

effluent elucidates the effect of high organic loads on treatment efficiency. Higher amounts of N exist in the NH_4^+, rather than NO_3^-, form thus indicating dominance of anaerobic conditions and accordingly limited nitrification (RSS, 1996; Tuffaha, 1996; and Shatanawi *et al.*, 1994).

3. Concentration of Na^+ did only in 1993 render STP effluent non-suitable for irrigation purposes.

4. Concentration of Cl^- deviated slightly in 1993 and 1996 from suitability for irrigation purposes.

5. Except in 1992/1993, bicarbonate concentrations did always render STP effluent non-suitable for irrigation use. This might, as a matter of fact, be ascribed to the high bicarbonate concentrations in drinking water sources in the study area where potable water supplies are derived primarily from carbonate (limestone and dolomite) aquifers (Bajjali, 1997; El-Sallag, 1996; and Prösl and Rimawi, 1986).

In addition, once we subject STP effluent characteristics to comparison with guidelines of Ayers and Westcot (1985), (Appendix 6), we reach to the conclusions that:

1. Effluent pH values do always fall within normal ranges identified for irrigation water.

2. Available EC values entail slight to moderate restriction on irrigation use of this effluent.

3. The combined effect of effluent SAR and EC values promises no infiltration problems and hence pose no restriction on irrigation use.

4. Data available for all years assure that the individual effect of Na^+ concentration exerts severe restriction on effluent use for sprinkler, and only slight to moderate restriction for surface irrigation purposes. As regards Cl^-, slight to moderate restriction on sprinkler irrigation was posed in all years while for surface irrigation purposes, severe restriction on use was posed in the years 1993, 1996 and 1998, and only slight to moderate in the years 1991/ 1992 and 1995/ 1996.

5. Effluent use in irrigation with respect to B concentration was safe except in 1998 when effluent B posed slight to moderate restriction on effluent irrigation use.

6. Except in 1998, effluent HCO_3^- and NO_3^- burdens dictate severe restriction on effluent irrigation use.

7. Heavy metal loads were always below recommended maximum, except in 1994 when Cd concentration was four times the maximum recommended, perhaps due to some non-controlled discharge of industrial wastewater to the sewerage system.

What explains low levels of heavy metals in STP effluent is that most of the heavy metals in sewage end as hydroxide, carbonate and phosphate precipitates in the sludge (Bouwer and Chaney, 1974).

In brief, Khirbit Es-Samra Treatment Plant effluent is rendered non-suitable for irrigation purposes due to high NO_3^- and HCO_3^- contents. In addition, captive of the somewhat fluctuating EC values and high Na^+ and Cl^- concentrations, degree of restriction on STP effluent use for irrigation purposes oscillates between slight to moderate and severe.

4.2 Soil

4.2.1 Results

Effluent irrigation increased soil pH and soil solution concentrations of B and K^+, as well as exchangeable K, available P, and DTPA-extractable Fe and Pb. Under both types of irrgation water, DTPA-extractable Cd was below detection. Reference soil had higher OM, total N, and DTPA-extractable Cu, Zn and Mn concentrations. Furthermore, in deep harmony with differences in the chemical compositions of both types of irrigation water and with its respective one, reference well water had higher, than STP, soil solution EC_e, and Na^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, NO_3^- and SO_4^{2-} concentrations, (Tables 3 through 6).

Tracing variations in all tested soil parameters from first sampling year to second reveals that reference soil did in 1997 score higher values of

DTPA-extractable Pb, and soil solution pH and B and less OM content and soil solution NO_3^-, Cl^- and Na^+ concentrations than in the first sampling year. Meanwhile, reference soil had very nearly the same total N in the two sampling years throughout the whole soil profile sampled. In 1997, reference surface soil had higher EC_e value, soil solution Ca^{2+}, DTPA-extractable Fe and Zn and lower SO_4^{2-} concentrations compared with 1996. In addition, its main root zone had higher soil solution K^+ and HCO_3^-, and DTPA-extractable Cu and Mn and less exchangeable K and solution Mg^{2+} concentrations in 1997 than in 1996.

Khirbit es-Samra soil had higher values of available P and soil solution pH and B, and lower OM content and DTPA-extractable Cu, Fe and Zn in 1997 than in 1996. Main root zone of STP soil had higher EC_e values and concentrations of exchangeable K and soil solution Na^+, K^+, Mg^{2+}, Cl^-, HCO_3^-, NO_3^- and SO_4^{2-} in 1997 than in 1996. In addition, no variations in whole soil profile content of total N and DTPA-extractable Pb concentrations in both sampling years were observed at STP field.

High concentrations in soil main root zone of such parameters as soil solution Na^+, Ca^{2+} and Mg^{2+}, DTPA-extractable heavy metals, exchangeable K and $NaHCO_3$-extractable P relative to lower depths at either site in either year are much expected to be reflections of recent inputs by irrigation water on the one pan of the balance and the relatively limited downward movement of which on the other. Soil solution Na^+, Cl^-, SO_4^{2-} and B concentrations of reference, and only Na^+, Cl^- and B of STP, soils were found to follow the distribution patterns of their respective EC_e values. This indicates that Na^+ and Cl^- are the main components of soil salinity at both fields on the one hand and pinpoints strong correlation between B and salinity on the other. In addition, soil salinity followed a general trend of increase with depth at both fields. This is quite sufficient an indicator that soils of both fields are well-drained and/or well-leached.

Table 3. Overall average and standard deviation of reference soil chemical properties in 1996.

Depth	pH	EC_e	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	NO_3^-	SO_4^{2-}	SAR
cm		dS m^{-1}	me L^{-1}								
0-15	8.54	3.75	24.16	0.44	8.29	7.85	16.34	4.05	2.84	17.52	8.51
	0.104	0.512	3.364	0.094	1.085	1.282	3.169	0.645	0.864	2.820	0.862
15-30	8.48	5.13	27.57	0.30	10.95	10.56	22.57	4.59	3.44	18.76	8.38
	0.137	0.833	6.650	0.056	2.164	1.974	8.633	0.738	0.707	2.094	1.549
30-45	8.38	5.92	33.46	0.25	12.42	12.27	27.47	4.65	4.34	21.81	9.54
	0.050	0.873	3.886	0.050	2.057	2.000	6.103	0.809	2.146	2.961	0.804
45-60	8.31	6.46	35.37	0.28	12.93	12.76	31.56	4.50	3.50	21.80	9.82
	0.089	1.423	7.149	0.093	1.913	1.600	7.402	0.368	0.926	2.137	1.355
60-75	8.29	7.02	39.59	0.27	14.03	13.23	35.68	4.73	4.13	22.56	10.69
	0.103	0.887	6.368	0.061	1.513	1.843	6.795	0.184	0.795	3.379	1.201

Table 3. Overall average and standard deviation of reference soil chemical properties in 1996 (Continued).

Depth	O.M	N	P	K	B	Cu	Fe	Mn	Zn	Pb
cm	% w/ w		ppm							
0-15	2.67	0.11	17.15	16.95	0.48	1.28	4.17	12.71	2.57	0.47
	0.432	0.018	0.823	0.466	0.092	0.500	0.227	1.152	0.929	0.040
15-30	1.96	0.09	15.28	13.25	0.43	1.13	3.73	10.91	1.60	0.39
	0.424	0.011	1.228	0.535	0.126	0.375	0.322	1.597	0.777	0.021
30-45	1.37	0.07	13.01	8.51	0.46	0.93	3.43	9.73	1.20	0.33
	0.380	0.014	0.816	2.235	0.097	0.141	0.294	0.869	0.239	0.020
45-60	1.27	0.07	11.21	6.48	0.58	0.82	3.27	8.68	1.02	0.27
	0.382	0.016	1.038	0.663	0.108	0.117	0.226	1.103	0.270	0.027
60-75	1.14	0.06	10.13	5.52	0.72	0.79	3.40	7.25	0.79	0.23
	0.312	0.013	0.491	0.537	0.052	0.106	0.733	0.839	0.226	0.029

Table 4. Overall average and standard deviation of reference soil chemical properties in 1997.

Depth	pH	ECe	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	NO_3^-	SO_4^{2-}	SAR
cm		dS m^{-1}	me L^{-1}								
0-15	8.55	3.83	21.70	0.46	8.49	8.31	13.86	5.04	2.74	17.31	7.53
	0.077	0.334	1.896	0.061	1.362	1.969	2.841	1.106	1.014	3.858	0.572
15-30	8.52	4.72	25.65	0.36	10.54	10.59	20.90	4.61	2.14	19.59	7.89
	0.110	0.553	2.584	0.062	1.082	1.357	4.159	0.600	0.890	1.319	0.535
30-45	8.43	5.39	30.62	0.25	11.84	11.44	26.74	4.85	2.36	20.26	8.97
	0.042	0.388	3.446	0.105	1.084	1.115	4.979	0.967	0.958	2.959	0.808
45-60	8.38	5.62	32.76	0.20	12.10	11.90	29.44	4.25	2.59	20.69	9.43
	0.040	0.881	6.182	0.118	2.129	1.464	7.562	0.592	0.936	4.060	1.190
60-75	8.35	6.45	35.33	0.20	13.59	12.48	33.69	4.50	2.39	21.05	9.78
	0.054	0.818	4.927	0.087	1.631	0.903	4.498	0.293	1.019	3.329	1.184

Table 4. Overall average and standard deviation of reference soil chemical properties in 1997.

Depth	O.M	N	P	K	B	Cu	Fe	Mn	Zn	Pb
cm	% w/ w		ppm							
0-15	2.58	0.11	17.28	16.68	0.55	1.35	4.20	13.00	2.66	0.46
	0.423	0.018	0.602	0.661	0.104	0.594	0.311	1.406	1.017	0.028
15-30	1.88	0.09	15.53	13.11	0.50	1.21	3.67	11.25	1.53	0.42
	0.439	0.014	1.405	0.366	0.144	0.428	0.206	2.036	0.694	0.042
30-45	1.31	0.07	13.25	8.81	0.52	0.99	3.38	9.66	1.23	0.38
	0.365	0.016	0.934	2.263	0.113	0.198	0.200	0.893	0.323	0.011
45-60	1.21	0.06	11.48	6.55	0.66	0.82	3.32	8.87	1.07	0.30
	0.381	0.014	1.108	0.586	0.126	0.065	0.292	0.901	0.288	0.018
60-75	1.12	0.06	10.50	5.53	0.82	0.74	3.29	7.21	0.78	0.25
	0.302	0.013	0.867	0.593	0.061	0.188	0.843	0.947	0.226	0.021

Table 5. Overall average and standard deviation of STP soil chemical properties in 1996.

Depth	pH	EC$_e$	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	Cl$^-$	HCO$_3^-$	NO$_3^-$	SO$_4^{2-}$	SAR
cm		dS m^{-1}	me L^{-1}								
0-15	8.52	1.82	13.16	0.46	4.18	2.22	10.61	3.51	2.28	3.46	7.63
	0.116	0.461	2.586	0.079	1.494	0.769	1.888	1.159	1.257	0.782	0.846
15-30	8.50	1.85	12.86	0.39	3.89	2.12	10.61	3.31	2.11	3.12	7.65
	0.105	0.494	2.231	0.076	1.184	0.598	2.420	0.615	0.689	0.643	0.668
30-45	8.48	1.80	13.04	0.36	3.69	1.95	10.17	3.70	1.80	3.24	7.98
	0.108	0.721	3.135	0.084	1.393	0.625	3.308	0.422	0.688	0.634	1.296
45-60	8.42	2.17	14.98	0.33	4.13	2.35	12.75	3.55	2.10	3.34	8.84
	0.106	0.452	0.762	0.068	1.787	0.828	2.032	0.574	0.729	0.605	1.179
60-75	8.38	2.54	17.28	0.38	4.68	2.60	14.70	3.32	2.77	4.15	9.56
	0.054	0.318	1.198	0.081	1.694	0.868	2.108	0.456	0.693	1.474	1.240

Table 5. Overall average and standard deviation of STP soil chemical properties in 1996 (Continued).

Depth	OM	N	P	K	B	Cu	Fe	Mn	Zn	Pb
cm	% w/ w		ppm							
0-15	1.55	0.06	124.30	38.89	1.05	1.15	5.12	9.69	2.17	1.33
	0.188	0.008	9.406	2.123	0.330	0.101	1.109	0.958	0.680	0.155
15-30	1.01	0.04	98.08	33.27	1.02	1.03	4.49	8.33	1.24	1.10
	0.118	0.004	15.474	1.877	0.138	0.039	0.508	1.000	0.384	0.057
30-45	0.80	0.04	74.11	27.78	1.09	0.89	4.67	7.05	1.01	0.94
	0.055	0.002	12.274	0.593	0.260	0.038	1.380	0.623	0.275	0.048
45-60	0.64	0.03	53.55	24.45	1.11	0.83	3.70	6.19	1.16	0.85
	0.081	0.003	6.676	0.671	0.241	0.057	0.281	0.616	0.593	0.050
60-75	0.51	0.03	38.94	21.68	1.30	0.75	3.55	5.36	0.76	0.75
	0.071	0.002	3.785	0.903	0.204	0.060	0.466	0.313	0.223	0.041

Table 6. Overall average and standard deviation of STP soil chemical properties in 1997.

Depth	pH	EC_e	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	NO_3^-	SO_4^{2-}	SAR
cm		dS m^{-1}	me L^{-1}								
0-15	8.59	2.71	17.13	0.55	6.04	3.28	15.10	4.03	3.67	4.14	8.629
	0.061	0.807	3.070	0.146	2.734	1.124	4.446	0.975	1.224	1.386	0.666
15-30	8.51	2.35	17.32	0.41	4.05	2.44	14.31	3.88	2.31	3.68	9.793
	0.081	0.394	2.701	0.061	1.278	0.565	2.613	0.450	0.525	0.716	1.448
30-45	8.47	2.18	15.98	0.31	3.69	2.13	12.51	3.60	2.59	3.45	9.490
	0.092	0.534	3.290	0.074	0.736	0.305	1.449	1.012	0.638	0.795	1.893
45-60	8.46	2.22	15.79	0.30	3.75	2.24	13.23	3.33	2.19	3.33	9.616
	0.068	0.353	1.261	0.096	0.600	0.481	1.268	0.449	0.340	0.593	1.061
60-75	8.46	2.33	16.99	0.28	3.72	2.31	13.55	3.26	2.48	4.02	10.041
	0.074	0.147	1.083	0.102	0.480	0.412	1.323	0.747	0.448	0.546	0.895

Table 6. Overall average and standard deviation of STP soil chemical properties in 1997 (Continued).

Depth	OM	N	P	K	B	Cu	Fe	Mn	Zn	Pb
cm	% w/ w		ppm							
0-15	1.46	0.06	130.51	41.86	1.05	1.11	5.09	9.76	1.70	1.32
	0.178	0.008	11.535	1.216	0.337	0.090	1.033	1.235	0.969	0.071
15-30	0.97	0.04	101.64	34.80	1.06	1.02	4.44	8.15	1.19	1.09
	0.107	0.004	15.436	0.743	0.191	0.082	0.688	1.022	0.527	0.067
30-45	0.74	0.03	75.59	29.12	1.12	0.87	3.86	6.85	0.87	0.94
	0.068	0.004	11.037	0.923	0.235	0.040	0.572	0.648	0.241	0.035
45-60	0.61	0.03	55.11	24.36	1.20	0.78	3.41	6.16	0.86	0.84
	0.075	0.003	6.636	0.480	0.320	0.044	0.374	0.672	0.227	0.048
60-75	0.50	0.03	39.93	21.23	1.50	0.70	3.03	5.18	0.69	0.74
	0.056	0.002	2.079	0.594	0.309	0.040	0.491	0.582	0.192	0.050

4.2.2 Long-Term Impact

To decide on long-term effects of effluent irrigation on STP soil chemical properties, overall averages of soil analysis results, (Tables 5 and 6), will be compared with results of the two earlier studies conducted at STP that I had access to (Fardous and Jamjoum, 1996; and Shatanawi *et al.*, 1994), (Table 7). Before we proceed in comparisons, several points should be pointed out. First, the first study was conducted on a virgin soil not previously cropped to any crop or exposed to effluent application (Shatanawi *et al.*, 1994). Accordingly, results obtained before the first effluent application and eggplant growing will be addressed as 'background concentrations' against which to compare our results. Second, the second study (Fardous and Jamjoum, 1996) was conducted at the same site nearly three months after termination of the first. Third, soil samples were in the second study only collected from the depths 0-10 and 10-20cm. For this reason, average value of the two depths for each and every tested parameter was incorporated in Table 7. Fourth, the second study comprised three rates of effluent application treatments, correspondig respectively to 75, 100 and 125% of class A pan evaporation. Only results of the treatment corresponding to 100% of class A pan evaporation were adopted.

Table 7. Earlier data available on Khirbit es-Samra Treatment Plant (STP) soil chemical properties.

Parameter	Unit	Depth	1993 (1), (3)	1993 (1), (4)	1996 (2), (5)
pH		0-20	7.9	8.1	7.83
		20-40	8.1	8.3	-
		40-60	7.8	8.5	-
EC_e	$dS\ m^{-1}$	0-20	2.87	3.62	5.66
		20-40	3.51	2.87	-
		40-60	13.21	3.3	-
P	ppm	0-20	-	-	106
		20-40	-	-	-
		40-60	-	-	-
K	ppm	0-20	-	-	317
		20-40	-	-	-
		40-60	-	-	-
CEC	me/100g	0-20	18.7	-	-
		20-40	20.1	-	-
		40-60	-	-	-
$CaCO_3$	%	0-20	25.4	-	-
		20-40	26.6	-	-
		40-60	35.5	-	-

(1) Source: Shatanawi *et al.*, 1994.
(2) Source: Fardous and Jamjoum, 1996.
(3) Before the first application of watewater.
(4) After crop harvest.
(5) After crop harvest.

Table 7. Earlier data available on STP soil chemical properties (Continued).

Parameter	Unit	Depth	1993 (1), (3)	1993 (1), (4)	1996 (2), (5)
Na^+	me L^{-1}	0-20	19.6	20.1	25.89
		20-40	23.7	19.4	-
		40-60	83.5	25.9	-
K^+		0-20	0.2	0.4	1.08
		20-40	0.2	0.3	-
		40-60	0.6	0.2	-
Ca^{2+}		0-20	9.23	10.87	22.53
		20-40	9.44	6.13	-
		40-60	20.93	2.57	-
Mg^{2+}		0-20	4.94	3.96	10.02
		20-40	6.91	2.77	-
		40-60	25.17	1.18	-
HCO_3^-		0-20	3.3	3.3	3.1
		20-40	3.0	3.0	-
		40-60	3.0	3.7	-
CO_3^{2-}		0-20	1.0	-	-
		20-40	0.9	-	-
		40-60	1.0	-	-
Cl^-		0-20	18.3	17.0	30.6
		20-40	25.3	14.3	-
		40-60	104.4	18.5	-
NO_3^-		0-20	7.35	12.00	-
		20-40	5.68	8.09	-
		40-60	1.26	6.11	-
SO_4^{2-}		0-20	4.50	1.59	-
		20-40	4.85	14.60	-
		40-60	17.76	7.15	-
SAR	$(me\ L^{-1})^{1/2}$	0-20	7.38	7.38	10.02
		20-40	8.40	9.21	-
		40-60	17.48	18.26	-

Table 7. Earlier data available on STP soil chemical properties (Continued).

Parameter	Unit	Depth	1993 (1), (3)	1993 (1), (4)	1996 (2), (5)
B	ppm	0-20	-	-	2.6
		20-40	-	-	-
		40-60	-	-	-
Cu		0-20	0.599	1.678	0.44
		20-40	0.486	1.498	-
		40-60	0.456	1.316	-
Fe		0-20	4.507	0.703	6.8
		20-40	4.186	8.114	-
		40-60	3.719	7.684	-
Mn		0-20	3.895	7.526	3.8
		20-40	4.407	3.324	-
		40-60	3.717	5.240	-
Zn		0-20	0.562	2.42	2.4
		20-40	0.378	1.186	-
		40-60	0.348	1.188	-
Cd		0-20	bd (6)	0.066	0.20
		20-40	bd	0.072	-
		40-60	bd	0.068	-
Pb		0-20	0.350	0.800	bd
		20-40	0.260	0.560	-
		40-60	0.215	0.520	-

(1) Source: Shatanawi *et al.*, 1994.
(2) Source: Fardous and Jamjoum, 1996.
(3) Before the first application of watewater.
(4) After crop harvest.
(5) After crop harvest.
(6) Below detection.

Overall average soil solution pH data obtained in our study, (Tables 5 and 6), were generally higher than any recorded earlier. Raised soil solution pH values could be explained by leaching and/or precipitation of acidic salts such as gypsum. In addition, increases in soil solution pH values within all depth horizons sampled at STP are much, in effect, expected to have resulted from excessive olive tree uptake of NO_3^-, PO_4^{3-} and SO_4^{2-} and concurrent release of OH^- to solution in order to maintain electrical neutrality. Several earlier studies reported raised soil solution pH under effluent irrigation, e.g., Smith *et al.* (1996), Neilsen *et al.* (1991), White and Dornbush (1988), De Jong (1978), and Day *et al.* (1972). In addition to this, our results reveal no variation in soil solution pH from first sampling year to second and all pH values obtained comply with the fact that our studied soils are dominated by $CaCO_3$ which buffers soils in the pH range of 7.14 to 8.5 (Lindsay and Schwab, 1982).

Soil salinity, expressed as EC_e, turned out in our study to be somewhat less than was obtained in earlier studies. Concentrations of Na^+, Cl^-, and NO_3^- were much lower than reported earlier and may thus reflect soil losses of these ions through leaching and plant uptake. Soil HCO_3^- concentrations as reported in this study are very nearly comparable to earlier data. Practically no CO_3^{2-} was detected in our study. Free carbonate was detected by Shatanawi *et al.*

(1994) before the first effluent application to soil but never after. It seems that effluent inputs to soil of Ca^{2+}, Mg^{2+} and divalent heavy metals precipitated carbonates as respective metal carbonates. Potassium ion was somewhat higher in the first 60cm of STP soil profile once compared with results of Shatanawi *et al.* (1994), albeit the upper 20cm of the profile were reported by Fardous and Jamjoum (1996) to have even higher K^+ concentrations than either studies. Before the first effluent application, the upper 60cm of STP soil profile was reported to have nearly double the solution Ca^{2+} and Mg^{2+} contents obtained by our study in either 1996 or 1997 sampling years. Precipitation, primarily, of Ca^{2+} and Mg^{2+} carbonates, phosphates and sulphates on the long run and olive plant uptake of these secondary nutrients must have resulted in such difference.

With the exception of the 40 to 60cm depth before any effluent application and the 20 to 40cm depth at the end of eggplant growing season, slight additions of SO_4^{2-} appeared in this study to be induced by prolonged effluent irrigation.

Surface soil SAR values in this study are very nearly comparable to earlier data for the site while remainder depths have very much lower SAR values than any reported earlier. Sodium adsorption ratio of reference field soil exhibited a little decrease in 1997 from values obtained in 1996 while exactly the reverse was observed at STP field. Furthermore, whereas STP soil had lower SAR values in

1996 than the reference, right the reverse was observed in 1997, i.e. a gradual slow buildup of sodicity is taking place at STP field.

Overall average soil solution B concentration ranged from a minimum of 1.02mg L^{-1} (for the 15-30cm depth in 1996) to a maximum of 1.50mg L^{-1} (for the 60-75cm depth in 1997). According to the guidelines introduced in Appendix 12 (Walsh and Beaton, 1973), only sensitive crops may show visible injury symptoms once subdued to such B levels as recorded in this study. Reference field soil had B concentrations in the range 0.42-0.82mg L^{-1}. As soil solution B was found to increase with depth, it may be stated that the main root zone of reference soil has a B content that is satisfactory for all crops. At lower depths, howevwr, a shift towards the 'sensitive crops may show visible injury' condition is approached. Boron concentration increase down the profile bears out results of Ayars *et al.* (1993) who reported an increase in B concentration down the profile under saline drainage and low salinity irrigation water treatments.

Sodium bicarbonate-extractable P and exchangeable K in the upper 20cm of soil profile were extremely high (Fardous and Jamjoum, 1996) and far very much higher than reported in the first depth increment in our study. In the study and Zn concentrations, though higher than corresponding 'background' concentrations, reflected different accumulation patterns. Manganese was available to plant throughout the whole soil profile of STP field at concentrations much higher than any reported earlier. Zn concentrations within the first 60cm of 1996 soil profile were comparable to those reported by Shatanawi *et al.* (1994) at the end of eggplant growing season. In addition, they were much lower in 1997 than in 1996 soil samples, perhaps due to higher Zn than Mn requirements of olives. Whereas DTPA-extractable Cd concentrations were below detection before any effluent application to STP soil and marked an active existence after application, our study ended up with no detectable Cd concentrations. From an environmental point of view, soil sorption of Cd is a fast process: More than 95% of the sorption takes place within 10 minutes, equilibrium is reached in 1 hour, and exposure up to 67 weeks did not reveal any long term changes in Cd sorption capacities (Christensen, 1984). Detectable concentrations of DTPA-extractable Pb were documented before and after eggplant growing season by Shatanawi *et al.* (1994). The fact that DTPA-extractable Pb concentrations in both sampling years of our study are higher than any reported earlier provide strict evidence in support of Pb accumulation and buildup in soil due to extended effluent application.

Cation exchange capacity analyses were only carried out for the surface soil (0-15cm) and results are introduced in Tables 8 and 9. Lowest CEC value of STP soil was recorded to be 14.1me/ 100g for the fourth sampling site in 1996 and highest was 19.7me/ 100g for the second and fifth sampling sites in 1997. Overall average soil CEC values were significantly higher under effluent, rather than well, water irrigation, (Tables 8 and 9).

Table 8. Cation exchange capacity data. (1)

Field	Reference		STP	
Site	1996	1997	1996	1997
A1(2)	14.0	13.8	17.5	16.5
A2	14.5	13.5	18.2	18.1
A3	14.4	13.6	16.5	15.6
B1	16.3	15.9	19.7	19.2
B2	15.2	15.4	18.8	18.2
B3	16.0	15.0	18.2	18.1
C1	16.2	16.4	14.3	13.8
C2	17.1	16.2	15.5	15.9
C3	16.6	15.8	16.3	15.5
D1	16.6	16.6	14.4	14.7
D2	16.0	16.3	16.4	16.1
D3	16.3	16.2	14.1	15.4
E1	15.9	15.8	18.2	18.8
E2	16.0	16.1	19.5	19.7
E3	15.7	15.7	16.6	16.1

(1) Unit: me/100g.
(2) Letters A, B, C, D, and E stand for plots within main sampling fields.

Table 9. Cation exchange capacity data
(Average and standard deviation).

Site	Reference		STP	
Year	1996	1997	1996	1997
A(1)	14.3(2) 0.233	13.6 0.152	17.4 0.854	16.7 1.266
B	15.8 0.573	15.4 0.434	18.9 0.755	18.5 0.608
C	16.7 0.436	16.1 0.268	15.4 1.007	15.1 1.115
D	16.3 0.292	16.3 0.235	15.0 1.250	15.4 0.700
E	15.9 0.183	15.9 0.192	18.1 1.453	18.2 1.873

(1) Letters A, B, C, D, and E stand for plots within main sampling fields.
(2) Each and every value corresponds to the average of three replicates at the particular site.

In summary, Khirbit Es-Samra Treatment Plant soil had higher pH value, and soil solution B, K^+ and SO_4^{2-}, and DTPA-extractable Cu, Fe, Mn and Pb concentrations than any reported for the site. Of these, effect exerted on soil by long-term effluent irrigation was very much more pronounced on soil solution pH, B and K^+ and DTPA-extractable Fe and Pb concentrations.

4.2.3 Discussion

From the salinity stand point, Khirbit Es-Samra Treatment Plant soil falls according to Appendix 10, in the low salinity classification. On account of this, only yields of very sensitive crops are restricted. Overall average soil solution electrical conductivity (EC_e) values of reference main root zone (0-30cm) fall within the medium salinity soil classification. Thereafter, EC_e values increase to the extent that only tolerant crops yield satisfactorily. However, according to USSL (1954) classification of salt-affected soils, (Appendix 9), reference field soil is classified as saline.

Outputs of soil chemical analysis were evaluated by comparison with available diagnostic criteria presented in Appendix 11 (Ryan *et al.*, 1996; and Walsh and Beaton, 1973). According to Ryan *et al.* (1996), organic matter content of reference soil is classified in both sampling years as adequate at the surface (0-15cm) and marginal in lower depth horizons. As to STP soil, adequate, marginal and low contents respectively of OM were found at 0-15, 15-30cm and rest of depth increments in both sampling years. Available P proved adequate throughout STP soil profile in both sampling years. Whereas in both sampling years only surface soil of reference field had adequate available P supplies, remainder depth horizons were marginal in their supplying capacity for P. Throughout the whole soil profile sampled in both sampling years, reference and STP soils contained low and adequate exchangeable K concentrations, respectively.

DTPA-extractable micronutrient cations at both sites followed the general trends of decline with depth and soil OM content decline. Moreover, both field soils entertained adequate levels of each. These results run in accord with Katyal and Sharma (1991) who point up that as similar soil factors govern distribution of micronutrient cations in soil, soils rich in one are rich in the rest and vice versa. DTPA-extractable Cu proved adequate at both sites throughout the whole soil profile sampled. Available Fe content within the whole soil profile of both fields is marginal, though in the main root zone of STP soil it fluctuates between marginal and adequate. Both fields had Mn concentrations very much higher than adequate. Reference, which once compared with STP, soil had significantly higher OM content and lower pH, had higer DTPA-extractable Mn. This result flows quite parallel to results obtained by Katyal and Sharma (1991) who found that DTPA-extractable Mn correlated negatively with pH, and positively with soil OM content. However, in deep contrast with Katyal and Sharma (1991) who found DTPA-extractable Mn and Fe distributions in the profile to follow one the other, our results revealed the reverse. Of all factors considered (soil OM, clay content, $CaCO_3$ equivalent, and pH), pH seemed to be the major one to dominantly dictate Mn availability in soils (Katyal and Sharma, 1991; and Tinker, 1986). However, as soil saturation (i.e. reduced condition) has a synergistic effect on Fe availability (Katyal and Sharma, 1991, Lindsay and Schwab, 1982; and Sims and Patrick, 1978), it might be inferred that STP soil is subjected to higher rates than reference of irrigation water or to more frequent irrigation. In addition, STP soil is much expected to have a higher clay content and lower $CaCO_3$ equivalent to further explain its higher plant available Fe content. The debate thus far is due to further be emphasized by the fact that STP surface soil had higher CEC than reference which has a higher OM content. As to Zn, the main root zone of reference soil on the average is sufficient in its supplying power for Zn while STP soil contains adequate supplies throughout the whole profile.

Numerous studies, e.g., Katyal and Sharma (1991), have pointed up that high levels of OM content are believed to be important in increased bioavailability of Zn and Cu and demonstrated high correlation between OM content and extractable or phytoavailable Cu and Zn. Sims and Patrick (1978) reported amounts of trace nutrients complexed with OM to decrease in the order Zn > Cu > Fe > Mn. Accordingly, higher reference than STP phytoavailable Cu and Zn may be ascribed to the higher OM content of the former than the latter. Petruzzelli *et al.* (1978) found that OM removal produced a noteworthy decrease in Cu adsorption contrasted by a smaller decrease or even a slight increase in Cd adsorption. Results of Soon and Bates (1982) suggest that the proportion of Cd, Zn and Ni complexed by soil increases with OM content. Similar results where obtained by Flores *et al.* (1997) who found that Cu, Cd, Pb and Zn were predominantly associated with the organic fraction in most soil samples. Effluent water adds Cu^{2+} to soil while no detectable Cu^{2+} was found in reference well water. Paradoxically, Khirbit Es-Samra Treatment Plant soil is much expected to have attenuated higher amounts of Cu than reference soil which had higher concentrations of phytoavailable Cu. This inference in turn will bear comparison with results obtained by Dhillon *et al.* (1981) who found that adsorption capacities of soils were related to CEC, clay content and $CaCO_3$ equivalent. In addition, higher plant availability of Cu in reference soil could be linked to its higher solution activity since, according to Dhillon *et al.* (1981) higher soil solution ionic strength is expected to decrease the activity of Cu^{2+} and amount of Cu adsorption. Further, significantly higher concentrations of Ca^{2+} and Mg^{2+} were detected in reference rather than STP soil solution. Presence of divalent cations, such as Ca^{2+} and Mg^{2+}, greatly reduces the efficiency of heavy metal adsorption by permanent charge clays as these metals compete more efficiently and strongly with heavy metals for exchange sites (McBride *et al*, 1981; Cavallero and McBide, 1977; and García-Miragaya and Page, 1977), it is thus much expected that relatively comparable plant available metal contents in soils of reference and STP reflect less amounts being adsorbed by exchange sites of the former soil while a better chance existed for metals to occupy some fraction of STP soil exchange sites. Furthermore, chloride was found to exert a marked effect on the mobility of divalent Cd, and to a lesser extent Ni and Cu, which are mobilized as chlorocomplexes (Doner, 1978). Accordingly, more ample Cl^- concentrations in reference soil must have mobilized Cu^{2+} down the profile to exceed concentrations in parallel depths of STP soil.

Though micronutrient defficiency is much more common in calcareous soils than excess or sufficiency (Tinker, 1986), still incidences of high concentrations of a micronutrient or more are reported in the literature. For example, Graham (1973) found extremely high levels of DTPA-extractable Cu and Mn in two Colorado calcareous soils, and Katyal and Sharma (1991) found DTPA-extractable Cu, Fe and Mn in Indian aridisols to exceed adequacy limits.

A general trend was observed of increased reference soil solution Na^+ (EC_e), Ca^{2+} and Mg^{2+} with depth. This derives from the fact that reference well water contained relatively higher concentrations of each relative to STP effluent. In addition, the higher reference soil solution ionic strength, which exacerbates leaching, has a more pronounced effect on, and hence cares for a larger proportion of, leaching of these metals. Movement of Ca^{2+} and Mg^{2+} in soil is slow because these divalent cations are more strongly bonded to the exchange complex than such monovalent ions as Na^+ (Stewart *et al.*, 1990). The greater mobility of Na^+ was ascertained further in our study by slight increases in SAR with depth within all depth horizons sampled at both fields, (Tables 3 to 6). This reflects displacement of Ca^{2+} and Mg^{2+} from exchange sites by Na^+. Higher soil SAR values at both fields in comparison with respective irrigation water are due accordingly to raise and heighten levels of concern about development of soil sodicity. If we decide to define Ca concentration in normal soils to be 120mg L^{-1} (Ma, 1996), we can then conclude that reference soil solution did in both sampling years contain Ca^{2+} concentrations above normal throughout the whole soil profile sampled while STP soil solution content of Ca^{2+} was always below normal. Higher reference soil solution Ca^{2+} may be linked to its higher total N and NO_3^- concentrations. Troncoso *et al.* (1987) found that application of urea, as a result of increasing NH_4^+ and NO_3^- concentrations within the soil profile, mobilizes other nutrients, particularly Ca^{2+}. However, despite high concentrations of organic and inorganic N in effluent, (Table 2), reference soil had significantly higher total N and NO_3^- concentrations. This may, in part, be due to extensive N fertilization and the higher soil OM content of reference orchard which serve as pools of N. Higher STP soil CEC and pH values, particularly within the main root zone (0-30cm), must have enhanced loss of N as NH_3 (NH_3 volatilization). This may further be ascertained by the higher soil solution pH at STP field compared with the reference which evidently has better aeration and, as a consequence, higher nitrification rates as nitrification of each one mole of NH_4^+ furnishes the soil solution with two moles of H^+. Moreover, a possibility holds that STP soil has higher clay content, particularly in the main root zone, than the reference. Higher clay content in the upper soil layer means lower infiltration rate, poorer aeration and hence more N volatilization (White and Dornbush, 1988) and thus explains lower total N as well as NO_3^- concentrations at STP field relative to reference.

Characterization of B status of irrigated soils is based on analysis of saturation extract (Gupta *et al.* 1985; and Goldberg and Foster, 1991). Reference soil B may correspond to background levels besides inputs due to increased dissociation of H_3BO_3 as affected by higher soil solution ionic strength (ionic strength background effect). Khirbit Es-Samra Treatment Plant soil B, on the other hand, corresponds to background concentrations besides inputs from applied effluent as conventional treatment of wastewater doesn't bring about any significant removal of B (Waggot, 1969).

Sodium bicarbonate-extractable P concentrations were much higher within the whole STP soil profile than that of reference. Irrigation water of reference field contained no detectable PO_4^{3-} while STP effluent is characterized by relatively high total P (organic) as well as PO_4^{3-} concentrations. Still, according to Walsh and Beaton (1973), both soils rank high in soil available P content (Appendix 11).

4.3 Olive Leaves

4.3.1 Results

Higher leaf concentrations of B, Cu, Fe, Mn, Cd and Pb on the one hand and higher aqueous leaf extract Na^+, K^+, SO_4^{2-} and PO_4^{3-} concentrations on the other turned out to have been brought about by effluent irrigation. While reference olive leaf concentrated higher N, Ca, B, Fe, Mn, Zn, and NO_3^- in

1996 than in 1997, right the reverse was observed in the rest of tested parameters. Olive leaves at STP field on the other hand accumulated higher concentrations of N, K, B, Ca, Mg, Fe, Mn, and Zn, and less concentrations of all other parameters in 1996, relative to 1997, sampling year, (Table 10).

Table 10. Overall average and standard deviation of olive leaf elemental content at both fields.

Parameter	Unit	Reference		STP	
		1996	1997	1996	1997
N	%	1.382 0.052	1.350 0.059	1.118 0.041	1.045 0.039
P	%	0.123 0.003	0.121 0.003	0.110 0.004	0.160 0.129?
K	%	0.115 0.002	0.114 0.003	0.100 0.005	0.095 0.004
B	mg kg^{-1}	39.045 0.916	44.408 2.624	80.505 1.756	79.820 3.402
Cu	mg kg^{-1}	30.537 2.739	30.808 2.111	68.709 4.960	74.875 3.217
Fe	mg kg^{-1}	119.900 3.531	110.540 1.686	134.381 7.982	118.330 5.054
Mn	mg kg^{-1}	54.527 0.811	53.755 0.528	71.132 3.096	63.015 2.977
Zn	mg kg^{-1}	45.924 0.978	40.541 5.598	44.530 3.368	42.546 1.760
Cd	mg kg^{-1}	0.854 0.036	0.882 0.020	0.897 0.042	0.909 0.023
Pb	mg kg^{-1}	2.841 0.197	2.858 0.109	4.506 0.206	4.440 0.301
Ca	%	0.992 0.538	0.982 0.015	0.711 0.062	0.599 0.027
Mg	%	0.368 0.048	0.237 0.007	0.222 0.038	0.178 0.023
Na^+	%	0.213 0.008	0.219 0.020	0.235 0.007	0.245 0.007
K^+	%	0.350 0.019	0.379 0.013	0.377 0.029	0.403 0.027
Cl^-	%	0.277 0.014	0.310 0.024	0.298 0.023	0.298 0.008
NO_3^-	%	0.529 0.022	0.495 0.017	0.425 0.046	0.436 0.030
SO_4^{2-}	%	0.360 0.007	0.363 0.020	0.408 0.042	0.443 0.047
PO_4^{3-}	%	0.021 0.002	0.023 0.003	0.030 0.002	0.031 0.001
Na^+/K^+		0.617 0.052	0.573 0.041	0.631 0.059	0.612 0.027

As far as olive nutritional status is concerned, the discussion to follow will merely focus on olive leaf, due to extreme scarcity of information in the literature concerning olive fruit, elemental content. For diagnosis of the nutritional status of olive trees in our study, outputs of olive leaf chemical analyses were subdued to comparisons with four documented standards. Two of which deal exclusively with olive leaf elemental content ranges (Jones, Jr. *et al.*, 1991; and Reuter and Robinson, 1986), and the other two are quite of a more general nature (Marr and Cresser, 1983; and Cajuste *et al.* 1991), (Appendices 13 to 16). Results of nutritional status characterization are collectively presented in Table 11.

Table 11. Diagnosis of olive leaf elemental content. (5), (6)

Parameter	Location	(1)	(2)	(3)	(4)
N	Reference	L	D	-	N
	STP	L	D	-	N
P	Reference	S	A	-	N
	STP	S	A	-	N
K	Reference	L	D	-	D
	STP	L	D	-	D
Ca	Reference	L	L	-	D
	STP	L	L	-	D
Mg	Reference	S	A	-	N
	STP	S	A	-	N
Na^+	Reference	-	T	-	-
	STP	-	T	-	-
B	Reference	S	A	-	N
	STP	H	A	-	H
Cu	Reference	-	A	N	H
	STP	-	A	N	H
Fe	Reference	-	A	-	N
	STP	-	A	-	N
Mn	Reference	S	A	N	N
	STP	S	A	N	N
Zn	Reference	S	-	N	N
	STP	S	-	N	N
Cd	Reference	-	-	N	-
	STP	-	-	N	-
Pb	Reference	-	-	N	-
	STP	-	-	N	-

(1) According to Jones, Jr. *et al.* (1991).

(2) According to Reuter and Robinson (1986).

(3) According to Cajuste (1991).

(4) According to Marr and Cresser, 1983.

(5) Legend: L stands for low, S for sufficient, H for high, D for deficient, A for adequate, T for toxic and N for normal.

(6) Valid for results of both sampling years. Apart from Mg in 1997 STP leaf samples which was low, no variations, not any, whatsoever, were observed from first sampling year to second.

Reference and STP olive trees proved to both be defficient in total N, K and Ca, while enjoying sufficient supplies of total P, Mg, Cu, Fe, Mn and Zn. However, leaf B was high in STP samples and sufficient in reference ones. On the other hand, leaf Cd and Pb were normal at both sites.

Sufficient levels of Cu, Fe, Mn and Zn in olive leaves at both fields followed their sufficiently available concentrations in their respective growing media. By this token, though no diagnostic criteria were at hand for soil total N, it could be inferred that since olives at both fields suffer N deficiency, both field soils must be deficient in their supplying capacities for N.

4.3.2 Discussion

Plant uptake of heavy metals is highly dependent on soil pH, OM, competing cations, and plant species as well as the amounts of wastewater-borne heavy metals. However, even under high root concentrations, only a fraction of the trace element is translocated to tops with an even smaller fraction eventually reaching the fruit. The root thus acts as a trap or filter which removes mineral nutrients and trace elements from the wastewater while translocating relatively little to the tops (Berry *et al.*, 1980). Reference olive orchard soil had significantly higher DTPA-extractable Zn than the control. Olive leaf Zn contents at both fields were very nearly the same while reference olive fruits accumulated a somewhat higher Zn concentration, albeit non-significant, than STP olives. The combined effect of high soil pH and P content at STP could have resulted in this relative reduction in Zn uptake by plants (Melton *et al.*, 1973). This bears resemblance with results obtained by El-Gazzar *et al.* (1979) who reported that Zn concentrations of olive leaves and roots showed a gradual decrease with increasing P fertigation.

Lower reference olive leaf B content might have been affected by the combined effect of relatively lower soil solution B concentrations at the reference site on one pan of the balance and higher salinity of reference soil on the other. This result runs in line with results obtained by Ferrera *et al.* (1997) who advocate that foliar levels of B may be reduced by high soil salinity levels which reduce plant water, and consequently nutrient, uptake. In addition, it was reported that plant uptake of B is inversely proportional to soil solution pH and Ca or Mg, and that the combined effect of these factors outweighs the single effect of any (Gupta and Macleod, 1981; and Fox, 1968). More than that, magnesium has a greater effect on reducing B concentrations in plant tissue than do Ca, Na and K (Gupta and Macleod, 1981). Accordingly, the lower reference leaf and fruit B concentrations might have resulted, besides from the originally lower reference soil solution B, from the higher soil solution and leaf Ca and Mg contents of reference orchard. This result accords with Gupta and Macleod (1981) who recorded highest tissue B concentrations in peas and barley when no lime was added to studied soil.

Though reference olive had higher total N and K, and aqueous leaf extract NO_3^- concentrations than that of STP, the former had lower aqueous leaf extract K^+ concentration. Plant NO_3^- level may be more sensitive an indicator of N nutrition than is total N (Curtin *et al.*, 1993). Reference olive samples had consistently higher leaf aqueous extract NO_3^- concentrations, suggesting that they enjoyed better N nutrition than effluent-irrigated ones. This complies with the fact that reference had higher total N and NO_3^- concentrations than STP soil.

Effluent, rather than well water, -irrigated olives had higher leaf PO_4^{3-} and fruit total P contents. Higher concentrations of soil available P at STP relative to reference affected higher olive leaf PO_4^{3-} as well as fruit total P concentrations, though no substantial differences in olive leaf total P content were observed between the two fields. Besides, though nigligible differences in leaf Cl^- contents were affected by type of irrigation water, higher Cl^- concentrations of reference than STP soil must have inhibited PO_4^{3-} uptake since inhibition of PO_4^{3-} uptake is one of Cl^--induced nutritional disorders (Curtin *et al.*, 1993).

In spite of the fact that the two studied fields practically had no substantial differences in foliar Cl^- contents, in contrast to Na^+, foliar Cl^- was always less than Na^+. Such trend was documented by Tattini *et al.* (1992) who advocate that this behavior is typical of olive plants. Furthermore, no toxicity is due to be exerted upon olive trees at both fields by their respective leaf Cl^- concentrations which in both years were well below the toxicity limit of 0.50% (Reuter and Robinson, 1986).

Olives at both fields compared well to one the other in that both had adequate total P concentrations while suffering N defficiency. Adequate leaf total P contents reflect response to adequate $NaHCO_3$-extractable P reserves at both sites. Another point to add is that olive leaves of STP field had lower than reference total N concentrations. In addition, olives at both fields proved to lack sufficient supplies of Ca as well as of N. A synergistic relationship was reported between Ca and N in olive leaves by Therios and Sakellariadis (1988) who found increases in Ca concentration to follow N concentration increases in olive leaf tissue.

For optimal efficiency in plant tolerance to salinity, foliar Na/K ratio for non-halophytes should be < 1.0 (Tattint *et al.*, 1992). In our study, overall average foliar Na/K ratios were 0.617 and 0.573 for reference olives, and 0.631

and 0.612 for STP ones respectively in 1996 and 1997, (Table 10). According to Reuter and Robinson (1986), olive leaf aqueous extract Na^+ concentrations at both fields in both years are considered phytotoxic. Paradoxically, however, no toxicity symptoms are due to appear at Na^+ concentrations less than 0.42% (dwb) according to Childers (1966).

4.4 Olive Fruits

4.4.1 Results

Olive fruits responded to effluent irrigation by exhibiting higher flesh fat content (fat %), and total N, P, K, Ca, Mg, B, Fe, Mn, Cd, and Pb concentrations, (Table 12). Reference olive fruits had higher average fruit flesh weight, fat content, and concentrations of P, K, Fe, Mn, Zn, Cd and Pb and lower contents of other tested parameters in the second, rather than the first, sampling year. Olive fruits at STP field had higher average fruit fresh weight, fat content, and concentrations of P, K, Ca, Mg, B, Fe, Mn, Zn, Cd and Pb and lower values of remaining parameters in 1997 than in 1996.

Table 12. Overall average and standard deviation of olive fruit flesh elemental content at both fields.

Parameter	Unit	Reference		STP	
		1996	1997	1996	1997
Average fruit fresh weight	g	3.899 0.033	3.993 0.079	2.506 0.123	2.703 0.246
Fat	%	40.427 1.125	42.071 0.475	45.602 1.478	47.121 1.559
N	%	0.271 0.013	0.257 0.018	0.288 0.008	0.277 0.013
P	%	36.295 1.385	36.316 0.733	49.308 2.800	49.978 4.069
K	%	0.182 0.003	0.186 0.011	0.219 0.011	0.230 0.011
Ca	%	523.579 27.799	519.894 29.623	526.418 11.757	528.464 10.234
Mg	%	258.690 7.642	251.697 7.055	301.902 28.036	302.901 21.615
B	mg kg^{-1}	9.573 0.659	9.654 1.192	16.816 1.068	17.291 1.409
Cu	mg kg^{-1}	20.030 2.350	17.377 1.777	13.434 1.200	13.339 0.844
Fe	mg kg^{-1}	17.620 4.193	19.822 5.395	23.321 2.731	24.924 2.170
Mn	mg kg^{-1}	10.556 1.035	11.612 1.947	12.270 0.588	12.498 0.938
Zn	mg kg^{-1}	12.176 1.233	14.525 3.191	12.566 1.531	12.719 1.277
Cd	mg kg^{-1}	0.277 0.023	0.280 0.020	0.297 0.042	0.301 0.010
Pb	mg kg^{-1}	0.565 0.094	0.572 0.098	1.154 0.025	1.146 0.026

4.4.2 Discussion

Even though olive trees are characterized by alternate bearing, average individual fruit fresh weight reflected a slight increase in the second sampling year at both sites over the first, (Table 12). Still, no clear-cut alternate bearing was observed at either field.

Albeit well water-irrigated olive trees had higher average fruit fresh weight than effluent-irrigated ones, fat content flowed in the opposite direction. This may have to do with differences in soil salinity at both fields. It was reported that an increase in groundnut seed oil content followed soil salinity up to an EC_e value of 3.16dS m^{-1} whereupon a decline started to take place (Rhoades *et al.*, 1992). The higher reference average individual fruit flesh weight and lower fat percentage compared with STP may also be explained by the higher total N and lower total K concentrations of former than the latter. 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 enhancement of vegetative growth and hence delayed fruit ripening. Higher olive yield at STP compared with reference may, in addition, be due to higher exchangeable, soil solution and leaf total K concentrations. Inglese *et al.* (1996) attributed higher oil yields in irrigated olives compared with non-irrigated ones to higher drupe K concentrations as well as to higher water content since oil content was highly correlated with fruit K concentration.

Higher olive fruit crude protein in STP olives accords with Day and Tucker (1977) who found that effluent-irrigated sorghum produced higher total crude protein than the control. Olives at STP, rather than reference, had higher fruit total N concentrations presumably as a reflection of the dilution effect induced by the higher average fruit fresh weight of reference rather than STP olives.

In brief, soil salinity is not expected to affect olive tree growth and yield at STP field while yield reduction is much expected to get affected by the significantly higher soil solution salinity of reference field. Olive yield reductions of 10, 25, and 50% have been reported to be induced respectively by EC_e values of 4, 5 and 8dS m^{-1} (Fernández, 1997). Cresti *et al.* (1994) found that salt treatments of 0, 10, and 120mM NaCl (0, 10 and 120me Na^+ L^{-1}) did not affect fruit drop and size while yield of salt-treated plants was decreased with respect to control plants. Therios and Misopolinos (1988) observed no toxicity symptoms (foliar injury) to have appeared at four tested NaCl concentrations (0, 15, 30 and 45me NaCl L^{-1}) in the growing medium on most of the examined olive cultivars while at NaCl concentrations greater than 60me L^{-1}, olive leaf edges turned chlorotic, then died peripherally and subsequently started to drop.

Ether-extracted olive oil from both fields contained no detectable concentrations of Pb and Cd, not any, whatsoever.

5. CONCLUSIONS and RECOMMENDATIONS

5.1 Conclusions

1. Soil chemical properties were not adversely affected by irrigation with Khirbit es-Samra effluent water over the past ten years. However, there has been a trend towards gradual buildup of soil salinity and sodicity in the studied soil profiles.

2. Heavy metal concentrations (Cd and Pb) in the olive oil pertaining to the olive orchard in Khirbit es-Samra site was far below any hazardous level. This implies a safe human consumption of this product.

3. Although soil and olive fruit and oil qualities were not adversely affected by irrigation with Khribit es-Samra effluent water, special attention should be directed towards a continuous monitoring and auditing of these components.

5.2 Recommendations

1. Treated effluent water of Khirbit es-Samra can be safely employed in irrigating olive orchards under semi-arid conditions.
2. Although the former recommendation represents current irrigation practices at Khirbit es-Samra site, further improvement on irrigated soil quality and fruit and olive yields can be achieved by optimizing irrigation water depth and schedule.
3. Subsequently, additional studies are needed to identify optimum irrigation practices, especially irrigation scheduling and leaching fraction management.

REFERENCES

- Allhands, M.N., Allick, S.A., Overman, A.R., Leseman, W.G. and Vidak, W. 1995. Municipal Water Reuse at Tallahassee, Florida. *Transactions of ASAE*, 38 (**2**): 411-418.

- American Public Health Association, 1985. Standard Methods for the Examination of Water and Wastewater. 16th. edition. American Public Health Association, New York, USA.

- Asano, T. and Levine, A.D. 1996. Wastewater Reclamation, Recycling and Reuse: Past, Present, and Future. *Water Science and Technology*, 133 (**10-11**): 1-14.

- Ayers, R.S. and Westcot, D.W. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29, Rev. 1. Food and Agriculture Organization of the United Nations, Rome, Italy.

- Bajjali, W. 1997. Using Arc View GIS to Determine the Origin of Groundwater Salinity in the Dhuleil, Halabat, and Khirbit Es-Samra Areas of Jordan. Proceedings of ESIR User Conference, San Diego, CA, USA, July, 7-11.

- Berry, W.L., Wallace, A. and Lunt, O.R. 1980. Utilization of Municipal Wastewater for the Culture of Horticultural Crops. *HortScience*, 15 (2): 167-171.

- Bingham, F.T. 1982. Boron. pp. 431-432. In: Page, A.L. (Editor), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2nd. Edition, Agronomy, Number 9, Part 2, ASA, Inc., SSSA, Inc., Madison, Wisconsin, USA.

- Bouwer, H. and Chaney, R.L. 1974. Land Treatment of Wastewater, pp. 133-176. In: Brady, N.C. (Editor): Advances in Agronomy, Volume 26, ASA, USA.

- Bradfield, E.G. and Cooke, D.T. 1985. Determination of Inorganic Anions in Water Extracts of Plants and Soils by Ion Chromatography. *Analyst*, 110 **(11)** 1409-1410.

- Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen-Total. pp. 595-622. In: Page, A.L. (Editor), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2nd. Edition, Agronomy, Number 9, Part 2, ASA, Inc., SSSA, Inc., Madison, Wisconsin, USA.

- Cajuste, L.J., Carrillo, R., Cota, E. and Laird, R.J. 1991. The Distribution of Metals from Wastewater in the Mexican Valley of Mezquital. *Water, Air, and Soil Pollution*, 57-58: 763-771.
- Cavallaro, N. and McBride, M.B. 1978. Copper and Cadmium Adsorption Characteristics of some Acid and Calcareous Soils. *Soil Science Society of America Journal*, 42 **(4)**: 550-556.
- Chapman, H.D. 1965. Cation-Exchange Capacity. pp. 899-900. In: Black, C.A. (Editor), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. Agronomy, Number 9, Part 2, ASA, Inc., SSSA, Inc., Madison, Wisconsin, USA.
- Childers, N.F. 1966. Nutrition of Fruit Crops: Tropical, Subtropical, Temperate Tree and Small Fruits. Horticulture Publications Rutgers- The State University, New Brunswick, New Jersey, USA.
- Christensen, T.H. 1984. Cadmium Soil Sorption at Low Concentrations: I. Effect of Time, Cadmium Load, pH, and Calcium. *Water, Air, and Soil Pollution*, 21 **(1)**: 105-114.

- Cresti, M., Ciampolini, F., Tattini, M. and Cimato, A. 1994. Effect of Salinity on Productivity and Oil Quality of Olive (*Olea europaea* L.) Plants. *Advances in Horticultural Science*, 8 **(2)**: 211- 214.

- Curtin, D., Steppuhn, H. and Selles, F. 1993. Plant Response to Sulfate and Chloride Salinity: Growth and Ionic Relations. *Soil Science Society of America Journal*, 57 **(5)**: 1304-1310.

- Day, A.D., Stroehlein, J.L. and Tucker, E.C. 1972. Effects of Treatment Plant Effluent on Soil Properties. *Journal of Water Pollution Control Federation*, 44 **(3)**: 372-375.

- Day, A.D. and Tucker, T.C. 1977. Effects of Treated Municipal Wastewater on Growth, Fiber, Protein, and Amino Acid Content of Sorghum Grain. *Journal of Environmental Quality*, 6 **(3)**: 325-327.

- De Jong, E. 1978. The Movement of Sewage Effluent through Soil Columns: The Major Ions (Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}). *Journal of Environmental Quality*, 7 **(1)**: 133-136.

- Dhillon, S.K., Sidhu, P.S. and Sinha, M.K. 1981. Copper Adsorption by Alkaline Soils. *Journal of Soil Science*, 32 **(4)**: 571-578.

- Doner, H.E. 1978. Chloride as a Factor in Mobilities of Ni (II), Cu (II), and Cd (II) in Soil. *Soil Science Society of America Journal*, 42 **(6)**: 882-885.

- El-Gazzar, A.M., Taha, M.W. and Ghally, E. 1979. Effect of Different Levels of Phosphorous on Growth and Mineral Composition of Glass-House Grown Oranges, Olives and Guavas. *Alexandria Journal of Agricultural Research*, 27 **(1)**: 107-118.

- El Hamouri, B., Handouf, A., Mekrane, M., Touzani, M., Khana, A., Khallayoune, K., and Benchokroun, T. 1996. Use of Wastewater for Crop Production under Arid and Saline Conditions: Yield and Hygienic Quality of the Crop and Soil Contaminations. *Water Science and Technology*, 33 **(10-11)**: 327-334.

- El-Sallag, M. 1996. Environmental Effect of Khirbit Es-Samra Stabilization Ponds. Workshop on 'Management of Municipal Water Supply in the Middle East Area'. Goeteborg, Sweeden, May 8-24.

- Fardous, A. and Jamjoum, K. 1996. Corn Production and Environmental Effects Associated with the Use of Treated Wastewater in Irrigation of Khirbet Al-Khirbit Es-Samra Region. Annual Report, National Center for Agricultural Research and Technology Transfer (NCARTT), Amman, Jordan.

- Fernández, J.E. 1997. Olive Production under Saline Conditions. Proceedings of the Naples Trans-National Meeting on 'Salinity as a Limiting Factor for Agricultural Productivity in the Mediterranean Basin'. March, 24-25. Naples, Italy.

- Ferreyra, R.E., Aljaro, A.U., Ruiz, R.S., Rojas, L.P. and Oster, J.D. 1997. Behavior of 42 Crop Species Grown in Saline Soils with High Boron Concentrations. *Agricultural Water Management*, 34 **(1)**: 111-124.

- Flores, L., Blas, G., Hernández, G. and Alcalá, R. 1997. Distribution and Sequential Extraction of Some Heavy Metals from Soils Irrigated with Wastewater from Mexico City. *Water, Air, and Soil Pollution*, 98 **(1)**: 105-117.

- Follet, R.H., Murphy, L.S. and Dinahue, R.L. 1981. Fertilizers and Soil Amendments. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA.

- Fox, R.H. 1968. The Effect of Calcium and pH on Boron Uptake from High Concentrations of Boron by Cotton and Alfalfa. *Soil Science*, 106 **(6)**: 435-439.

- García-Miragaya, J. and Page, A.L. 1977. Influence of Exchangeable Cation on the Sorption of Trace Amounts of Cadmium by Montmorillonite. *Soil Science Society of America Journal*, 41 **(4)**: 718-721.

- Gedeon, R., 1996. The Environmental and Health Aspects of Wastewater Reuse in Jordan. Workshop on 'Wastewater Treatment and Reuse in Jordan'. Aqaba Gulf Hotel, Aqaba, Jordan.
- Goldberg, S. and Forster, H.S. 1991. Boron Sorption on Calcareous Soils and Reference Calcites. *Soil Science*, 152 (**4**): 304-310.
- Graham, E.R. 1973. Selective Distribution and Labile Pools of Micronutrient Elements as Factors Affecting Plant Uptake. *Soil Science Society of America Proceedings*, 37 (**1**): 70-73.
- Gupta, S.K. and Gupta, I.C. 1987. Management of Saline Soils and Waters, pp.49-100. Published by Mohan Primlani for Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, India.
- Gupta, U.C., Jame, Y.W., Campbell, C.A., Leyshon, A.J. and Nicholaichuk, W. 1985. Boron Toxicity and Deficiency: A Review. *Canadian Journal of Soil Science*, 65 (**3**): 381-409.
- Gupta, U.C. and Macleod, J.A. 1981. Plant and Soil Boron as Influenced by Soil pH and Calcium Sources on Podzol Soils. *Soil Science*, 131 (**1**): 20-25.

- Hamzé, M., Nimah, M. and Zaabout, M. 1984. Effectiveness of Six Digestion Procedures to Evaluate the Status of Major Elements (Ca, K, Mg, and Na) in Citrus Leaves. *Communication in Soil Science and Plant Analysis*, 15 (9): 1135-1145.
- Hayes, A.R., Mancino, C.F. and Pepper, I.L. 1990. Irrigation of Turfgrass with Secondary Effluent: I. Soil and Leachate Water Quality. *Agronomy Journal*, 82 **(5)**: 939-943.
- Hooda, P.S. and Alloway, B.J. 1998. Cadmium and Lead Sorption Behavior of Selected English and Indian Soils. *Geoderma*, 84 **(1)**: 121-134.
- Inglese, P., Barone, E. and Gullo, G. 1996. The Effect of Complementary Irrigation on Fruit Growth, Ripening Pattern and Oil Characteristics of Olive (*Olea europaea* L.) cv. Carolea. *Journal of Horticultural Science*, 71 (2): 257-263.
- Jame, Y.W., Biederbeck, V.O., Nicholaichuk, W. and Korven, H.C. 1984. Salinity and Alfalfa Yield under Effluent Irrigation in Southwestern Saskatchewan. *Canadian Journal of Soil Science*, 64 **(3)**: 323-332.
- Jiménez-Cisneros, B. 1995. Wastewater Reuse to Increase Soil Productivity. *Water Science and Technology*, 32 **(12)**: 173-180.

- John, M.K. 1974. Wastewater Renovation through Soil Percolation. *Water, Air, and Soil Pollution*, 3 **(1)**: 3-10.
- Jones, Jr., Benton, J., Wolf, B. and Mills, H.A. 1991. Plant Analysis Handbook: A Practical Sampling, Preparation, Analysis, and Interpretation Manual. Micro-Macro Publishing Inc., Georgia, USA.
- Katyal, J.C. and Sharma, B.D. 1991. DTPA-Extractable and Total Zn, Cu, Mn, and Fe in Indian Soils and their Association with Soil Properties. *Geoderma*, 49 **(1/2)**: 165-179.
- Khattari, S. and Jamjoum, K. 1988. Concentrations of Nutrients and some Heavy Metals in Soil and Sweet Corn Irrigated by Treated Wastewater. *Dirasat*, 15 **(11)**: 29-44 (Arabic).
- Knudsen, D., Peterson, G.A. and Fratt, P.F. 1982. Lithium, Sodium, and Potassium. In: Page, A.L. (Editor), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2nd. Edition, Agronomy, Number 9, Part 2, ASA, Inc., SSSA, Inc., Madison, Wisconsin, USA.
- Lindsay, W.L. and Norvel, W.A. 1978. Development of a DTPA Soil Test for Zinc, Iron, Manganese, and Copper. *Soil Science Society of America Journal*, 42 **(3)**: 421-428.

- Lindsay, W.L. and Schwab, A.P. 1982. The Chemistry of Iron in Soils and its Availability to Plants. *Journal of Plant Nutrition*, 5 (4-7): 821-840.

- Loupassaki, M.H., Perica, S. and Androulakis, I.I. 1993. Seasonal Changes in the Olive Fruit and the Effects of Summer-Applied Nitrogen and Potassium. *Advances in Horticultural Science*, 2 (7): 65-68.

- Ma, L.Q.Y. 1996. Factors Influencing the Effectiveness and Stability of Aqueous Lead Immobilization by Hydroxyapatite. *Journal of Environmental Quality*, 25: 1420-1429.

- Marr, I.L. and Cresser, M.S. 1983. Environmental Chemical Analysis. Textbook Company, New York, USA.

- McBride, M.B., Tyler, L.D. and Hovda, D.A. 1981. Cadmium Adsorption by Soils and Uptake by Plants as Affected by Soil Chemical Properties. *Soil Science Society of America Journal*, 45 (4): 739-744.

- Melton, J.R., Mahtab, S.K. and Swoboda, A.R. 1973. Diffusion of Zinc in Soils as A Function of Applied Zinc, Phosphorous, and Soil pH. *Soil Science Society of America Proceedings*, 37 (3): 379-381.

- Nasser, M. 1988. Use of Sewage Effluent for Irrigation in Jordan, pp. 135-137. In: Biswas, A.K. and Arar, A. (Editors): Treatment and Reuse of Wastewater. Food and Agriculture Organization of United Nations. Robert Hartnoll Ltd., Bodmin, Cornwall, Britain.
- Neilsen, G.H., Stevenson, D.S., Fitzpatrick, J.J. and Brownlee, C.H. 1989. Nutrition and Yield of Young Apple Trees Irrigated with Municipal Waste Water. *Journal of American Society of Horticultural Science*, 114 (3): 377-383.
- Neilsen, G.H., Stevenson, D.S., Fitzpatrick, J.J. and Brownlee, C.H. 1991. Soil and Sweet Cherry Response to Irrigation with Wastewater. *Canadian Journal of Soil Science*, 71 **(1)**: 31-41.
- Nelson, D.W. and Sommers, L.E. 1982. Total Carbon, Organic Carbon, and Organic Matter. pp. 539-577. In: Page, A.L. (Editor), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2nd. Edition, Agronomy, Number 9, Part 2, ASA, Inc., SSSA, Inc., Madison, Wisconsin, USA.
- Olsen, S.R. and Sommers, L.E. 1982. Phosphorous. In: Page, A.L. (Editor), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2nd. Edition, Agronomy, Number 9, Part 2, ASA, Inc., SSSA, Inc., Madison, Wisconsin, USA.

- Page, A.L., and Chang, A.C. 1981. Trace Metals in Soils and Plants Receiving Municipal Wastewater Irrigation. pp. 351-372. In: D'Itri, F.M., Martinez, J.A. and Lámbarri, M.A. (Editors), Municipal Wastewater in Agriculture. Academic Press, San Diego, Mexico.

- Papadopoulos, I. and Stylianou, Y. 1988. Trickle Irrigation of Cotton with Treated Sewage Effluent. *Journal of Environmental Quality*, 17 (4): 574-579.

- Papadopoulos, I. and Stylianou, Y. 1991. Trickle Irrigation of Sunflower with Municipal Wastewater. *Agricultural Water Management*, 19 (1): 67-75.

- Paquot, C. 1979. Standard Methods for the Analysis of Oils, Fats and Derivatives. Part 1 (Sections I and II), pp. 9-11. International Union of Pure and Applied Chemistry. Pergamon Press Ltd., Oxford, England.

- Pescod, M.B. 1992. Wastewater Treatment and Use in Agriculture. FAO Irrigation and Drainage paper 47, Food and Agriculture Organization of the United Nations, Rome, Italy.

- Petruzzelli, G., Guidi, G. and Lubrano, L. 1978. Organic Matter as an Influencing Factor on Copper and Cadmium Adsorption by Soils. *Water, Air, and Soil Pollution*, 9 (3): 263-269.

- Prösl, K.H. and Rimawi, O. 1986. Nitrates in Groundwater. Bulletin of the Water Research and Study Center (Currently, Water and Environment Research and Study Center), 6th. Issue, Amman, Jordan.
- Reneau, Jr., R.B., Hagedorn, C. and Degen, M.J. 1989. Fate and Transport of Biological and Inorganic Contaminants from On-Site Disposal of Domestic Wastewater. *Journal of Environmental Quality*, 18 (2): 135-144.
- Reuter, D.J. and Robinson, J.B. 1986. Plant Analysis: An Interpretation Manual. Inkata Press, Melbourne, Australia.
- Rhoades, J.D. 1982. Soluble Salts. pp. 167-178. In: Page, A.L. (Editor), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2nd. Edition, Agronomy, Number 9, Part 2, ASA, Inc., SSSA, Inc., Madison, Wisconsin, USA.
- Rhoades, J.D., Kandiah, A. and Mashali, A.M. 1992. The Use of Saline Water for Crop Production. FAO Irrigation and Drainage Paper 48. Food and Agriculture Organization of the United Nations, Rome, Italy.

- Royal Scientific Society, 1996. Project of Monitoring Khirbit Es-Samra Treatment Plant Influent and Effluent, and Zerqa Stream Water Quality and Studying their Effect on Groundwater Quality. Final Annual Report, March 1995- March 1996. Royal Scientific Society, Environmental Research Center, Amman, Jordan.
- Royal Scientific Society, 1995. Study of the Design of Waste Stabilization Ponds in Jordan. Royal Scientific Society, Amman, Jordan.
- Royal Scientific Society, 1994. Socio-Economic and Environmental Study of King Talal Reservoir Region. Volume (IV): Environmental Study. Royal Scientific Society, Environment Research Center, Amman, Jordan.
- Ryan, J., Garabet, S., Harmsen, K. and Rashid, A. 1996. A Soil and Plant Analysis Manual Adapted for the West Asia North Africa Region. International Center for Agricultural Research in the Dry Region (ICARDA), Aleppo, Syria.
- Sahouri, M.M. 1988. Existing Wastewater Reuse and its Future Potential in Jordan. pp. 121-127. In: Biswas, A.K. and Arar, A. (Editors): Treatment and Reuse of Wastewater. Food and Agriculture Organization of United Nations. Robert Hartnoll Ltd., Bodmin, Cornwall, Britain.

- Sawhney, B.L. 1978. Leaching of Phosphate from Agricultural Soils to Groundwater. *Water, Air, and Soil Pollution*, 9 (**4**): 499-505.
- Shatanawi, M.R., Al-Nakshabandi, G.A., Fayyad, M., Al-Horani, H. and Saqqar, M. 1994. Minimizing Environmental Problems Associated with the Use of Treated Wastewater for Irrigation in Jordan. Final Report, Phase I. Water and Environment Research and Study Center, Technical Bulletin No. 18. The University of Jordan, Amman, Jordan.
- Shorrocks, V.M. 1997. The Occurrence and Correction of Boron Deficiency. *Plant and Soil*, 193 (**1-2**): 121-148.
- Sidle, R.C. and Sopper, W.E. 1976. Cd Distribution in Forest Ecosystem Irrigated with Treated Municipal Wastewater and Sludge. *Journal of Environmental Quality*, 5 (**4**): 419-422.
- Sims, J.L. and Patrick, Jr., W.H. 1978. The Distribution of Micronutrient Cations in Soil under Conditions of Varying Redox Potential and pH. *Soil Science Society of America Journal*, 42 (**2**): 258-262.
- Smith, C.J., Hopmans, P., and Cook, F.J. 1996. Accumulation of Cr, Pb, Cu, Ni, Zn, and Cd in Soil Following Irrigation with Treated Urban Effluent in Australia. *Environmental Pollution*, 94 (**3**): 317-323

- Sommers, L.E., Nelson, D.W. and Owens, L.B. 1979. Status of Inorganic Phosphorous in Soils Irrigated with Municipal Wastewater. *Soil Science*, 127 **(6)**: 340-351.
- Soon, Y.K. and Bates, T.E. 1982. Chemical Pools of Cadmium, Nickel and Zinc in Polluted Soils and some Preliminary Indication of Their Availability to Plants. *Journal of Soil Science*, 33 **(3)**: 477-488.
- Stewart, H.T.L., Hopmans, P., Flinn, D.W. and Hillman, T.J. 1990. Nutrient Accumulation in Trees and Soil Following Irrigation with Municipal Effluent in Australia. *Environmental Pollution*, 63 **(2)**: 155-177.
- Tattini, M., Bertoni, P. and Caselli, S. 1992. Genotipic Responses of Olive Plants to Sodium Chloride. *Journal of Plant Nutrition*, 15 (9): 1467-1485.
- Therios, I.N. and Misopolinos, N.D. 1988. Geenotypic Response to Sodium Chloride Salinity of Four Major Olive Cultivars (*Olea europaea* L.). *Plant and Soil*, 106 **(1)**: 105-111.
- Therios, I.N. and Sakellariadis, S.D. 1988. Effects of Nitrogen Form on Growth and Mineral Composition of Olive Plants (*Olea europaea* L.). *Scientia Horticulturae*, 35 **(3/4)**: 167-177.

- Tinker, P.B. 1986. Trace Elements in Arable Agriculture. *Journal of Soil Science*, 37 **(4)**: 587-601.

- Troncoso, A., Barroso, M., Martin-Aranda, J., Murillo, J.M. and Moreno, F. 1987. Effect of the Fertilization Level on the Availability of Nutrients in an Olive Orchard Soil. *Journal of Plant Nutrition*, 10 **(9-16)**: 1555-1561.

- Tsadilas, C.D., Yassoglou, N., Kosmas, C.S. and Kallianou, Ch. 1994. The Availability of Soil Boron Fractions to Olive Trees and Barley and their Relationships to Soil Properties. *Plant and Soil*, 162 **(2)**: 211-217.

- Tuffaha, A.Sh. 1996. Technologies, Practices, and Performance of Wastewater Treatment Plants in Jordan. Workshop on 'Wastewater Treatment and Reuse in Jordan'. Aqaba Gulf Hotel, Aqaba, Jordan, pp. 18-22.

- United States Environmental Protection Agency, 1981. Process Design Manual for Land Treatment of Municipal Wastewater. EPA 625/1-81-013. United States Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio, USA.

- United States Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Salinity Laboratory Handbook 60. Washington, DC, USA.

- Waggot, A. 1969. An Investigation of the Potential Problem of Increasing Boron Concentrations in Rivers and Water Courses. *Water Research*, 3 (**10**): 749-765.

- Water Authority of Jordan, 1998. Sanitary Drainage Sector, Annual Report. Amman, Jordan.

- Walsh, L.M. and Beaton, J.D. 1973. Soil Testing and Plant Analysis. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

- White, E.M. and Dornbush, J.N. 1988. Soil Changes Caused by Municipal Watewater Application in Eastern South Dakota. *Water Resources Bulletin*, 24 (**2**): 269-273.

- World Health Organization, 1984. Guideline for Drinking Water Quality, Volume No. 1, Recommendation. Geneva, Switzerland.

Appendix 1. Heavy metal concentrations in soil and corn tissue under effluent irrigation at Queen Alia International Airport Experimental Station.⁽¹⁾

Pool	Irrigation Water	Cu	Fe	Mn	Zn	Cd	Pb
		mg kg^{-1}					
Soil 0-20cm	Effluent	2.91	5.80	9.56	0.94	0.14	1.03
	Fresh	2.84	5.56	8.50	0.91	0.13	0.96
20-40cm	Effluent	2.74	5.20	8.94	0.88	0.14	1.06
	Fresh	2.62	4.98	8.05	0.60	0.14	1.03
Leaves	Effluent	13.00	257.30	139.0	133.2	0.60	11.90
	Fresh	12.40	212.30	136.3	128.0	0.60	11.90
Seeds	Effluent	9.60	66.80	6.70	38.20	bd⁽²⁾	bd
	Fresh	9.60	66.80	6.70	32.10	bd	bd

(1) Khattari and Jamjoum (1988).

(2) Below detection limits.

Appendix 2. Soil DTPA-Extractable micronutrient cation concentrations at Arizona.⁽¹⁾, ⁽²⁾

Irrigation Water	Potable				Effluent			
Period	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn
April, 1986	1.4	3.9	3.0	2.1	1.3	3.5	2.7	1.9
June, 1988	1.4	6.6	5.4	1.3	1.4	6.4	6.6	1.1

(1) Hayes *et al.* (1990).

(2) Unit: ppm.

Appendix 3. Heavy metal concentrations in eggplant tissue at STP field.(1)

Plant Tissue	Irrigation Water	Cu	Fe	Mn	Zn	Cd	Pb
		mg kg^{-1}					
Leaves	Effluent	0.191	49.57	1.128	1.130	0.083	0.730
	Fresh	0.150	26.31	0.962	0.782	0.036	0.720
Fruits	Effluent	0.173	2.224	0.186	0.242	0.021	0.610
	Fresh	0.106	2.167	0.107	0.235	0.001	0.490

(1) Shatanawi *et al.* (1994).

Appendix 4. Heavy metal concentrations in sweet corn tissue at STP field. (1), (2)

Corn Tissue	Cu	Fe	Mn	Zn	Cd	Pb
	mg kg^{-1}					
Leaves	7.760	258.200	137.700	17.600	0.470	bd (3)
Seeds	1.900	55.200	11.700	21.300	bd	0.020

(1) Fardous and Jamjoum (1996).

(2) Concentrations corresponding to 100 % class A pan evaporation.

(3) Below detection.

Appendix 5. Effluent irrigation guidelines 893/1995 (Jordan). (1), (3)

No.	Parameter (2)	Cooked vegetables	Fruit and forestry trees and corps	Fodder crops
1.	PH	6.0 - 9.0	6.0-9.0	6.0-9.0
2.	BOD_5	150	150	250
3.	COD	500	500	700
4.	DO	> 2	> 2	> 1
5.	TDS	2000	2000	2000
6.	TSS	200	200	250
7.	Na^+	230	230	230
8.	Ca^{2+}	400	400	400
9.	Mg^{2+}	60	60	60
10.	SAR	9	9	9
11.	Cl^-	350	350	350
12.	SO_4^{2-}	1000	1000	1000
13.	CO_3^{2-}	6	6	6
14.	HCO_3^-	520	520	520
15.	NO_3^--N	50	50	50
16.	Total N	100	100	-
17.	B	1	1	1
18.	Cu	0.2	0.2	0.2
19.	Fe	5	5	5
20.	Mn	0.2	0.2	0.2
21.	Zn	2	2	2
22.	Pb	5	5	5
23.	Cd	0.1	0.1	0.1

(1) Source: Tuffaha (1996).

(2) Apart from pH, all parameters are assigned the unit mg L^{-1}.

(3) Remark: This standard didn't include any specification for EC_{iw}, NH_4^+ and PO_4^{3-}.

Appendix 6. Guidelines for interpretation of water quality for irrigation.

Potential Irrigation Problem	Unit	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity				
EC_W	$dS\ m^{-1}$	< 0.7	0.7-3.0	> 3.0
or, TDS	$mg\ L^{-1}$	< 450	450-2000	> 2000
Infiltration				
SAR = 0-3 and EC_W =	$dS\ m^{-1}$	> 0.7	0.7-0.2	< 0.2
SAR = 3-6 and EC_W =		> 1.2	1.2-0.3	< 0.3
SAR = 6-12 and EC_W =		> 1.9	1.9-0.5	< 0.5
SAR = 12-20 and EC_W =		> 2.9	2.9-1.3	< 1.3
SAR = 20-40 and EC_W =		> 5.0	5.0-2.9	< 2.9
Specific Ion Toxicity				
(1) Na^+				
Surface Irrigation	SAR (1)	< 3	3-9	> 9
Sprinkler Irrigation		< 3	> 3	-
(2) Cl^-				
Surface Irrigation	$me\ L^{-1}$	< 4	4-10	> 10
Sprinkler Irrigation	$me\ L^{-1}$	< 3	> 3	-
(3) Boron				
B	$mg\ L^{-1}$	< 0.7	0.7-3.0	> 3.0
Miscellaneous Effects				
NO_3^-	$mg\ L^{-1}$	< 5	5-30	> 30
HCO_3^-		< 1.5	1.5-8.5	> 8.5
pH	Normal Range 6.5-8.4			

(1) Unit: $(me\ L^{-1})^{1/2}$.

Appendix 6. Guidelines for interpretation of water quality for irrigation (Continued).(1)

Recommended Maximum Concentration	
Cd	0.01
Cu	0.20
Fe	5.0
Mn	0.20
Pb	5.0
Zn	2.0

(1) Source: Ayers and Westcot, 1985.

Appendix 7. Classification of saline water.(1)

Water Class	EC ($dS\ m^{-1}$)	Salt Concentration ($mg\ L^{-1}$)	Water Type
Non-saline	< 0.7	< 500	Drinking and irrigation water
Slightly saline	0.7-2	500-1500	Irrigation water
Moderately saline	2-10	1500-7000	Primary drainage and ground water
Highly saline	10-25	7000-15000	Secondary drainage and ground water
Very highly Saline	25-45	15000-35000	Very saline groundwater
Brine	> 45	> 35000	Seawater

(1) Source: Rhoades *et al.* 1992.

Appendix 8. Irrigation water classification (USSL, 1954). (1)

Salinity Hazard		
Classification	EC (2)	Code
Low	0.1-0.25	C1
Medium	0.25-0.75	C2
High	0.75-2.25	C3
Very high	2.25-5.0	C4
Sodium Hazard		
Classification	SAR (3)	Code
Low	0-10	S1
Medium	10-18	S2
High	18-26	S3
Very high	26-31	S4

(1) Source: USSL Staff, 1954.
(2) Unit: dS m^{-1}.
(3) Unit: $(me\ L^{-1})^{1/2}$.

Appendix 9. Classification of salt-affected soils.

Classification	EC_e [1] $dS\ m^{-1}$	pH [2]	ESP [1]	Physical Condition[1]
Saline	> 4.0	7.5-8.5	< 15.0	Normal
Sodic	< 4.0	8.2-10.0	> 15.0	Poor
Saline-sodic	> 4.0	8.5-10.0	< 15.0	Normal

(1) Source: Follet *et al.*, 1981.
(2) Source: Gupta and Gupta, 1987.

Appendix 10. Soil salinity classification.[6]

Classification	EC_e ($dS\ m^{-1}$)	Plant Growth
Normal	< 1.5	(1)
Low salinity	1.5-3.0	(2)
Medium salinity	3.0-5.0	(3)
High salinity	5.0-10.0	(4)
Very high salinity	> 10.0	(5)

(1) Normal for all crops.
(2) Yields of very sensitive crops restricted.
(3) Yields of many crops restricted.
(4) Only tolerant crops yield satisfactorily.
(5) Only few very tolerant crops yield satisfactorily.
(6) Gupta and Gupta (1987).

Appendix 11. Generalized guidelines for interpretation of soil analysis data.

Parameter	Unit	Low	Marginal	Adequate
OM(1)	%	< 0.86	0.86-1.29	1.29
P(1)	ppm	< 8	8-15	> 15
K(1)	ppm	< 100	100-150	> 150
Cu (1), (2)	ppm	< 0.2	-	> 0.20
Fe (1), (2)	ppm	< 4.5	-	> 4.5
Mn (1), (2)	ppm	< 1.0	1.0-2.0	> 2.0
Zn (1), (2)	ppm	< 0.5	0.5-1.0	> 1.0

(1) Source: Ryan *et al.* (1996).

(2) Source: Walsh and Beaton (1973).

Appendix 12. Guidelines for interpretation of soil solution B.(1)

B (ppm)	Classification
0.5	Satisfactory for all crops
1.0	Sensitive crops may show visible injury
5	Semitolerant crops may show visible injury
10	Tolerant crops may have visible injury

(1) Source: Walsh and Beaton, 1973.

Appendix 13. Metal levels in plant tissue. (1)

Metal	Normal	Phytotoxic
	mg kg^{-1}	
Cu	3-20	25-40
Mn	15-150	400-2000
Zn	15-150	500-1500
Cd	0.1-1.0	5-700
Pb	2-5	-

(1) Source: Cajuste *et al.*, 1991.

Appendix 14. Typical concentrations of elements in dried healthy foliage. (1)

Element	Unit	Range
N	%	0.8-3.0
P		0.08-0.35
K		0.5-2.5
Ca		1.5-2.8
Mg		0.15-0.45
B	mg kg^{-1}	10-50
Cu		5-12
Fe		40-150
Mn		30-100
Zn		30-200

(1) Source: Marr and Cresser, 1983.

Appendix 15. Standard olive leaf nutrient content for diagnostic purposes.(1), (2)

Concentration Range					
Nutrient	Unit	Deficient	Marginal	Adequate	Toxic or Excessive
N	%	< 1.4	-	1.5-2.0	-
P		-	-	0.1-0.3	-
K		< 0.4	0.4-0.8	> 0.8	-
Ca		-	-	> 1.0	-
Mg		-	-	> 0.1	-
Na^+		-	-	-	> 0.2
Cl^-		-	-	-	> 0.5
B	mg kg^{-1}	< 14	14-18	19-150	> 185
Cu		-	-	> 40	-
Zn		-	-	10-30	-
Mn		-	-	> 20	-

(1) Source: Reuter and Robinson, 1986.

(2) Standards based on Californian experiments and observations.

Appendix 16. Olive leaf nutrient content for diagnostic purposes.(1)

Element	Unit	Low	Sufficient	High
N	%	< 1.5	1.5-2.5	> 2.5
P		< 0.1	0.1-0.3	> 0.3
K		0.5-0.8	0.9-1.2	> 1.2
Ca		< 1.0	> 1.0	-
Mg		< 0.2	> 0.2	-
B	mg kg^{-1}	15-19	20-75	> 75
Mn		< 25	> 25	-
Zn		< 25	> 25	-

(1) Source: Jones, Jr. *et al.* (1991).

ملخص

تأثير الري طويل الأمد لمياه الخربة السمراء على نوعية التربة والزيتون في موقع المحطة

إعداد

نبيل محمد محمد القزاز

إشراف

أ. د. طالب أبو شرار

المشرف المشارك

أ. د. عبد الجواد الجيلاني

تم الشروع بدراسة امتدت لسنتين متتاليتين بهدف تحديد الأثر طويل المدى للري بمخرجات محطة الخربة السمراء من المياه العادمة المعالجة على خصائص تربة الموقع الكيميائية ونوعية نبات الزيتون، مع ايلاء عناية خاصة لموضوع تراكم عنصر البورون (B) والمعادن السامة الثقيلة، خاصة الكادميوم (Cd) والرصاص (Pd) في قطاع التربة وأنسجة نبات الزيتون.

ابتدئ بري أشجار الزيتون ريا سطحيا بالمياه العادمة المعالجة في محطة الخربة السمراء منذ عام 1986. تضمنت الدراسة جمع عينات تربة وورق وثمر زيتون في الثلث الأخير من شهر تشرين الأول – في تزامن مع موسم جمع الزيتون – من داخل محطة الخربة السمراء ومن موقع مجاور لها ليعتمد كمرجع نقيس به مدى التلوث الطارئ على التربة والزيتون والذي يعزى للري بالمياه العادمة المعالجة، وأخضعت العينات المجموعة لتحاليل كيميائية حسب الطرق القياسية المعتمدة.

أفادت معطيات التحاليل أن تركيز البورون (B) في محلول التربة وأيون البوتاسيوم (K^+) وتراكيز البوتاسيوم (K) المتبادل والفوسفور (P) المتاح للنبات وكذلك الحديد (Fe) والرصاص (Pb) كانت أعلى في التربة المروية بالمياه العادمة منها في تربة الموقع المرجع. أما تركيز الكادميوم (Cd) المتاح للنبات فقد كان دون مستوى الكشف في كلا الموقعين. وقد كانت الموصيلة الكهربائية

لمستخلص تربة الموقع المرجع (EC_e) وكذلك تراكيز أيونات الصوديوم (Na^+) والكالسيوم (Ca^{2+}) والمغنيسيوم (Mg^{2+}) والكلورايد (Cl^-) والبايكربونات (HCO_3^-) والنترات (NO_3^-) والكبريتات (SO_4^{2-}) أعلى منها في محلول تربة الخربة السمراء. أما نسبة المادة العضوية وتراكيز النيتروجين الكلي (N) والنحاس (Cu) والزنك (Zn) والمنغنيز (Mn) المتاح للنبات فقد كانت أعلى في تربة الموقع المرجع منها في تربة محطة الخربة السمراء.

بالنسبة لنبات الزيتون، اتضح أن الري بالمياه العادمة أدى إلى رفع محتوى ورق الزيتون من البورون (B) والنحاس (Cu) والحديد (Fe) والمنغنيز (Mn) والكادميوم (Cd) وكذا الرصاص (Pd)، وكذلك تراكيز أيونات الصوديوم (Na^+) والبوتاسيوم (K^+) والكبريتات (SO_4^{2-}) والفوسفات (PO_4^{3-}) في المستخلص المائي لورق الزيتون مقارنة بأوراق زيتون المرجع. أما بالنسبة للثمر، فقد أدى الري بالمياه العادمة المعالجة مقارنة بماء البئر في موقع المرجع إلى زيادة نسبة الدهن في لحم الثمر وكذلك تراكيز النيتروجين (N) والفسفور (P) والبوتاسيوم (K) والكالسيوم (Ca) والمغنيسيوم (Mg) والبورون (B) والحديد (Fe) والمنغنيز (Mn) والكادميوم (Cd) والرصاص (Pb).