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Reuse of municipal effluent with drip irrigation and evaluation the effect on soil properties in a semi-arid area

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Abstract Irrigation with municipal effluent was evaluated during 25 months in Southern Iran from 2003 to 2005 in which 14 tree species were irrigated with effluent and borehole water at an annual supply rate of 3,940 and 5,395 m^3 ha^{-1}, respectively. To mitigate the environmental effects, a drip irrigation system was designed and the amount of applied water based on pan evaporation was measured by flow meters and soil properties were monitored. The statistical results showed that the applied effluent had no adverse effect on soil properties. The soil salinity was reduced from 8.2, 6.8 and 7.0 dSm^{-1} to 1.07, 1.12 and 3.5 dSm^{-1} in the soil layers 0–30, 30–60 and 60–90 cm, respectively. The SAR decreased significantly, while soil pH increased by 0.8 and 0.6 units in the layers 0–30 and 30–60 cm. A total application of 9,335 m^3ha^{-1} of effluent with a nitrogen and phosphorus concentration of 7.9 and 10.3 mg l^{-1}, added 73 and 101 kg ha^{-1} of nitrogen and phosphorus to the soil. Organic carbon also increased significantly. Twenty-five months irrigation with effluent caused a slight increase in soil bulk density and a slight decrease in mean permeability. Because of an efficient filtration and high discharge rate of bubblers (drippers), no considerable sign of clogging was observed.

Keywords Municipal treated effluent · Reuse effluent · Soil properties · Drip irrigation

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Introduction

There is not always sufficiently good quality water available to meet demands for agriculture, domestic use, and industry in arid and semi-arid regions. One strategy to increase available water resources is to reuse treated sewage effluent for irrigation, and this is widely practiced in many countries. This water may contain high levels of salts, toxic ions, heavy metals, and organic residues. Accumulation of these pollutants in water and soil poses a threat to agricultural production and the environment (Abbott and Quosy 1996).

Leaching of some chemical substances, particularly nitrogen is an important factor potentially limiting the sustainability of effluent-irrigated plantations. The main sustainability issues associated with P loading in spit of slow mobility are the potential for P-rich topsoil to be eroded and washed into surface water bodies by overland flow (Myers et al. 1999). However, irrigation of tree crops is a practical means of effluent disposal on land as well as being a method of reusing effluents with minimal health risks (Stewart et al. 1990). There are many examples of such a practice in the world (e.g. Urie 1986; Stewart and Flinn 1984; Cromer et al. 1984). Cromer (1980) reviewed the potential effects of wastewater irrigation on soil properties and tree growth in Monterey pine plantations. Stewart et al. (1990) measured the accumulation of nutrients by the trees and changes in soil chemical properties as result of effluent reuse. They reported that effluent significantly increased pH throughout the soil profile, phosphorus, sodium, calcium, and magnesium were also increased in the upper profile. They concluded that overall soil chemical properties were not adversely affected by effluent irrigation and the nutrient accumulation in soil occurred mainly in the upper 0.35 m. Cromer et al. (1984) reported chemical changes in the soil and in the composition of the groundwater, which were recorded during 3 years of using effluent for tree growth. They concluded that irrigation with wastewater led to substantial increases in tree growth. Hassanli and Javan (2005) reported that treated municipal effluent could be used in plantations with trickle irrigation systems without serious concern of adverse effects on the environment. Hanna et al. (1994) and Schrale et al. (1993) reported satisfactory findings regarding the public health, environment, and technical issues in the Bolivar sewage treatment plant in South Australia. According to Sheltered (1994), the higher the sodium adsorption ratio (SAR) in irrigation water, the greater the reduction in hydraulic conductivity (K) and soil permeability. Sodium at high concentrations in irrigation water can replace exchangeable Ca^{2+} and Mg^{2+} by mass action, leading to a greater swelling and dispersion of clay particles and a reduction of the permeability and a poor aeration. If soil water salinity increases at a constant value of SAR, the negative effect of exchangeable Na^+ on permeability will decrease (Ayers and Westcott 1985; Sheltered 1994). The detrimental effect of a high SAR is diminished as the total salt concentration in the soil solution increases. CSIRO (1999) reported that the purpose of irrigating a tree plantation with drip irrigation in the VegaVega project was to find safe and sustainable ways to dispose of the effluent, and to characterize the impact of effluent irrigation on the environment. An additional benefit of using plantations is pumping water to the atmosphere by transpiration, which causes any toxic element present in the reclaimed water to be absorbed into the biomass (Myers et al. 1999).

The objective of this study was to evaluate the effects of irrigation with treated municipal effluent with drip irrigation systems on soil properties in a semi-arid area.

Materials and methods

This study was conducted from February 2003 to March 2005. Fourteen tree species were planted and irrigated with two water qualities. The total effluent applied during the experiment was 9,335 m^3ha^{-1}. To mitigate negative environmental effects of the effluent, drip irrigation was designed and the mount of applied water measured by volumetric flow meters. The study was conducted at the Marvdasht city sewage treatment site, in southern Iran (longitude 52° 42′ E and latitude 29° 47′ N) with elevation of 1,604 m above the mean sea level. Mean annual precipitation and potential evaporation are 340 and 2,585 mm, respectively. The climate is semi-arid with hot and dry summers. A flat area of approximately 1 ha was prepared for the experiment. Fourteen tree species of the genera *Cupressus*, *Pinus*, *Allantus*, *Robinia*, *Pseudoacacia*, *Platanus*, *Acer*, *Fersinos*, *Tamarix*, *Melia*, *Populus*, *Acacia* and *Eucalyptus* (two species) were planted. The soil was a silty clay loam in the top 30-cm layer, over silty loam subsoil with poor drainage conditions. Some characteristics of treated effluent and borehole water are shown in Table 1. Soil chemical characteristics prior, and after the effluent application is given in Table 2. The experiment designed as a split-plot based on randomized complete blocks with three replicates. Each of the 84 plots was 12 m by 10 m with a tree spacing of 2.5 m by 3 m (16 trees in each plot and 1,333 trees per ha) having a total surface area of 10,080 m^2. Forty-two plots were irrigated with treated municipal effluent and 42 plots with borehole water extracted from a 15-m deep well located nearly 500 m from the experimental site. The amount of irrigation water was calculated using equation: $I = K_p E_p A C_p$ in which I is the amount of irrigation water (liter), K_p: the pan factor (in this study was 0.8), E_p: cumulative

Table 1 Some chemical properties of effluent and borehole water (mean of monthly samples during a 25-month experiment, cations and anions in $mmol_c\ l^{-1}$)

Irrigation water	EC[a] (dSm^{-1})	SAR ($mmol\ l^{-1/2}$)	pH[a]	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Effluent	1.5 1.48–1.85	7.5	7.7 7.45–7.76	5.92	1.46	6.24	1.49	1.43	9.09	0.08
Borehole	2.0 1.83–2.65	14.7	7.6 7.16–7.79	10.18	4.05	7.62	1.39	1.76	18.39	0.05

EC: electrical conductivity, *SAR*: sodium adsorption ratio

[a] The ranges for EC and pH show the minimum and maximum.

evaporation from pan class A based on weekly irrigation interval (mm), A: plot area (m^2) and C_p: canopy area index as measured. Pan evaporation data collected from the nearest meteorological station (5 km far from the experimental site). Irrigation was scheduled on a weekly basis. To avoid possible surface run-off, a micro-pond was constructed around each tree. Each tree was supplied by a dripper (bubbler) connected to a 16-mm plastic lateral pipe laid along each tree row and branched from a manifold. Each manifold supplied a set of seven plots and the volume of required water controlled by a flow meter installed at upstream of each manifold. For chemical analysis, six soil sampling points, each point being located in a randomly selected individual plot, were established. In each soil sample point three samples each representing one layer (0–30, 30–60 and 30–90 cm) were removed. Totally 18 soil samples (6 plots × 3 layers) were taken before the experiment commencement and 54 soil samples (3 occasions × 6 points × 3 layers) taken, 3 occasions during and after the experiment.

The soil samples were air-dried and sieved to remove gravel (>2 mm in diameter) and finally one composite sample per layer for each occasion was provided (Stewart et al. 1990). Soil pH and EC were

Table 2 Soil chemical characteristics before, during and after the experiment (irrigated with effluent)

Soil characteristics	November 2002 (prior to irrigation)			October 2003 (during irrigation)			May 2004 (during irrigation)			March 2005 (after irrigation)		
Soil depth (cm)	0–30	30–60	60–90	0–30	30–60	60–90	0–30	30–60	60–90	0–30	30–60	60–90
EC (dSm^{-1})	8.2	6.8	7	5.8	5.5	5.2	1.9	3.2	5.2	1.07	1.12	3.5
PH	7.95	8.18	8.1	8.41	8.35	8.38	8.45	8.36	8.16	8.75	8.8	8.78
O.C ($mg\ kg^{-1}$)	Bdl	Bdl	bdl	4.4	4.4	0.5	11.2	5.1	3.2	3.5	6.4	6.10
Total N ($mg\ kg^{-1}$)	Bdl	Bdl	bdl	0.46	0.42	bdl	1.1	0.49	0.3	0.3	0.62	0.80
P ($mg\ kg^{-1}$)	4.2	2.5	1.3	15.5	8.4	5.3	13.1	6.0	1.8	7.1	7.5	5.0
K ($mg\ kg^{-1}$)	340	300	270	390	395	355	368	351.2	293.3	310	310	300
HCO_3^- ($mmol_c\ l^{-1}$)	2.4	2.8	2.5	3.5	5.8	4.7	3.6	3.6	3.0	2.3	3.8	3.90
Cl^- ($mmol_c\ l^{-1}$)	27.5	17.5	12.5	20	19.5	12.5	7.5	10.5	12.5	2.2	2.9	4.5
SO_4^{2-} ($mmol_c\ l^{-1}$)	40.25	32.25	34.25	20	15.25	18.15	3.3	5.25	17.4	3.5	3.25	13.10
Ca^{2+} ($mmol_c\ l^{-1}$)	15	10	12.5	10	7.5	7.5	2.1	3.25	9.75	1.25	1.15	4.5
Mg^{2+} ($mmol_c\ l^{-1}$)	9.0	5.0	7.5	10	8.75	7.5	2.35	2.15	3.15	1.5	1.5	3.0
Na^+ ($mmol_c\ l^{-1}$)	70	56	50	22.5	21	19.5	8.7	19	22	7.2	7.8	12.0
K^+ ($mmol_c\ l^{-1}$)	0.46	0.38	0.4	0.3	0.4	0.3	0.1	0.17	0.3	0.09	0.07	0.33
SAR ($mmol\ l^{-1/2}$)	20.2	20.4	15.8	7.1	7.4	7.1	5.8	12.8	8.7	6.2	6.8	6.2
Fe ($mg\ kg^{-1}$)	5.2	5.4	3.4	9.3	12.4	12.9	4.2	13.0	13.3	3.5	3.5	3.3
Zn ($mg\ kg^{-1}$)	1.0	0.7	0.7	0.9	0.7	0.6	1.3	2.4	4.2	0.82	1.4	1.8
Mn ($mg\ kg^{-1}$)	4.5	1.9	1.3	4.9	11.2	15.3	5.8	14.1	10.7	2.7	2.8	3.0
Cu ($mg\ kg^{-1}$)	1.8	1.1	0.8	1.7	1.5	1.2	1.38	1.9	1.1	1.4	1.3	1.2
B ($mg\ kg^{-1}$)	3.21	3.69	3.3	–	–	–	2.0	2.6	2.8	–	–	

bld: below the detection limit

measured by pH meter and EC meter from saturated soil paste extracted by vacuum pump. Organic carbon (OC) contents in soil were determined by the wet digestion method (Walkley and Black 1934), total N by the Kjeldhahl method and available P according to Olsen et al. (1958). Available K^+ and Na^+ were extracted by vacuum pump, from saturated paste and analyzed by flame emission spectrophotometer, B was analyzed by the Azomethin H method. Microelements were extracted by DTPA and analyzed by atomic absorption spectrophotometer (Page et al. 1982 and APHA 1990). Chemical characteristics of the soil irrigated with effluent were measured in four occasions (one occasion prior to irrigation and three during and after irrigation (Table 2). The 20% of the irrigation requirement considered as leaching requirement. The total nutrient loading rate was calculated using the equation: $L_p = \frac{1}{100} \times L_w \times C_p$ (Myers et al. 1999):

L_p: nutrient loading rate (kg ha^{-1}), L_w: the amount of applied effluent (mm), C_p: the average total nutrient concentration in the effluent (mg l^{-1}).

To evaluate soil physical properties, eight soil pits were dug in the eight experimental plots (four plots irrigated with effluent and four plots with borehole water). Six undisturbed core sampling in layers 0–30 and 30–60 cm (three subcore sampling in each layer to minimize the influence of micro-variations) in each pit were taken for bulk density (BD) determination (Table 4). Three different points within eight selected plots were selected for permeability measurement and a mean for each plot was obtained. The soil permeability was measured using double ring cylinders (cylinder infiltrometer method, (Garg 2004)). Soil texture was determined by hydrometer method and the soil moisture contents at field capacity and the permanent wilting point were determined by pressure plate cells at 0.33 and 15 atmospheres and the equilibrium times of 24 and 48 h, respectively. Soil physical characteristics were measured in two occasions (prior to irrigation and after the experiment). Characteristics of effluent and borehole water were measured monthly. To minimize the effect of the spatial variation of soil characteristics, the sampling points were selected adjacent to the original points that were established prior to irrigation.

Results and discussion

In sewage treatment, often about 85% of organic matter (OM) and 20% of nitrogen and phosphorus are removed (Myers et al. 1999). The Marvdasht effluent with 44.5 (41–48) mg l^{-1} BOD_5, 55 (52–58) mg l^{-1}, COD, 37 (34–40) mgl^{-1} suspended solids (SS), 7.24 mmol$_c$ l^{-1} Cl^-, and 7.5 mmol l$^{-1/2}$ SAR classified as a moderate effluent (neither low nor high hazard effluent). This effluent with 0.4 mg l^{-1} B, 7.9 mg l^{-1} N and 10.76 mg l^{-1} P (Table 3), classified as a low hazard effluent (Myers et al. 1999). Soil texture was silty clay loam in the layer 0–30 cm, silty clay from 30 to 120 cm and silty loam from 120 to 180 cm. The volumetric soil moisture content of field capacity and permanent wilting point were 22.3%, 23.9% and 23.5% and 17.4%, 18.9% and 19.4% in the soil layers 0–30, 30–60 and 60–90 cm, respectively.

Na^+, Ca^{2+} and Mg^{2+} were the dominant cations and the concentration of $HCO_3^- > Cl^- > SO_4^{2-}$. The concentrations of the anions mentioned were below the permissible levels for irrigation (Ayers and Westcott 1985). In the borehole water EC, SAR, Cl^-, HCO_3^-, SO_4^{2-}, Na^+ and Mg^{2+} were higher than in the effluent (Table 3). The only heavy metal detected by atomic absorption was Zn with 1.16 mg l^{-1} in the effluent and 0.29 mg l^{-1} in borehole water. The mean salinity of effluent and borehole water (EC) was 1.5 and 2.0 dSm^{-1}, respectively. The salinity (EC) in the soil prior to irrigation was 8.2, 6.8 and 7 dSm^{-1} in the layers 0–30, 30–60 and 60–90 cm. The leaching requirement had a significant influence on lowering the soil salinity. This significant salinity reduction shows irrigation with effluent had more effect on decreasing the salinity in upper layers and also low deep percolation has occurred in the lower layers. The

Table 3 The macronutrient contents in the effluent and borehole water (mg l^{-1})

Irrigation water	NO_2^-	NO_3^-	NH_4^+	Total N	Total P	K	B
Effluent	0.05	5.50	2.30	7.90	10.76	3.20	0.4
Borehole	0.097	10.50	0.5 0	11.10	1.78	1.80	0.3

Table 4 Mean Soil bulk density before and after irrigation (g cm^{-3})

	Before irrigation		25 months after irrigation			
	–	–	Effluent water		Borehole water	
Plots	0–30 cm	30–60 cm	0–30 cm	30–60 cm	0–30 cm	30–60 cm
Plot no. 10	1.24	1.35	1.4	1.38	1.42	1.43
Plot no. 9	1.44	1.44	1.46	1.49	1.42	1.52
Plot no. 7	1.34	1.38	1.46	1.48	1.38	1.59
Plot no. 3	1.42	1.39	1.43	1.59	1.45	1.46
Mean	1.36	1.39	1.44	1.49	1.42	1.5

reduction of SAR as shown in Table 2 is another effluent effect on the soil. This significant reduction would be mainly due to a significant decline in Na^+ compared to Ca^{2+} and Mg^{2+} due to the salinity of effluent. This shows that effluent with mean salinity of 1.5 dSm and proper management could reduce the soil salinity which is a desirable practice.

Soil chemical properties

Effluent irrigation with 1.5 dSm^{-1} salinity caused a significant reduction in the soil salinity. The salinity was reduced to 1.9, 3.2 and 5.2 dSm^{-1} in the soil layers 0–30, 30–60 and 60–90 cm after 15 months, and to 1.07, 1.12 and 3.5 dSm^{-1} after 25 months of irrigation. Measurements indicated that salinity reduction (leaching) in the lower soil layers was much less than in the upper layers. This shows a low deep percolation in the lower most layers, which is consistent with the sustainable use of effluents. Prior to irrigation, pH was 7.95 and 8.18 in the 0–30 and 30–60 cm layers. After 25 months pH had increased by 0.8 units and 0.6 units in the same layers. These results were in accordance with those obtained by Stewart et al. (1990) and Cromer et al. (1984). They found an increase of 1 and 3 U of pH using industrial effluent as irrigation. Organic carbon (OC), prior to irrigation was not detectable. Twenty-five months later it had increased significantly to 3.5 mg kg^{-1} in the top layer (0–30 cm) and to 6.4 mg kg^{-1} in the 30–60 cm layer. As shown in Table 3, the average concentration of total N, total P and K in the effluent was 7.90, 10.76 and 3.20, mg l^{-1}, respectively. By applying 9,335 m^3 ha^{-1} of effluent during the experiment a total amount of 73, 101 and 30 kg ha^{-1} of N, P and K was added to the soil. The addition of this amount of nutrients to the soil in a uniform manner by a drip system could represent a significant portion of the plant nutrient requirement. This was the reason why it was not needed to add fertilizer to the soil during the experiment.

Nitrogen was not detectable in the soil prior to application of effluent (Table 2). However, during the experiment total nitrogen increased gradually. In March 2005 (after 25 months) it rose to 0.3 and 0.6 and 0.8 mg kg^{-1} in the layers 0–30, 30–60 and 60–90 cm. Leaching of N may be an important factor potentially limiting the sustainability of effluent-irrigated plantations. When nitrogen exceeds the requirement of trees it can be easily leached out, unless it is immobilized in soil organic matter or minimize the deep percolation. In this experiment 20% leaching requirement for decreasing the soil salinity within the root zone could be a concern for N leaching from the root zone and possibly contaminating the groundwater. However, the results show that deep percolation in lower layers is not much. The main sustainability issues associated with P loading are the potential for groundwater contamination and for P-rich topsoil to be eroded and washed into surface water bodies by overland flow. Unlike $NO_3^- - N$, the mobility of P is slow and P accumulation by trees is low (Myers et al. 1999). Thus most of the applied P remains in the topsoil where it is retained by soil particles. In this study, P was not added to the soil except by effluent. Moreover, the runoff and deep percolation were controlled by drip systems. As shown in Table 2, the P concentration prior to irrigation was 4.2, 2.5 and 1.3 mg kg^{-1} in the soil layers 0–30, 30–60 and 60–90 cm. The final concentration of P after 25 months was 7.1, 7.5 and 5.0 mg kg^{-1}, respectively. This indicated an increase of P has occurred in the soil layers in spite of low mobility. Measurements showed that K changed from 340 to 310 mg kg^{-1} in the horizon 0–30 and from 300 to 310 mg kg^{-1} in the horizon 30–60 cm showing a slight leaching in upper layer.

Application of effluent for 25 months also caused 3.73 kg ha^{-1} B to be added to the soil. However, reduction of B in the soil horizons from 3.2, 3.7 and 3.3 mg kg^{-1} (prior to irrigation) to 2.0, 2.6 and 2.8 $mgkg^{-1}$ (in May, 2004) in the layers 0–30, 30–60 and 60–90 cm would be associated with the mobility of B and a possible uptake by the trees.

Statistical analyses showed a substantial change in the soil sodium concentration. Before irrigation, Na^+ was 70, 56 and 50 $mmol_c$ l^{-1} at 0–30, 30–60and 60–90 cm, whereas 25 months later a considerable reduction (7.2, 7.8 and 12 $mmol_c$ l^{-1}) was observed. This reduction could be associated with the salinity of effluent. The concentration of Ca^{2+} and Mg^{2+} also showed a considerable reduction as a result of effluent application. Initially the Ca^{2+} concentration in the 0–30 and 30–60 cm layers was 15 and 10 $mmol_c$ l^{-1} and that of Mg^{2+} was 9.0 and 5.0 $mmol_c$ l^{-1}. At the end of the experiment, Ca^{2+} had decreased to 1.25 and 1.15 $mmol_c$ l^{-1} and Mg^{2+} to 1.5 $mmol_c$ l^{-1} in the 0–30 and 30–60 cm layers. Based on the amount of irrigation applied (9,335 m^3 ha^{-1}), totally 555.4 kg ha^{-1} Ca^{2+} and 319.7 kg ha^{-1} Mg^{2+} were added to the soil during the 25 month-experiment which is good for swapping with Na^{+1}. Prior to irrigation SAR was 20.2, 20.4 and 15.8 mmol $l^{-1/2}$ in the layers 0–30, 30–60 and 60–90 cm. Twenty five months later, SAR had decreased to 6.2, 6.8 and 6.19 $(\text{mmol } l^{-1})^{1/2}$, in the three upper soil layers· This significant reduction that could improve the soil permeability is mainly due to the reduction of Na^+ in the soil and shows that effluent application in the experimental condition had significant influence on reduction of soil sodicity. The concentration of the micronutrients (Fe, Zn, Mn and Cu) in the topsoil layer (0–30 cm), prior to irrigation were slightly larger than in the deeper layers. Measurements after 25 months showed a slight reduction of these elements in the soil profile (Table 2). This reduction could be associated with plant consumption.

Soil physical properties

Bulk density (BD)

Soil physical properties can be adversely affected by increase in sodicity (high SAR or Na) or by irrigation with effluents containing high concentrations of suspended solids (Myers et al. 1999). The mean BD in the soil layers 0–30 and 30–60 cm varied from 1.36 to 1.39, and from 1.44 to 1.49 g cm^{-3}, respectively (e.g. the results of four plots are shown in Table 4). The mean BD in the plots irrigated with effluent showed an increase of 6% and 8% in the soil layers 0–30 and 30–60 cm, and an increase of 4% and 8% in the corresponding layers in plots irrigated with borehole water. The low content of organic matter in the effluent, the efficient filtration by the sand and screen filters and almost the low amount of effluent applied (9,335 m^3 ha^{-1} during the experiment) would be the reasons for a very slight change in BD of soil.

Soil permeability (intake rate)

Effluents with a high SAR (or sodicity) and low to moderate salinity are associated with a high risk of declining soil permeability, as are effluents with a high concentration of suspended solids (Myers et al. 1999). The mechanisms involved are different, but both a high SAR and high amounts of SS can lead to clogging of soil pores and a resulting decrease in soil permeability. Effluents having a SAR greater than 3 may cause an increase in soil sodicity and are therefore potentially hazardous to soil structure and permeability. The mean soil permeability at two pairs of the plots (each pair with the same number, one irrigated with effluent and one with borehole water (as the examples, plot 7 shows the trend of intake rate changes of plot 7 which was irrigated with effluent and the other plot 7 irrigated with borehole water) before and after experiment is shown in Figs. 1 and 2. The final permeability in the measured plots before experiment was 5.2 and 2.6 cm h^{-1} and 25 months after irrigation with effluent was 4 and 2.5 cm h^{-1} and with borehole water was 5 and 9 cm h^{-1}. Comparisons between the mean final permeability in the plots before and after effluent irrigation showed a reduction of 1.65 cm h^{-1}(28%); while in the plots irrigated with borehole water there was an increase of 0.65 cm h^{-1} (12%). It seems as if the higher salinity of borehole water compared to the effluent water has caused these changes, which are consistent with the findings by CSIRO (1999). Although suspended solids can cause a clogging and thus lead to a reduction in permeability, low values of SS in the effluent (34–40 mg l^{-1}) and efficient filtration system that was designed have probably reduced the effect of suspended solids on permeability.

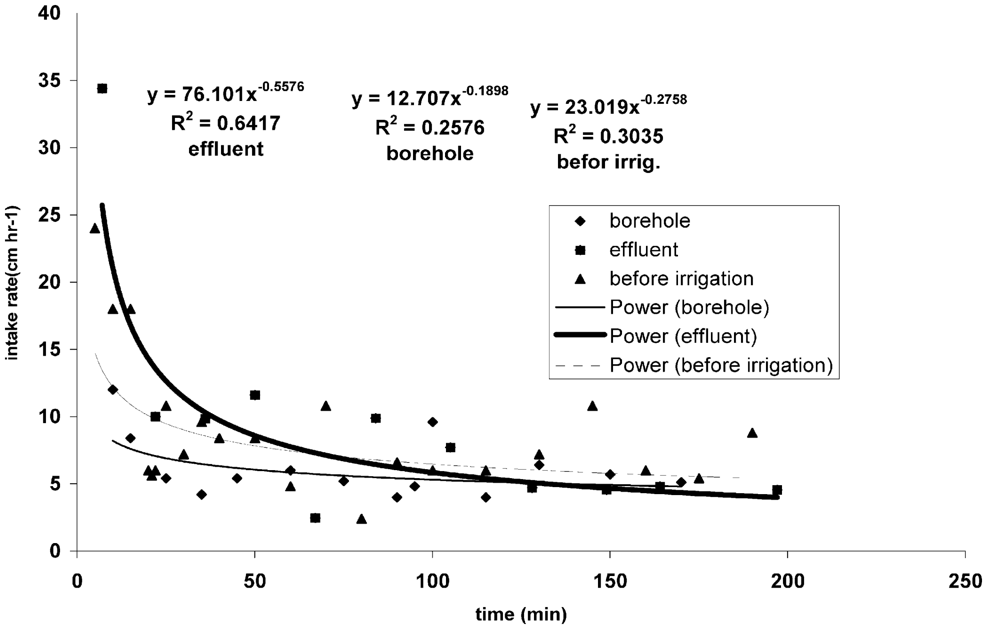

Fig. 1 Intake rate before and after irrigation with effluent and borehole water (plot 7 as an example)

Conclusion

The effect of municipal effluents on the soil properties was examined by implementing drip irrigation system. The drip systems supplied effluent and borehole water for 25 months to the experimental plots. The results showed that irrigation with a moderate treated effluent with drip systems had no adverse affects on the soil chemical properties over a 25-month period. However, in the long-term perspective the dynamics of some chemical elements such as nitrogen and sodium would require further observations. Effluents could significantly decrease the soil salinity and sodicity in soil profile within the root zone. Municipal effluents can be successfully used by applying a drip irrigation system to diminish the possible adverse

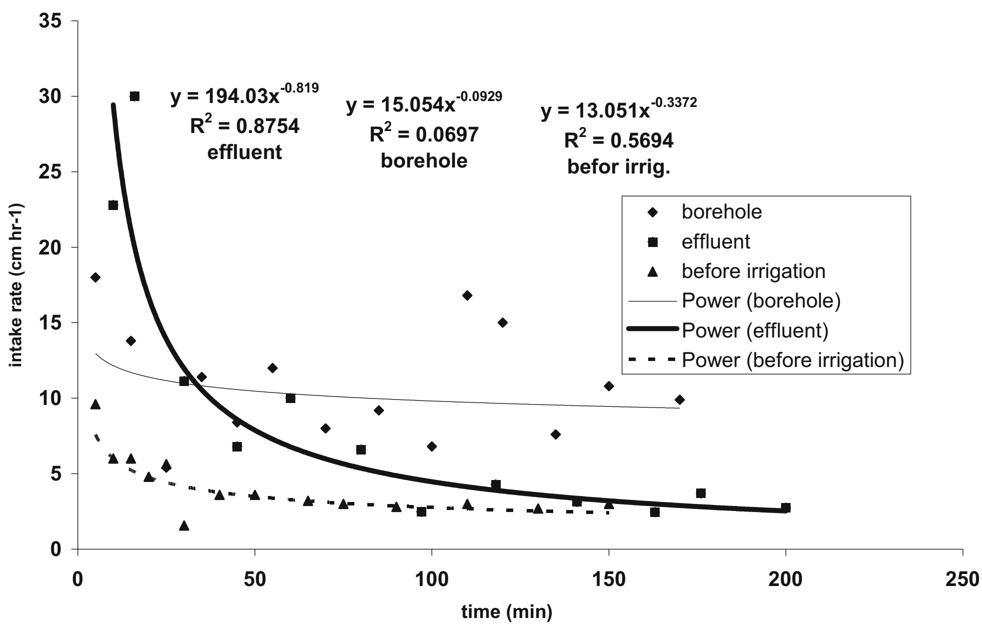

Fig. 2 Intake rate before and after irrigation with effluent and borehole water (plot 10 as an example)

effects. This will make the technique more sustainable. This study showed that land based disposal of municipal effluents by irrigating tree crops is feasible in the study region with the semi arid climate. The quality of the effluent water was slightly better than that of the borehole water at the experimental site. Thus, considering water scarcity in the study region using treated effluent as available water could be a good alternative for irrigation water. The results of this research indicated that under the present experimental conditions the effect of the effluent on tree growth was better than the effect of borehole water (Hassanli and Javan 2005). The main conclusion that may be drawn is that, considering water scarcity in arid and semiarid regions, reuse of municipal treated effluents in irrigation, particularly for plantations with drip systems may be highly recommended. A major issue relating to water reuse schemes and to this case study is sanitation concern due to the faecal coliform which was much higher than 1,000 FC/ml, recommended by WHO (1989). Thus application of chloride to reduce microbiological pollutants in this study is highly recommended.

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