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Impact of Recycled Wastewater Irrigation on Soil Chemical Properties in an Arid Region

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Abstract: The present study was undertaken to assess its impacts on soil quality. Analysis for soil was done from the area used for wastewater irrigation. Soil sample were collected from ten locations such as pasture and irrigated fields of Sistan area near Zabol city. Analysis was done for Electrical Conductivity (EC) and soil texture and key chemical parameters. Results indicated that soils (sampled to 12 cm) from pasture with RWW irrigation exhibited 0.3 units of higher pH and 172, 34 and 40% higher concentrations of extractable Na, B and P, respectively. Compared with sites irrigated with surface water, sites irrigated with RWW exhibited 176% higher EC and 485% higher Sodium Adsorption Ratio (SAR). Comparison of soil chemical properties before and 3 or 5 year after RWW irrigation on two parts of pasture also revealed the following findings: 89 to 136% increase in Na content; 44 to 63% increase in B content and 88 to 116% increase in P content at the surface depth. Regular monitoring of site-specific water and soil and appropriate management are needed to mitigate the negative impacts of sodium and salts accumulations.

Key words: Irrigation, environmental, Pasture, surface water, soil texture

INTRODUCTION

The environmental problems emphasize the urgent need to evaluate the available natural resources and their requirement by a rapidly growing human population (Hardin, 1993). All the basic natural resources including the land, water, energy and biota have been inherently limited for human use (Lubchenco, 1998). As the human population continues to grow, the water is being divided amongst the increasing number of people.

The rapid population growth in many municipalities in the arid eastern Iran continues to place increasing demands on limited fresh water supplies. Many cities and districts are struggling to balance water use among municipal, industrial, agricultural and recreational users. Treated or recycled wastewater appears to be the only water resource that is increasing as other sources are dwindling. Use of Recycled Waste Water (RWW) for irrigating landscapes is often viewed as one of the approaches to maximize the existing water resources. Often, recycled wastewater contains different levels of dissolved solids, nutrients (N and P) and other elements. Nitrogen, P and K are three important elements in maintaining a healthy turf stand with N producing the greatest growth response.

Research done in the central Iran has indicated that dense, well-managed turf grass areas are among the best bio-filtration systems available for removal of excess nutrients and further reclamation of recycled wastewater. Pasture was the earliest and currently the leading urban landscape users of RWW in southeastern Iran. Recently, this reuse practice has been extended to include some of the large area, open spaces and greenbelts. There is limited information available in the arid eastern Iran concerning effects of irrigation with RWW on soil chemical characteristics. Most research addressing this issue has been conducted in the center Iran where the soil type and climate conditions are quite different from Sistan region. Research is needed to examine the impact of different term RWW irrigation on soil chemical properties in hot regions. In this study, we examine the soil chemical properties of 5 part of Sistan that have been irrigated with RWW for 3 to 14 year, in comparison with 5 pasture with similar age ranges, soil texture, landscape management regimes and plant species, but use surface water for irrigation and assess changes in soil chemical properties after 3 to 5 year of RWW irrigation on two selected part of pasture.

MATERIALS AND METHODS

Study sites: This research study was conducted from 21st October, 2003 to 03 December, 2007 (but some data available from 1990) in Sistan, Iran. Ten sites were selected from Sistan region pasture, for the study. Sistan has an arid climate. The average annual precipitation is 6

Table 1: Age, years of recycled wastewater irrigation (RWI) and surface texture soil of pasture selected for the study to evaluate Recycled Waste Water (RWW) irrigation on soil properties and landscape plant health

Years of RWS	Water surface	Surface texture classification
3	RWW	Sandy loam
5	RWW	Sandy loam
8	RWW	Sandy loam
11	RWW	Sandy loam
14	RWW	Sandy loam
	Ditch	Sandy loam
	Ditch	Sandy loam
	Ditch	Sandy loam
	Ditch	Sandy loam
	Ditch	Sandy loam

Table 2: Average water quality values of ditch water and Recycled Waste Water (RWW) from advanced wastewater treatment plants in Sistan

	Average	
Parameters	Recycle wastewater	Ditch water
pH	8.60	8.10
Eelectrical conductivity (mmhos cm^{-1})	2.10	0.30
Sodium Absorption Ratio (SAR)	4.20	1.10
Adjusted SAR	7.30	1.40
Total P (mg L^{-1})	0.60	0.20
Total dissolved salts (mg L^{-1})	716.00	181.00
Na (mg L^{-1})	102.00	17.00
Cl (mg L^{-1})	98.00	12.00
Bicarbonate (mg L^{-1})	118.00	69.00
Ca (mg L^{-1})	83.00	21.00
Mg (mg L^{-1})	18.00	9.00
Sulfate (mg L^{-1})	180.00	29.00
B (mg L^{-1})	0.27	0.06
Fe (mg L^{-1})	0.41	0.47
K (mg L^{-1})	14.70	1.10

and 7 cm in East and West of the Sistan, respectively. The main soil series and surface texture for the 10 sites were obtained with the assistance of the Natural Resources Center (NRC) of the Sistan (Table 1). All of the pasture was in a hyperthermic soil temperature regime. Among these pasture, five had been irrigated with RWW for 3, 5, 8, 11 and 14 year, respectively, in 2005 (Table 1). On all recycled wastewater irrigation sites, RWW from wastewater treatment plants are stored in irrigation ponds and used exclusively as the irrigation source. Turf grass grown on pasture were perennial ryegrass (*Lolium perenne* L.), Kentucky blue-grass (*Poa pratensis* L.), *Cyperus* sp., *Cynodon dactylon* pasture received approximately 55 cm of RWW.

Five parts of pasture with similar ranges in age, soil texture, landscape management regimes and plant species, but irrigated with surface water were selected as controls (Table 1). Most of the surface water comes from Helmand River good quality (Table 2). The Helmand River rises in the mountainous region of north Afghanistan and flows in a westerly direction towards Iran-Afghamistan border to meet the Hamoun lakes. Pasture received approximately 70 cm of irrigation water annually. The average water quality values of water and recycled wastewater used in the 10 selected parts of pasture are presented in Table 2.

Sampling from study area: A total of 120 soil samples (60 samples were from pasture with RWW irrigation and 60 were from pasture with surface water irrigation) were collected to a depth of 15 cm from these pasture points in 2004-2005 to test soil chemical properties. This sampling depth is very common in pasture where turf is mowed to less than 3.5 cm height and majority of turfgrass roots are concentrated in the surface 10 cm. Soil samples were tested by Zabol University Laboratory. Parameters of each soil sample tested included pH; extractable salt content (Ca, Mg, K, Na, Fe, Mn, Cu, Zn, P and B); base saturation percent of Ca, Mg, K and Na; Soil Organic Matter (SOM) content and Cation Exchange Capacity (CEC). Zabol University Laboratory soil-testing lab provided information on analytical methods. Soil pH was analyzed using a saturated paste extract. Sieved soil samples were extracted using the Mehlich III extractant (0.015 M NH_4F+0.20 M CH_3COOH+0.25 M NH_4NO_3+0.013 M HNO_3+0.0005 M EDTA chelating agent) to determine Ca, Mg, K, Na, Fe, Mn, Cu, Zn, B and P by inductively coupled plasma-emission spectrophotometry instrumentation. Mehlich III extracted Ca, Mg, K and Na plus soil buffer pH data are used to calculate CEC. Base saturation percent of Ca, Mg, K and Na was calculated by dividing the extracted Ca, Mg, K and Na by the calculated CEC, respectively. Base saturation percent of Na is considered the Exchangeable Sodium Percentage (ESP). Soil organic matter was determined by reaction with $Cr_2O_7^{2-}$ and sulfuric acid. The remaining unreacted $Cr_2O_7^{2-}$ is titrated with $FeSO_4$ using ortho-phenanthroline as an indicator and oxidizable organic matter was calculated by the difference in $Cr_2O_7^{2-}$ before and after reaction (Nelson and Sommers, 1982). In 2006, three additional soil samples from each site were collected to measure soil EC and SAR of saturation paste in the Soil, Plant and Water Analytical Lab at Zabol University. Electrical conductivity of soil saturation paste extract was determined with a conductivity meter. Cation (Ca, Mg and Na) concentrations of saturation paste extracts were analyzed by inductively coupled plasma-emission spectrophotometry instrumentation and SAR was calculated.

Soil tests before and 3 or 5 years after recycled wastewater irrigation: At pasture I and pasture II, soil samples were collected before (1998 and 1990, respectively) and 3 or 5 year after the commencement of recycled wastewater for irrigation (2005 and 1995, respectively). Soil sampling depth and soil analysis protocols were the same as previously described. The before and after comparisons provide indications about the impacts of RWW irrigation on soil chemical properties. However, one of the disadvantages of the before and after comparison of soil chemical properties is the inability to separate the effects of RWW constituents and the effects of irrigation water itself.

Data analysis: Data were subjected to analysis of variance (SAS, 1991) to test the effect of irrigation water source on individual soil chemical characteristics. Significant differences in soil chemical properties before and 3 or 5 year after RWW irrigation were also determined using an analysis of variance ($p<0.05$).

RESULTS AND DISCUSSION

Comparison of reuse sites surface water irrigated sites: Sites irrigated with RWW exhibited an average soil salinity 4.7 mhos cm^{-1} that was 212% higher than site irrigated with surface water EC 1.7 mmhos cm^{-1} (Table 3).

Variations in increase in EC under RWW irrigation appeared to relate to soil texture and drainage effectiveness. Previously, Qian *et al.* (2001) reported that the salinity levels that caused 25% shoot growth reduction were 3.2 (mmhos cm^{-1}) for a salt-sensitive Kentucky bluegrass cultivar and 4.7 mhos cm^{-1} for a salt-tolerant Kentucky bluegrass cultivar. It is apparent that the salinity build-up in sites irrigated with RWW would result in growth reduction of salt sensitive Kentucky bluegrass cultivars that may slow the recovery of erosion from over grazing and/or other biotic and abiotic stresses. We have observed salinity stress for sites with long-term RWW irrigation, especially for sites with fine soil texture and poor drainage. Several sites on IV of the pasture, which had been irrigated with RWW for 14 year, were replaced by more salt-tolerant grass, such as alkaligrass *Puccinellia distans*, *Aeluropus* sp., *Jgphacea* sp., *Typha* sp. and *Phragmites communis*. Soils from sites with RWW for irrigation exhibited 188% (279 mg kg^{-1}) higher concentration of extractable Na and 28% higher concentration of extractable Ca than sites irrigated with surface water (Table 3). The high Na content reflected the greater than six fold increase in Na via RWW. The average Na concentration of over 35 RWW samples collected was 102 mg L^{-1}, ranging from 32 to 180 mg L^{-1} (Table 2). Runoff of P was likely to be minimal from turf sites due to the dense vegetation cover that could effectively prevent P runoff. Soil pH was higher (approximately 0.5 units) in RWW-irrigated sites than in the control sites. Increases in soil pH under land application of wastewater have been previously reported by Schipper *et al.* (1996), Pepper and Mancino (1992) and Qian and Mecham (2005). In New Zealand, Schipper *et al.* (1996) found an increase in soil pH by 0.8 units after applying tertiary-treated domestic wastewater to a forest site for 3 year at 4.9 cm week^{-1}. In addition, in Colorado, Qian and Mecham (2005) found an increase in soil pH by 0.3 units after applying tertiary-treated domestic wastewater to a Golf Course site for 5 year in via RWW. The researcher suggested that the rise in soil pH was likely related to a high rate of denitrification that produced hydroxyl ions. Pepper and Mancino (1992) found that effluent water irrigation increased soil pH by 0.1 to 0.2 units when compared with potable water irrigation. The soil pH increase in present study likely resulted from the 0.5 unit higher pH and higher bicarbonate concentration in RWW than surface water. The average bicarbonate concentration in the RWW was 118 mg L^{-1}. The small magnitude of increase in soil pH in this study suggests the effectiveness of management in controlling soil pH.

Table 3: Mean soil chemical properties pasture courses with recycled wastewater irrigation vs. surface water irrigation

Soil parameters	Recycled wastewater irrigation	Surface water irrigation
pH	8.6***	8.1
Cation exchange capacity (mg 100 g^{-1})	33.4	29.9
Na (mg L^{-1})	427.0***	248.0
Ca (mg L^{-1})	4623.0*	3616.0
Mg (mg L^{-1})	531.0*	624.0
B (mg L^{-1})	1.6*	1.2
Fe (mg L^{-1})	148.0**	190.0
Mn (mg L^{-1})	63.0**	46.0
Cu (mg L^{-1})	3.9**	6.3
Zn (mg L^{-1})	12.7	11.9
Al mg L^{-1})	231.0**	316.0
K (mg L^{-1})	412.0	387.0
Ca (%)	79.6	78.3
Mg (%)	18.6**	22.7
K (%)	9.6	10.3
Na (%)	10.7**	3.3
Soil organic matter (%)	3.6**	2.2
Electrical conductivity (mmhos cm^{-1})	4.7**	1.7
Sodium absorption ratio	9.6***	1.3
Extractable P (mg L^{-1})	63.0***	45.0

*Significantly different from surface water-irrigated sites at $p \leq 0.005$.
**Significantly different from surface water-irrigated sites at $p \leq 0.05$.
***Significantly different from surface water-irrigated sites at $p < 0.001$

Soil B content was about 34% higher in the RWW-irrigated sites than in surface water-irrigated sites. Although the average B concentration in the RWW was only 0.16 mg L^{-1}, lower than the permissible limits for the allowable concentration of B in irrigation water presented by Van der Leeden *et al.* (1990), we consistently observed an increase in B content in the soil. Likely the accumulation of B was associated with the borate adsorption by soil. With increasing soil pH, B adsorption by soil would increase, reaching the maximum B adsorption by soil at a pH of 9 (Ayers and Westcot, 1985).

Despite the fact that Mg content was two fold higher in RWW than surface water (Table 2), soil Mg content was 18% lower in RWW-irrigated sites than the control sites (Table 3). The cation exchange site occupied by Mg was reduced, reflecting the replacement of this element with Na.

The ESP and SAR for RWW irrigated sites was 224 and 638% higher than the surface water-irrigated soil, respectively (Table 3). Soil ESP and SAR would have continued to increase without the regular amendment of Ca products. In soil collected from the rough at pasture II that was not amended with Ca products, the ESP rose to as high as 17.0. Although the ESP and SAR values on pool are not high enough to be classified as a sodic soil, Halliwell *et al.* (2001) stated that the dispersion and deflocculation effects of sodicity might be evident in soils that are well below reported threshold values. Long-term uses of RWW with marginal high SAR may result in reductions of soil infiltration and permeability in clayey soils and for sites with high traffic and compaction pressure. Further research is needed to monitor soil hydraulic properties for sites irrigated with RWW. Our results indicated predominant differences in soil SAR; EC; ESP; extractable soil Na, Ca, P, B and Mg concentration; and soil pH between RWW-irrigated and surface water-irrigated sites ($p<0.05$). Differences in CEC, SOM and K content between the two types of irrigation sites were not significant.

Soil analysis at two parts of pasture before and 3 to 5 years after recycled wastewater irrigation: At pasture I, we observed an increase of Na by 372 mg kg^{-1} (135%) after 3 year of irrigation with RWW (Table 4). This is higher than the Na increase observed in a sandy loam soil at pasture II. Pepper and Mancino (1992) reported an increase of water-extractable Na content by 155 mg kg^{-1} after 3.2 year of using RWW in a bermudagrass [*Cynodon dactylon* (L.) Pers.] fairway in Arizona. The increase in soil Zn (by 82%), B (by 55%) and P (by 88%) content after 3 year of RWW irrigation were also significant (Table 4). The increased Na, Zn, B and P in the soil solution reflected the characteristics of RWW. We did not observe significant differences in soil pH or K content. The addition of an S burner in the irrigation system appeared to effectively prevent the increase of soil pH by RWW for irrigation.

At pasture II, soil Na, Mg, Mn, P, B and K content were increased by 192, 137, 13, 43, 0.3 and 262 mg kg^{-1}, respectively, after 5 year irrigation with RWW (Table 5). These corresponded to 85, 42, 20, 116, 13 and 80% increases. We also observed an increased SOM after 5 year And of RWW irrigation, which likely resulted from input of organic C from turfgrass roots.

Table 4: Mean soil chemical properties from pasture No. 1 before and 3 year after recycled wastewater irrigation

Soil parameters	Before	After
pH	8.4	8.5
Na (mg L^{-1})	226.0	534.0
Ca (mg L^{-1})	7432.0	7842.0
Mg (mg L^{-1})	873.0	734.0
B (mg L^{-1})	0.9	1.3*
Fe (mg L^{-1})	63.0	57.0
Mn (mg L^{-1})	63.0**	46.0
Cu (mg L^{-1})	3.9	6.3
Zn (mg L^{-1})	2.7	4.9**
Al mg L^{-1})	181.0	35.0**
K (mg L^{-1})	217.0	236.0
Ca (%)	69.0	70.0
Mg (%)	18.6	16.7
K (%)	1.3	1.5
Na (%)	2.7	4.3**
Soil organic matter (%)	0.6	1.2
Electrical conductivity (mmhos cm^{-1})	6.3	6.5
Sodium absorption ratio	9.6	9.3
Extractable P (mg L^{-1})	93.0	175.0***
Cation exchange capacity (Meg 100 g^{-1})	51.4	56.9

*Significantly different from surface water-irrigated sites at $p\leq 0.005$. **Significantly different from surface water-irrigated sites at $p\leq 0.05$. ***Significantly different from surface water-irrigated sites at $p<0.001$

Table 5: Mean soil chemical properties from pasture No. II before and 5 year after recycled wastewater irrigation

Soil parameters	Before	After
pH	8.4	8.5
Na (mg L^{-1})	226.0	418.0***
Ca (mg L^{-1})	2561.0	3134.0
Mg (mg L^{-1})	325.0	462.0*
B (mg L^{-1})	1.1	1.3*
Fe (mg L^{-1})	83.0	117.0
Mn (mg L^{-1})	63.0	76.0
Cu (mg L^{-1})	3.9	6.3
Zn (mg L^{-1})	2.7	4.9
Al mg L^{-1})	281.0	375.0**
K (mg L^{-1})	327.0	589.0**
Ca (%)	71.0	66.0**
Mg (%)	18.6	19.7
K (%)	6.3	7.5**
Na (%)	5.7	8.3*
Soil organic matter (%)	0.9	2.3**
Electrical conductivity (mmhos cm^{-1})	2.3	4.5
Sodium absorption ratio	6.6	8.3
Extractable P (mg L^{-1})	37.0	80.0***
Cation exchange capacity (Meg 100 g^{-1})	16.2	23.4

*Significantly different from surface water-irrigated sites at $p\leq 0.005$. **Significantly different from surface water-irrigated sites at $p\leq 0.05$. ***Significantly different from surface water-irrigated sites at $p<0.001$

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