Chemosphere 119 (2015) 654–661

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Impact of reclaimed water irrigation on soil health in urban green areas

Weiping Chen [a,*], Sidan Lu [a], Neng Pan [a], Yanchun Wang [b], Laosheng Wu [c]

[a] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[b] Beijing Garden Scientific Research Institute, Beijing 100102, China
[c] Department of Environmental Sciences, University of California, Riverside, CA 92521, United States

HIGHLIGHTS

- Reclaimed water irrigation improved soil nutrient conditions.
- Salinity increasing but no salinization occurred under reclaimed water irrigation.
- Difference of soil heavy metals contents under reclaimed and tap water irrigation is insignificant.
- Reclaimed water irrigation improved significantly soil microorganism activities.

ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 9 July 2014
Accepted 13 July 2014
Available online 24 August 2014

Handling Editor: Keith Maruya

Keywords:
Reclaimed water irrigation
Soil nutrients
Soil salinity
Soil heavy metal pollutions
Soil microbial activities

ABSTRACT

Rapid increase of reclaimed water irrigation in urban green areas requires investigating its impact on soil health conditions. In this research, field study was conducted in 7 parks in Beijing with different histories of reclaimed water irrigation. Twenty soil attributes were analyzed to evaluate the effects of reclaimed water irrigation on the soil health conditions. Results showed that soil nutrient conditions were ameliorated by reclaimed water irrigation, as indicated by the increase of soil organic matter content (SOM), total nitrogen (TN), and available phosphorus (AP). No soil salinization but a slight soil alkalization was observed under reclaimed water irrigation. Accumulation of heavy metals in soil was insignificant. It was also observed that reclaimed water irrigation could significantly improve the soil microorganism activities. Overall, the soil health conditions were improved with reclaimed water irrigation, and the improvement increased when the reclaimed water irrigation period became longer.

1. Introduction

In urban areas, demand for water has been increasing steadily, owing to population growth, industrial development, and needs for environmental enhancement. Irrigation with reclaimed water has become one of the important alternatives to sustain the existing water resources and enhance current urban water supplies in many cities (Biggs and Jiang, 2009). The conservational benefits of reclaimed water reuse in landscape irrigation are obvious (Anderson, 2003). Furthermore, it can reduce nutrient discharges into downstream and benefit the soil and plants as reclaimed water often contains high contents of N and P, and many micronutrients (Duncan et al., 2009; Martinez et al., 2011).

The safety of reclaimed water irrigation was occasionally questioned as some potential hazardous compounds like salts and heavy metals were reported to accumulate in soils under reclaimed water irrigation, thus reducing the soil functions (Toze, 2006). Field investigations had been conducted on heavy metal pollution (Smith et al., 1996; Kang et al., 2007; Xu et al., 2010; Yang et al., 2011), salinity (Stevens et al., 2003; Qian and Mecham, 2005; Wang et al., 2007; de Miguel et al., 2013), and microbial activities (Chen et al., 2008; Truu et al., 2009; Jiao et al., 2010; Adrover et al., 2012) in soils receiving reclaimed water from various sources and with different lengths of irrigation. But there was no conclusive report since the impact of reclaimed water irrigation on soil depends largely on the quality of reclaimed water, which varies with influent water characteristics and treatment process, irrigation practices, soil properties, plant characteristics and local climate conditions. So far, there were few comprehensive investigations including all these attributes to illustrate the impact of reclaimed water irrigation on soil health.

As the capital of China, Beijing has taken great efforts in municipal wastewater reclamation and reuse to satisfy the ever increasing demand for water. The city has become the national leader of reclaimed water reuse in recent years. In 2010, 680 million tons

* Corresponding author. Tel./fax: +86 10 62843981.
E-mail address: wpchen@rcees.ac.cn (W. Chen).

http://dx.doi.org/10.1016/j.chemosphere.2014.07.035
0045-6535/

of reclaimed water from the municipal wastewater reclamation and recycling system was reused in Beijing, accounting for 19.3% of its total annual water consumption (Chang and Ma, 2012). The annual reuse amount is expected to be over 1000 million tons in 2015.

There were more than 60000 hectares urban green areas in Beijing, which consume about 220 million tons of water annually (Wang et al., 2011). To promote the reclaimed water irrigation, the government required all the parks to use reclaimed water for irrigation whenever it is possible. With the growth in reclaimed water reuse, it is imperative to understand the responses of urban landscape plants and soils to reclaimed water irrigation to assure the long-term success of this practice. The information will be useful to landscape planners and managers to determine what should be monitored and what proactive steps should be taken to minimize any negative effects of reclaimed water use.

The objective of this research was to comprehensively evaluate the effect of reclaimed water irrigation on urban green areas soil health conditions including nutrient conditions, salinity, heavy metal pollution, and microbial activities. Totally, 20 soil attributes were selected and measured. Seven parks with different lengths of reclaimed water irrigation in Beijing were selected for the investigation.

2. Materials and methods

2.1. Soil sampling

Field investigations were conducted in late May, 2011, in Beijing. Plots in 7 parks located inside the 5th Ring Road of Beijing were selected for soil sampling. The region has a typical monsoon-influenced semi-humid continental climate with annual mean precipitation of about 520 mm, annual mean temperature of 13.1 °C, and annual mean evaporation of about 980 mm. The rainfall is unevenly distributed during the year, with more than 70% of the rainfall concentrated in July, August and September. Table 1 summarized some of the basic soil properties for these sites. The sites have Fluvo-aquic soil with soil pH ranging from 8.2 to 8.8, sand content ranging from 65.0% to 79.1%, silt content ranging from 15.9% to 28.5%, and clay content ranging from 4.8% to 6.5%.

Information for the sampling sites is also described in Table 1. The sampling plots had irrigated with reclaimed water for 3–9 years. The amount of reclaimed water irrigation was about 400 mm per year using typical local management practices (if no precipitation, the plots were irrigated 2–3 times per week during the growth season with drip irrigation or sprinkler irrigation).

Four plots irrigated with reclaimed water were randomly selected at each park. At each plot, paired soil samples were taken at depths of 0–10 cm, and 10–20 cm using a 5 cm bucket auger. Each of the paired soil samples was a composite of five to seven sub-samples that were taken randomly from the entire grassland plot (greater than 300 m^2). Approximately 1 kg of composite soil was collected from each plot. Eleven control plots were selected in 3 of the 7 parks. Soil sampling for the control plots followed the same method as described above. The control plots were irrigated with tap water following similar irrigation practices as those using reclaimed water. Table 2 shows some basic properties of reclaimed water (RW) and tap water (TW) used in the parks.

The soil samples were air dried, ground and screened to pass a sieve with 10 mesh openings or 100 mesh openings (for analysis of different attributes), and stored in the plastic bags for further analysis.

2.2. Soil samples analysis

Based on results from existing literatures, a total of 20 attributes reflecting the soil health conditions were measured, including (1) soil nutrient condition attributes of soil pH (pH), soil organic matter content (SOM), total nitrogen (TN), available phosphorus (AP); (2) soil salinity related attributes of electrical conductivity of the saturated soil-paste (EC_e), sodium adsorption ratio (SAR), and total porosity (TP) and total boron (TB); (3) soil heavy metal contents of As, Cd, Cr, Cu, Pb, Zn; and (4) soil microbial attributes of soil microbial biomass carbon (MBC), enzyme activity of urease, alkaline phosphatase, invertase, dehydrogenase, and catalase.

Soil pH was determined in distilled water at a soil-to-solution mass ratio of 1:5 by a Mettler-Toledo 320-S pH meter. Soil organic matter, total nitrogen and available phosphorus were determined based on Bao (2000) by external heating method for the determination of potassium dichromate, potassium dichromate-sulfuric acid digestion and Olsen method, respectively.

Electrical conductivity of the soil extracts at soil and water ratio of 1:5 ($EC_{1:5}$) was measured by a Mettler Toledo 326 conductivity meter. $EC_{1:5}$ was then transformed to EC_e based on the results of Li et al. (1996). SAR was obtained based on the concentrations of Na^+, Ca^{2+} and Mg^{2+} determined by ICP-OES. Total porosity was determined by ring sampler method.

Aliquots of 0.25 g finely ground soil were digested using a 4-acid mixture containing 10 ml HCl, 5 ml HNO_3, 5 ml HF, and 3 ml $HClO_4$. Digested extracts were combined with 1:1 aqua regia and made up to 50 ml with deionized water for the soil Cu, Zn, Cr con-

Table 1
Number of plots, irrigation histories, and irrigation water sources for the treated and control plots, and some basic soil properties in the 7 sampling parks.[a]

Site		TRT	LT	BTB	LY	RCEES	CY	OFP
Treated plots	Number	4	4	4	4	4	4	4
	Irrigation history	9 years	9 years	9 years	9 years	6 years	4 years	3 years
	Irrigation water source	RW#1[b]	RW#1	RW#1	Self-produced	RW#3[d]	RW#2[c]	RW#2
Control plots	Number	4	–	3	–	4	–	–
	Irrigation water source	TW	–	TW	–	TW	–	–
Soil properties	Bulk density (g cm^{-3})	1.45	1.51	1.44	1.46	1.39	1.36	1.65
	pH (–)	8.38	8.44	8.20	8.63	8.61	8.60	8.71
	Clay (%)	4.86	6.30	4.78	5.08	6.49	6.55	5.90
	Silt (%)	15.94	21.13	16.14	19.27	22.84	28.45	23.56
	Sand (%)	79.19	72.58	79.08	75.64	70.67	65.00	70.53
	CEC (cmol kg^{-1})	21.4	13.9	11.1	19.3	17.0	13.3	32.4

[a] TRT means Taoranting Garden; LT means Longtan Park; BTB means Beijing Teaching Botanical Garden; LY means Liuyin Park; RCEES means Research Center for Eco-environmental Sciences; CY means Chaoyang Park; OFP means Olympic Forest Park. RW represents reclaimed water; TW represents tap water.
[b] From Beijing sixth water source plant, under treatment process of anaerobic–anoxic–oxic denitrification biofilter, film filter and ozone oxidation.
[c] From Beixiaohe effluent treatment plant, under treatment process of membrane bio-reactor + reverse osmosis.
[d] Self-produced from Research Center for Eco-environmental Sciences, under treatment process of activated carbon filter and ozone oxidation.