Environmental Science and Pollution Research (2022) 29:17570–17579
https://doi.org/10.1007/s11356-021-16983-9

RESEARCH ARTICLE

The effects of reclaimed water irrigation on the soil characteristics and microbial populations of plant rhizosphere

Pei Liang[1,2] · Xiao Jingan[1,2] · Sun Liying[1]

Received: 27 April 2021 / Accepted: 6 October 2021 / Published online: 20 October 2021

Abstract

In this paper, the effects of irrigation with different water qualities on the soil characteristics of 8 kinds of garden plants were analyzed. The results showed that soil pH (ranging at 7.76–8.73) had no significant difference in different soils compared with the contrast treatment. Under the reclaimed water irrigation, the content of soil total salinity, chloride ions, and water soluble sodium in soil of most plants was averagely 160.3%, 83.3%, and 67.5% higher than that of tap water, respectively. The influences of reclaimed water irrigation on soil nutrients were changed with the types of plants. The content of soil organic matter and the available potassium showed no significant differences in most plants. Compared with the tap water irrigation, the content of alkaline nitrogen in 5 plants increased (averagely 25.8%) after 5-year irrigation with reclaimed water. In terms of soil microorganism, the increase of soil microbial population, including bacteria, fungus and actinomycetes, has been promoted by different levels of reclaimed water irrigation, which is closely related with soil nutrients.

Keywords Reclaimed water · Soil nutrients · Microbes · Actinomycetes · Fungus · Total salinity

Introduction

The source of reclaimed water is generally urban sewage, including sewage, partial industrial effluent, and trapped rainwater. In addition to containing conventional pollutants, heavy metals, and dissolved salts, urban sewage contains a variety of refractory organics, pathogens, viruses, and certain parasitic eggs (Lu et al. 2020a, b; Solaiman and Micallef 2021; Rachmadi et al. 2021; Martinez-Piernas et al. 2021). Modern sewage treatment technology to treat wastewater as reclaimed water is very effective and reliable. According to the long-time experience of reclaimed water reuse and a large number of scientific studies, reclaimed water recycling is normally accepted for both public health and environmental safety (Gu et al. 2018; Martínez-Piernas et al. 2019; Hu et al. 2021). It was reported that the reuse of reclaimed water for farmland had reached 20 million ha, and the reclycle amount is supposed to increase greatly due to the water crisis (Zhang et al. 2018).

However, the hazards from substandard industrial waste water in the urban sewage system increased the risk of reclaimed water recycling. Soil properties may change with different pollutions in the reclaimed water. For example, pH would be influenced by the acidity pollutions, soil elements would change with organic chemicals, and soil capacity of holding nutrient elements would alter electrical conductivity (EC) (Zalacáin et al. 2019a, b; Romero-Trigueros et al. 2019; Lu et al. 2020a, b). Toxic elements and organic pollutions may be transferred to soils by reclaimed water irrigation (Gu et al. 2018; Pablos et al. 2018; Wang et al. 2019; Meng et al. 2021). The influences of reclaimed water irrigation on the microbial health risks were also reported (Moazeni et al. 2017; Farhadkhani et al. 2018; Gomez-Bellot et al. 2020; Chopyk et al. 2020; Xie et al. 2021; Abadia et al. 2021). The population of microorganisms is affected by the quality of reclaimed water, method of irrigation, and the type of plant (Singer and Brown 2018; Li et al. 2020). For example, the reclaimed lawn irrigation could increase the population of root microbe, while has no significant effects

Responsible editor: Elena Maestri

✉ Sun Liying
sunliying@igsnrr.ac.cn

1 Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, People's Republic of China

2 University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China

on the microbial community in the root layer (Guo et al. 2006). The Shannon index (H'), Pielou evenness index (J_{si}) and the Margalef richness index (R1, R2) changed with the reclaimed water irrigation as well (Chen et al. 2014).

Water quality should be identified according to the needs of different types of crops and irrigation methods when applying the reclaimed water irrigation (Moller et al. 2005; Morillo et al. 2007; Gwenzi and Munondo 2008; Romero-Trigueros et al. 2019; Deviller et al. 2021). Therefore, standards for reclaimed water were developed in many countries. The potential harm of the reclaimed water irrigation to green space plants, soil pollution, and the decline of groundwater quality were discussed in the previous studies (Lyu and Chen 2016; Xiao et al. 2017; Hu et al. 2018; Lyu et al. 2019; Wu et al. 2020; Lu et al. 2021). Currently, no harmful effects were demonstrated in short term in domestic studies of tertiary reclaimed water irrigation on green space, lawns, and golf course (Lu et al. 2016a, b). However, the effects of reclaimed water irrigation on soil environment of garden plants are not well explained. For this situation, this study investigated the effects of reclaimed water with different water qualities on soil physical and chemical properties of several common garden plants, comparing with contract treatment irrigated by Tap water. Potted experiments in 8 kinds of plant were carried out in Baoding city, Hebei province. The annual average water resource per capita in Baoding city is 282 m^3, which suggest that Baoding City is facing huge water shortage crisis. Hence, alternative water resources are significant for the regional sustainability. Meanwhile, surface water suffers serious pollution. According to China environmental quality standard for surface water (GB3838-2002), the length of river with water quality worse than V standard was approximately 147 km long in 2010s, which means the water is unusable in these rivers due to the serious pollution. The main pollution source of surface water is COD, ranging at 34 – 89 mg L^{-1} in serious polluted river, with the average value at an approximately 50 mg L^{-1}, presenting about 25% higher than the V standard (Huang et al. 2019). The influence of reclaimed water irrigation on the conventional soil nutrients and microbial population structure was also investigated to provide experimental basis for the standards setting when applying reclaimed water in garden irrigation.

Materials and methods

Test site was in Hebei agricultural university in Baoding City, Hebei province. Reclaimed water (RW) was from the drainage group of Baoding sewage treatment plant. The water resource for contrast treatment was tap water. The experimental irrigation period was from 2012 to 2016. The initial water quality of tap water and reclaimed water was compared in Table 1. The organic matter (COD) and nitrogen content (NH_3–N) were much higher in reclaimed water than that in tap water. The suspended sediment concentration (SS) was also much higher in reclaimed water. pH did not show significant difference between reclaimed water and tap water. We put the flowchart (Fig. 1) here to assist the comprehension of the research process in this study.

Test plant species

In this experiment, we selected 8 potting soil of garden plants, namely *Platanus acerifolia* Willd. (PA), *Sophora japonica* Linn. (SJ), *Pinus tabuliformis* Carr. (PT), *Pinus bungeana* Zucc. ex Endl. (PB), *Ginkgo biloba* L. (GB), *Magnolia denudata* Desr. (MD), *Hemerocallis fulva* L. (HF), and *Ilex chinensis* Sims (IC).

Soil sample collection

The experimental soil was collected from the potted plant with reclaimed water irrigation in Hebei agricultural university, Baoding City, Hebei province. Three duplicates of each plant rhizosphere soil were collected, and 72 soil samples were collected. After collecting the soil, the soil was quickly brought back to refrigerate. Soil microorganism and soil nutrients were determined in a few days.

Analysis methods of soil samples

Soil physicochemical properties were determined using conventional methods (Bao 2000). Soil acidity (pH value) was determined by potentiometric method (PHK-613acidity meter). Soil pH in distilled water at a soil-to-solution mass ratio of 1:5. The total salinity in soil was determined by residue drying-quality method. The chloride ions were measured using silver nitrate titration method and water soluble sodium was

Table 1 Different water qualities for irrigation

Irrigation water	COD /(mg L^{-1})	NH_3–N /(mg L^{-1})	Turbidity /NTU	SS /(mg L^{-1})	pH
TW (COD_{Mn})	3.2–5.8	0.08–0.17	0.4–2.0	2.0–10.0	7.0–8.0
RW(COD_{Cr})	68.0–112.0	14.0–29.0	21.0–98.0	30.0–60.0	6.0–9.0

TW tap water, RW reclaimed water, SS suspended sediment

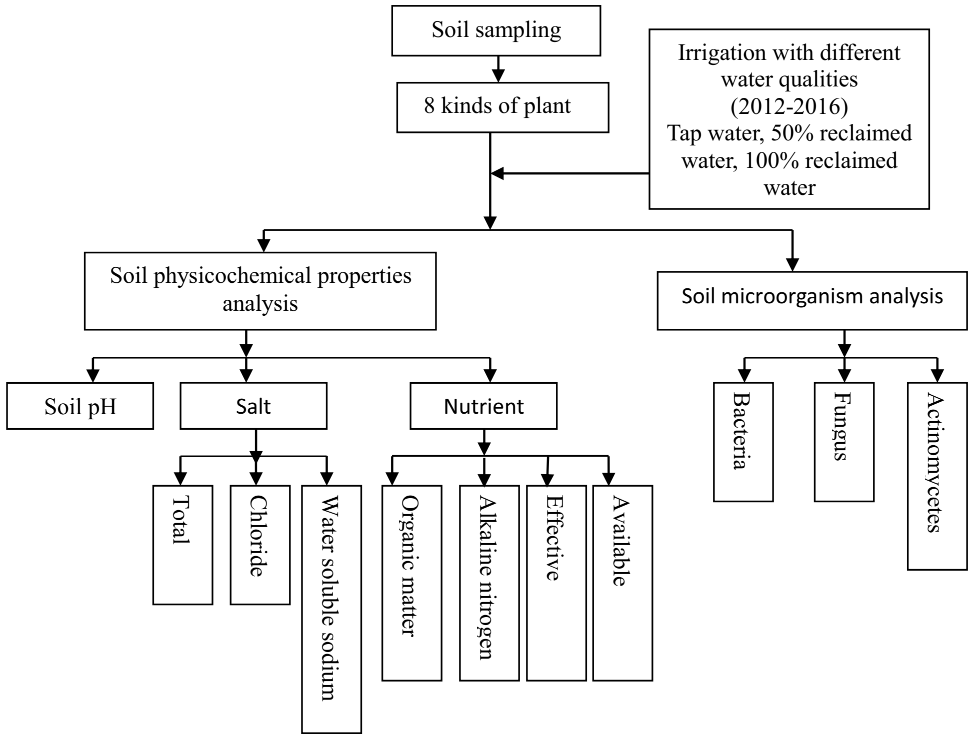


Fig. 1 Flowchart of the research process in this study

measured by flame photometry (FP6410flame photometer). The organic matter was determined using potassium dichromate-capacity method. The alkaline nitrogen was measured using alkali solution-diffusion method. The effective phosphorus was determined by $NaHCO_3$ leaching molybdenum blue colorimetry (752 spectrophotometers). The available potassium was measured using NH_4OAc leaching-flame photometry (FP6410 flame photometer).

Soil microbial group number is calculated by conventional method according to document (Rivero-Huguet and Marshall 2011). The bacteria were cultured by beef extract-peptone medium, the fungus was cultured by Martin's medium, and the actinomycetes were cultured by Gao's medium (No. 1). The volume fractions of soil suspensions for bacteria were 10^{-5}, 10^{-6}, and 10^{-7}. The volume fraction of soil suspensions for fungus and actinomycetes were 10^{-3}, 10^{-4}, and 10^{-5}. Each concentration of medium was cultured in the incubator and repeated 3 times for the culture. All materials, such as glass rod, straws, triangle bottle, and glass beads, were treated by uperization and the inoculation was taken place on ultra-clean bench to ensure the operation process was strictly controlled under aseptic conditions.

Results and discussion

Analysis of soil physical and chemical properties

Compared with tap water irrigation, the amount of salt showed significant increase trend in the soil of the 4 plants (PA, PT, PB, GB). According to the local standard of China, when the total salt mass fraction of the soil is higher than 1.2 g kg^{-1}, some plant growth is inhibited or damaged, and the soil is in danger of salinization. The total salt mass fraction in the soil of this study is 0.199–0.501 g $kg^{-1}$when irrigated by reclaimed water in 5 years, which is below the standard of 1.2 g kg^{-1}, but averagely 160.3% (ranging at 71.1–210.2%) higher than the contract treatments (0.098–0.446 g kg^{-1}). Thus, concern should be paid to the salt accumulation caused by reclaimed water irrigation in green space to avoid the harm of salinization. Chloride ion content ranged at 71.25–103.60 mg kg^{-1} after 5-year reclaimed water irrigation. Under two kinds of irrigation water quality, chloride ion content had significant differences with the contrast treatments in soil of SJ, PB, MD, and HF, averagely 83.3% (ranging at 44.6–156.6%) higher than that after tap water irrigation. And, water soluble sodium ranged at 52.33–80.21 mg kg^{-1} after 5-year reclaimed water irrigation, which showed significant differences in six kinds of plant (SJ, PT, PB, GB, MD, HF), compared with tap water irrigation, averagely 67.5% (ranging at 20.1–123.2%) higher than that after tap water irrigation. In other plants, water soluble sodium and chloride content in soil showed increasing trend after reclaimed water irrigation, although there were no significant differences. It indicated that the years of reclaimed water irrigation have resulted in the accumulation of chloride ions and sodium ions in the soil. These results are consistent with previous findings, which indicate that salt accumulation in soils and plants may often occur under reclaimed water irrigation and reclaimed water irrigation is one of significant processes to enhance soil salinization (Zalacáin et al. 2019b; Chen et al. 2013; Wang et al. 2017). For example, Zalacáin et al. (2019b) indicated the increase of Cl^- and Na^+ after 5 years of irrigation by reclaimed water. Chen et al. (2013) also indicated that the soil salinity increased about 20% in the top 0.20 m after irrigation by reclaimed water than those by drinking water in Beijing, where is approximately 150 km away from the experimental area in this study. In this study, the reclaimed water may pose the risk of salinization due to its high saline content, as reported from 600 to 1700 μS cm^{-1} (2017).

According to the test data (Table 2), the soil pH in different plants is in the range of 7.76 - 8.65 after 5-year reclaimed water irrigation. Compared with tap water irrigation, soil pH did not show significant changes, but showed a bit decrease trend. This is similar with the previous results, which also showed no significant difference in soil pH after years of reclaimed water irrigation (Liu et al. 2011).

Nitrogen, phosphorus, potassium, and organic matter in soil are essential nutrients for plant growth and development, and thus be assigned as the main indices to determine soil fertility. It is reported that these soil nutrients are significantly increased by long-term reclaimed water irrigation (Chen et al. 2015; Urbano et al. 2017). For example, Chen et al. (2015) indicated that soil total nitrogen, available phosphorus and organic matter content increased by 6–17% in 7 urban areas of Beijing with different reclaimed water irrigation histories. In this study, the influences of reclaimed water irrigation on soil nutrients were changed with the type of plant. As shown in Table 2, the content of soil organic matter showed no significant differences in most of plants, with the exception of increasing 55% in PB after reclaimed water irrigation.

Compared with the tap water irrigation, the content of alkaline nitrogen in soil significantly increased (averagely 25.8%) in 5 plants (PA, SJ, PB, HF, IC) after 5-year irrigation with reclaimed water. The content of the effective phosphorus only showed significant increases in 2 kinds of plant (PT, PB) after 5-year irrigation with reclaimed water, approximately 82.5% higher than that after tap water irrigation.

Table 2 Soil data analysis under different water quality irrigation conditions

Index	Irrigation water	PA	SJ	PT	PB	GB	MD	HF	IC
pH	RW	7.87	8.12	7.76	7.94	7.85	8.65	8.08	7.97
	TW	8.29	8.31	7.96	8.30	8.02	8.73	8.14	8.26
Total salinity (g kg^{-1})	RW	0.361*	0.279	0.449**	0.381**	0.304**	0.199	0.501	0.229
	TW	0.211	0.251	0.103	0.307	0.098	0.149	0.446	0.213
Chloride ions (mg kg^{-1})	RW	86.25	103.60*	91.25	90.02*	71.25	80.37*	99.8*	90.69
	TW	83.41	55.89	70.33	61.31	63.46	55.57	38.90	84.24
Water soluble sodium (mg kg^{-1})	RW	65.34	56.78*	80.21**	61.21**	52.33**	61.12**	70.44**	70.48
	TW	67.21	47.29	50.23	38.67	29.48	36.77	31.56	69.22
Organic matter (g kg^{-1})	RW	20.12	13.78	9.21	16.43*	13.22	18.90	21.22	20.54
	TW	22.88	16.89	10.33	10.59	14.37	17.47	16.48	21.20
Alkaline nitrogen (mg kg^{-1})	RW	121.22*	106.78*	79.21	89.79*	80.23	89.78	128.66*	109.48*
	TW	110.32	89.66	75.44	70.23	77.41	80.34	108.76	71.22
Effective phosphorus (mg kg^{-1})	RW	35.78	58.21	34.32*	33.45**	41.44	35.33	26.78	43.22
	TW	50.22	60.20	20.22	17.13	37.21	34.28	28.31	50.98
Available potassium (mg kg^{-1})	RW	137.22	108.89	98.46	132.45*	123.33*	120.21	158.49**	100.25
	TW	141.54	107.54	89.55	101.21	99.58	130.41	109.87	121.38

A single asterisk indicates significant difference ($p < 0.05$); a double asterisk indicates extremely significant difference ($p < 0.01$), RW reclaimed water; TW tap water; *PA Platanus orientalis* L.; *SJ Sophora japonica* Linn.; *PT Pinus tabuliformis* Carr.; *PB Pinus bungeana Zucc. ex Endl.*; *GB Ginkgo biloba* L.; *MD Magnolia denudata* Desr.; *HF Hemerocallis fulv*a L.; *IC* indicates *Ilex chinensis* Sims

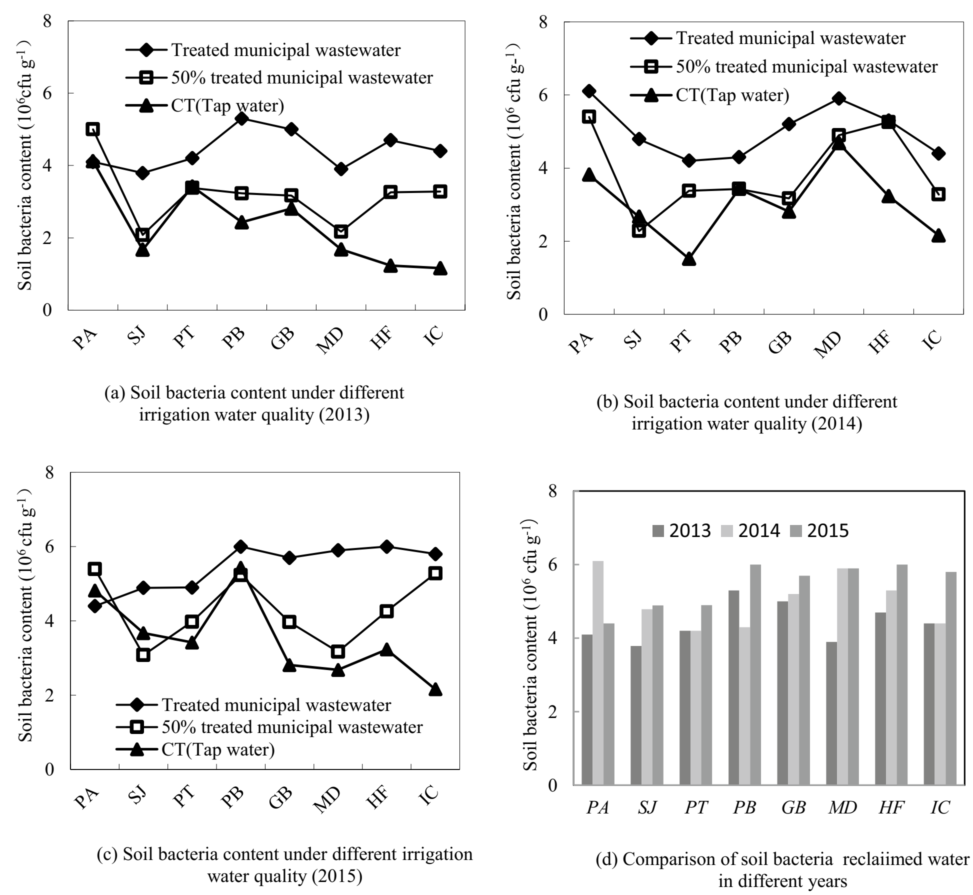
Compared with tap water irrigation, the content of available potassium in soil showed significant increases in 3 kinds of plant (PB, GB, HF), with the average increasing rate at 34.1% after 5-year reclaimed water irrigation. The higher content of nitrogen in reclaimed water only resulted in the significant increases in the content of soil nutrients in parts of plants. It is noticeable that all kinds of nutrient (alkaline nitrogen, effective phosphorus, available potassium, and organic matter) in soil significantly increased in PB plant after reclaimed water irrigation. In other plants, the differences of soil nutrients content varied with the type of plant, mainly due to the uptake capacity differences during the grow and leaf-, root-decay recycles of different plant species. The absorption efficiency with the types and ages of plant species was shown in previous studies (Zhu et al. 2019; Rytter and Rytter 2020; Liu et al. 2020). For example, Rytter and Rytter (2020) indicated the different nutrient distribution under five tree species in an afforestation project in Sweden. Zhu et al. (2019) compared the differences of uptake pattern of glycine, ammonium, and nitrate in three kinds of tree species in the Northeast of China.

Analysis of soil microbial quantity

Soil bacteria content in different water quality irrigations

Contrary results were found in the previous researches. For example, the total number of soil bacteria and actinomycete fungi in grassland soil of Kentucky bluegrass were lower after years of irrigation by reclaimed water than that of tap water irrigation (Han et al. 2006). However, Guo et al. (2006) indicated that the reclaimed water irrigation was not only beneficial to the increasing of the number of lawn grass rhizosphere microbes, but also helpful to the microbial community diversity of lawn grass, comparing with the conventional irrigation. In this study, the number of soil bacteria after irrigation with different water qualities followed the order as reclaimed water > 50% tap water 50% reclaimed water > tap water in the majority of the testing plants (Fig. 2a–c). Figure 2d showed that the number of soil bacteria showed an increasing trend in the most selected plants from 2013 to 2015. The number of soil bacteria in 8 types of plant in 2015 was higher than soil bacteria number in 2014 and 2013 except for the PA, which may be related to the contents of refractory organic compounds, pathogenic bacteria, viruses, and parasitic ovum in the reclaimed water.

Fig. 2 Changes in the number of bacteria in different plants



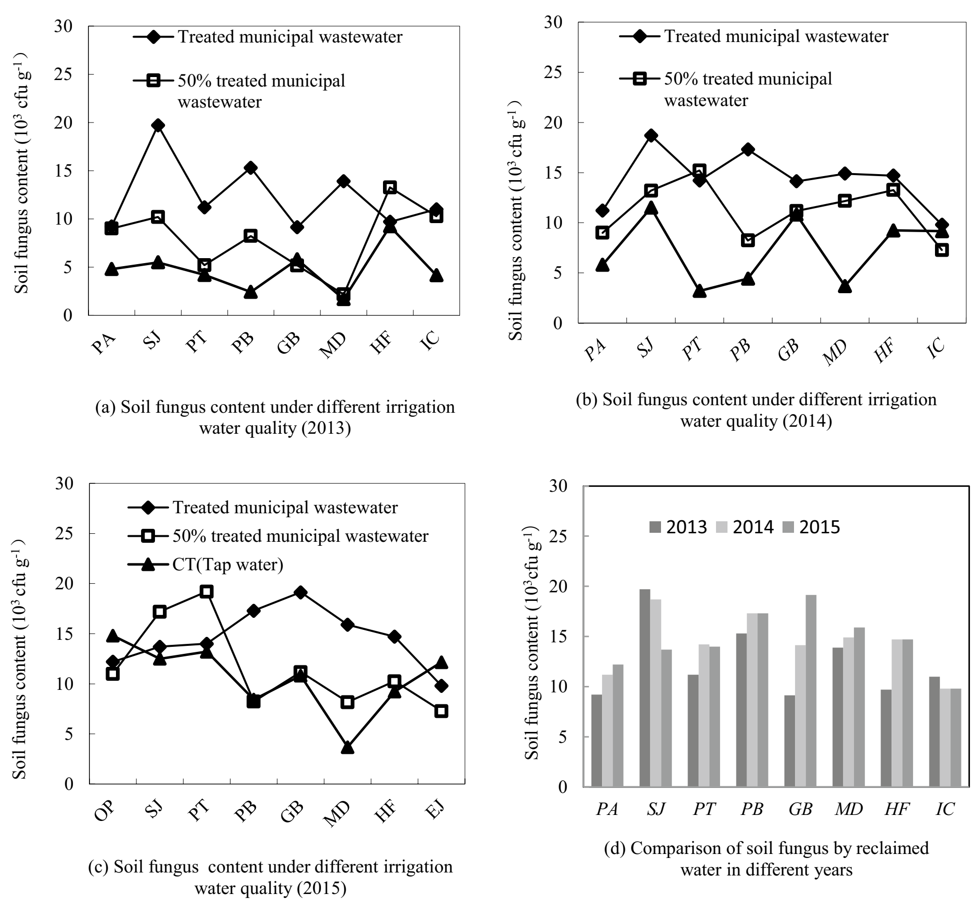
In addition, the reclaimed water usually needs to be disinfected with chlorides. When chlorides gas enters into the reclaimed water, the organic matter or suspended substance in the water can be broken down and decomposed, resulting in some volatile phenols and odors. When the reclaimed water with high salt content enters the soil, it will affect the soil's EC, which will affect the change of the total number of soil bacteria (Klay et al. 2010).

Soil fungus content in different irrigation water qualities

Soil fungus is a common soil microorganism, which is suitable for acidity, and the number of fungus is generally low due to the high pH in the experimental soils. The number of fungus showed increasing trend with the increasing content of reclaimed water from 0, 50, to 100% in most plants in 2013 (Fig. 3a). The number of fungus demonstrated different trends with the irrigation time with reclaimed water depending on the type of the testing plant. As shown in Fig. 3d, soil fungus content showed increasing trend with the irrigation years (2013–2015) in 4 kinds of plant (PA, GB, MD, PB), decreasing trend in 2 kinds of plant (SJ and IC), and fluctuations in other plants. Specifically, the number of soil fungus increased in 2014 and then decreased in 2015 in 2 kinds of plant (PT and HF). During 2015, the differences of soil fungus number reduced in three kinds of irrigation water qualities in SJ, IC, PT, and HF, due to the decreasing trend of fungus in reclaimed water irrigation in 2015.

In addition, the root secretions of trees have a great influence on soil microorganisms. The root secretion causes a great change in the variety and quantity of the rhizosphere microorganism, which leads to the higher number of rhizosphere microorganisms than that of non-rhizosphere soil microorganisms (Marupakula et al. 2021). The number of rhizosphere microorganisms largely depends on the amount of sugar, organic acids, and amino acids in the root secretions. The more secretions, the more microbes grow. The number of soil microorganism is also affected by the plant itself, soil type and soil management measures (Li et al. 2021; Guo et al. 2021). Wang et al. (2006) indicated that the role of plants extended from plant community structure diversity, plant species, genotypes of the same plant, and even to the different root regions of the same plant.

Fig. 3 Changes in the number of fungus in different plants



Soil actinomycetes content in different irrigation water qualities

Actinomycetes play important roles in soil organic matter decomposition process, because they are characterized by having high G + C contents and can recycle the dead organic matter by breaking down the compounds that is not well utilized by other microorganisms (Hozzein et al. 2019). The actinomycetes can also fix nitrogen by the genus *Frankia* and their symbiotic relations with plant roots (Hozzein et al. 2019; Zhang et al. 2012).In this study, the number of actinomycetes in soil increased with the higher content of reclaimed water in the irrigation water resources, which is similar as the changing of the soil bacteria content in different irrigation water qualities during years 2013–2015 (Fig. 4a–c). Also, the number of actinomycetes is increasing with the reclaimed water irrigation years, showing the similar increasing trend as the number of bacteria (Fig. 4d).

The relationship between soil microorganism and soil nutrient factors

Although the types of plants have influences on soil fertility, soil nutrient content, especially the content of alkaline nitrogen, effective phosphorus, and the available potassium, may increase in the long-term reclaimed water irrigation, due to the higher content of nitrogen and phosphorus in the reclaimed water than that in tap water. The growth of microorganisms is enhanced by the soil fertility, to increase the number of different kinds of group, like bacteria, fungus and actinomycetes after irrigation by reclaimed water.

Soil bacteria are the main components of soil microorganisms, which can decompose various organic substances. Because the reclaimed water contains rich nutrition such as N, P and K, it provides abundant carbon source and nitrogen source for the growth of bacteria. These nutrition can increase the permeability of the soil and stimulate the growth and development of bacteria, thus greatly increasing the number of bacteria. It is also related to the various

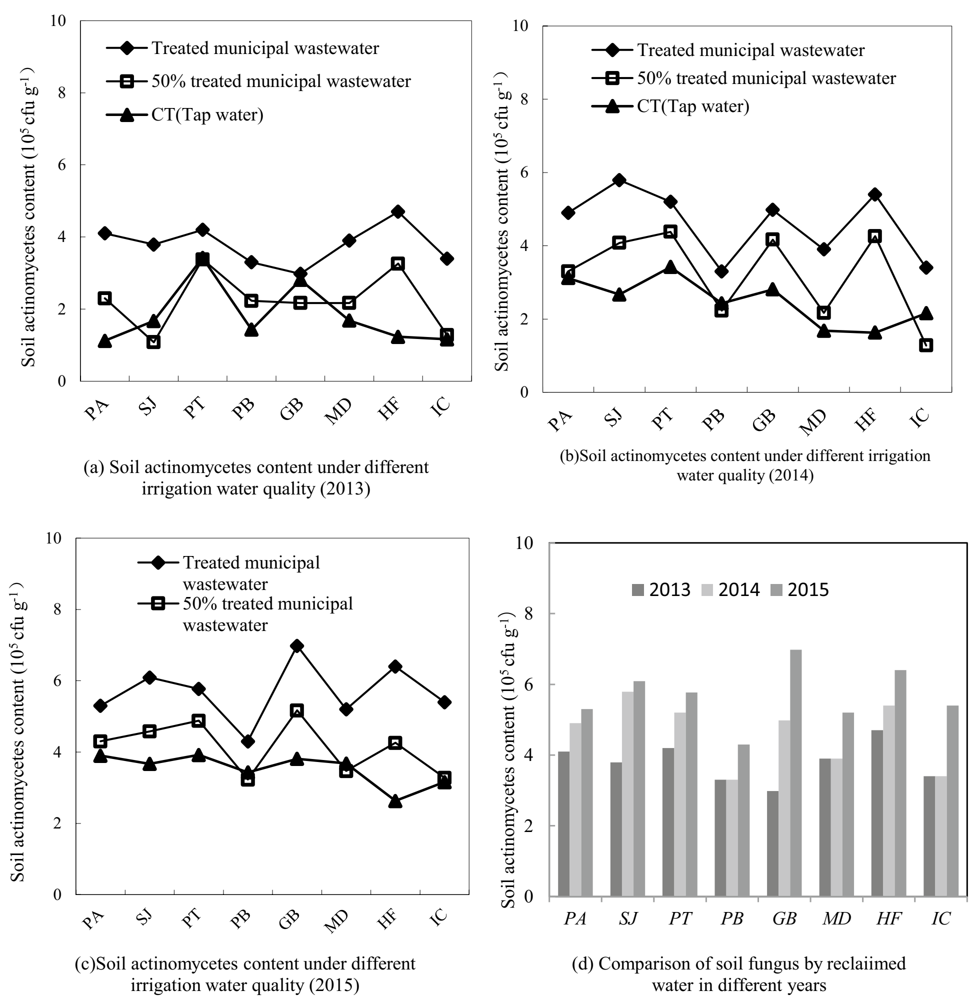


Fig. 4 Changes in the number of actinomycetes in different plants

refractory organisms, pathogens, viruses, and certain parasitic eggs in reclaimed water.

Fungus is one of the most common soil microbial communities. In terms of quantity, they are significantly lower than other kinds of microorganisms, but they are extremely important in terms of biomass. Actinomycetes are the second only to bacteria in quantity, playing an important role in the decomposition of organic compounds in soil and the synthesis of soil humus.

Meanwhile, soil microorganisms not only controlled the soil organic matter and important nutrient element (such as N, P, S) bioconversion, but also deeply influenced soil physical and chemical properties, such as the formation of soil aggregate structure, and pH changes. For example, the increasing number of actinomycetes helps to accelerate the organic matter decomposition and decrease the content of soil organic matter, which result in the insignificant changes of soil organic matter after irrigation by different water qualities. The unchanged pH of soil after irrigation by different water qualities is mainly due to the high soil buffer capacity (Guo et al. 2017).

It is noticeable that the BOD substance in the reclaimed water (oxygen-consuming organic matter) is extremely high, and when it enters the soil, it will rapidly deplete the oxygen in the soil. In this way, the anaerobic microorganism is developed, the denitrification of soil bacteria is strengthened, and the N in soil is oxidized to the gas N_2 to volatilize.

The relations between soil microorganism and soil nutrients are regressed as Eqs. (1), (2), and (3), where soil organic matter (×1), available potassium (×2), effective phosphorus (×3), and alkali solution nitrogen (×4) as the independent variable, total number of bacteria in the soil with reclaimed water irrigation (*y*1), the total number of fungus (*y*2), and the total number of actinomycetes (*y*3) as the dependent variable:

$$y1 = 19092.743x1 - 20401.654x2 + 60315.622x3 + 2978554.112 \quad (1)$$

$$y2 = -1496.243x1 + 281.403x2 + 36.511x3 + 5960.143 \quad (2)$$

$$y3 = -2015.214x2 + 504811.654 \quad (3)$$

The regression equation of the total number of soil bacteria (Eq. (1)) showed that the soil organic matter and effective phosphoruswere beneficial to the improvement of the total number of bacteria, but the content of the soil available potassium was negatively correlated with the total number of bacteria.

The regression equation of soil fungus content (Eq. (2)) showed the total number of fungus was improved by the content of the available potassium and the effective phosphorus in the soil, but decreased by the content of soil organic matter.

The regression equation of soil actinomycetes content (Eq. (3)) showed that the content of available potassium had great influence on the total number of actinomycetes.

The relationships between the number of soil bacteria, fungus and actinomycetes shown in Eqs. (1), (2), and (3) are consistent with Zhang and Wang (Zhang and Wang 2009). Gong (Gong et al. 2014) also indicated the benefit of organic matter (OM), total nitrogen (TN), and total phosphorus (TP) in soil to the number of bacteria after reclaimed water irrigation.

Conclusions

The influences of irrigation water qualities on the soil physiochemical properties and microorganism were examined in 8 kinds of potted plant in this study. The pH of soil ranged at 7.76–8.65 after 5-year reclaimed water irrigation and did not show significant difference compared with the contrast treatment. However, the contents of soil total salinity (0.199–0.501 g kg^{-1}), water soluble sodium (52.33–80.21 mg kg^{-1}), and chloride ions (71.25–103.60 mg kg^{-1}) were higher after reclaimed water irrigation than that of tap water irrigation. In terms of soil nutrient, the content of soil organic matter, effective phosphorus, and available potassium in soil was not significantly changed after the reclaimed water irrigation in the most of the plants.

Water quality is one of the most direct factors affecting soil microbial (no significant interactions between plants and water quality). It is important to note that the BOD substance in the reclaimed water (oxygen-consuming organic matter) is too high to deplete the oxygen in the soil void. In this way, the anaerobic microorganism is developed, the denitrification of soil bacteria is strengthened, and the N in soil is oxidized to the gas N_2 to volatilize. In addition, the reclaimed water usually needs to be disinfected with chloride. When chloride gas enters into the reclaimed water, the organic matter or suspended substance in the water can be broken down and decomposed, resulting in some volatile phenols and odors. When the reclaimed water with high salt content enters the soil, it will affect the soil's EC, which will affect the change of the total number of soil bacteria. The root secretions of trees have a great influence on soil microorganisms. The more secretions, the more microbes grow. The amount of soil microorganism is also affected by the plant itself, soil type, and soil management measures.

All these results suggest that reclaimed water is one of the valid alternative sources for irrigation in green space in Hebei Province, where is suffering water scarce. When reclaimed water irrigation is implemented in Hebei province, total salinity of soil needs to be monitored to prevent the risk of soil salinization. The change of soil characteristics and microbial population in different seasons is of great significance to the application of reclaimed water irrigation, thus the seasonal changes of soil characteristics and microbial populations will be further analyzed. Moreover, the soil microbial community structure and diversity should be studied in depth.

Acknowledgements The authors would like to acknowledge the kind help and suggestions of all the anonymous reviewers.

Author contribution Pei Liang analyzed and interpreted the effects of irrigation with different water quality on the soil characteristics of 8 kinds of garden plants, and was a major contributor in writing the manuscript. Sun Liying analyzed and interpreted the relationship between soil microorganism and soil nutrient factors. Xiao Jingan analyzed and interpreted the soil physical and chemical properties. All authors read and approved the final manuscript.

Funding The authors appreciate the financial support of the National Key Research and Development Project of China (Grant No.: 2017YFD0800900) and National Natural Science Foundation of China (Grant No.:51109197).

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Abadia J, Bastida F, Romero-Trigueros C et al (2021) Interactions between soil microbial communities and agronomic behavior in a mandarin crop subjected to water deficit and irrigated with reclaimed water. Agric Water Manag 247:106749

Bao S (2000) Soil agrochemical analysis method. The soil agrochemical analysis (3rd version), Beijing: China Agricultural Press 49-66 (**in Chinese**)

Chen D, Wang J, Guan J et al (2014) Effects of reclaimed water irrigation on soil physicochemical properties and culturable microbial community. Chin J Ecol 33(5):1304–1311 (**in Chinese**)

Chen W, Lu S, Pan N et al (2013) Impacts of long-term reclaimed water irrigation on soil salinity accumulation in urban green land in Beijing. Water Resour Res 49:7401–7410

Chen W, Lu S, Pan N et al (2015) Impact of reclaimed water irrigation on soil health in urban green areas. Chemosphere 119:654–661

Chopyk J, Nasko DJ, Allard S et al (2020) Comparative metagenomic analysis of microbial taxonomic and functional variations in untreated surface and reclaimed waters used in irrigation applications. Water Res 169:115250

Deviller G, Lundy L, Fatta-Kassinos D (2021) Recommendations to derive quality standards for chemical pollutants in reclaimed water intended for reuse in agricultural irrigation. Chemosphere 240:124911

Farhadkhani M, Nikaeen M, Yadegarfar G et al (2018) Effects of irrigation with secondary treated wastewater on physicochemical and microbial properties of soil and produce safety in a semi-arid area. Water Res 144:356–364

Gomez-Bellot MJ, Ortuno MF, Alvarez S et al (2020) Influence of mycorrhizal or microbial complex inoculation on laurustinus plants irrigated with reclaimed water. J Hortic Sci Biotechnol 95:661–672

Gong X, Wang JH, Guan JF et al (2014) Impact of reclaimed water irrigation on soil chemical properties and culturable microorganisms. Environ Sci 35:3572–3579(**in Chinese**)

Gu X, Xiao Y, Yin S et al (2018) Impact of long-term reclaimed water irrigation on the distribution of potentially toxic elements in soil: An in-situ experiment study in the North China Plain. Int J Environ Res Public Health 16:649

Guo W, Andersen M, Qi X et al (2017) Effects of reclaimed water irrigation and nitrogen fertilization on the chemical properties and microbial community of soil. J Integr Agric 16:679–690

Guo X, Dong Z, Gong, H (2006) The effect of reclaimed water irrigation on the microbial community of lawn soil. China Environ Sci 26(4):482–485 (**in Chinese**)

Guo YJ, Qiu TL, Gao M et al (2021) Diversity and abundance of antibiotic resistance genes in rhizosphere soil and endophytes of leafy vegetables: Focusing on the effect of the vegetable species. J Hazard Mater 415:125595

Gwenzi W, Munondo R (2008) Long-term impacts of pasture irrigation with treated sewage effluent on nutrient status of a sandy soil in Zimbabwe. Nutr Cycl Agroecosyst 82(2):197–207

Han LB, Zhou, LB, Gan YP, et al (2006) The effect of reclaimed water irrigation on the microorganism of lawn soil. J Beijing Forestry Univ 28(1):73–77 (**in Chinese**)

Hozzein W, Abuelsoud W, Wadaan M et al (2019) Exploring the potential of actinomycetes in improving soil fertility and grain quality of economically important cereals. Sci Total Environ 651:2787–2798

Hu YQ, Wu WY, Xu D et al (2018) Impact of long-term reclaimed water irrigation on trace elements contents in agricultural soils in Beijing, China. Water 10:1716

Hu YQ, Wu WY, Xu D et al (2021) Occurrence, uptake, and health risk assessment of nonylphenol in soil-celery system simulating long-term reclaimed water irrigation. J Hazard Mater 406:124773

Huang S, Tian F, Du Z (2019) Change of COD in Fuhe river and analysis of pollution sources in Baoding city. Environ Prot Circ Econ 39(4):50–53 (**in Chinese**)

Klay S, Charef A, Ayed L et al (2010) Effect of irrigation with treated wastewater on geochemical properties (saltiness, C, N and heavy metals) of isohumic soils (Zaouit Sousse perimeter, Oriental Tunisia). Desalination 253:180–187

Li J, Sun YJ, Wang XY et al (2020) Changes in microbial community structures under reclaimed water replenishment conditions. Int J Environ Res Public Health 17:1174

Li WQ, Huang YX, Chen FS et al (2021) Mixing with broad-leaved trees shapes the rhizosphere soil fungal communities of coniferous tree species in subtropical forests. Forest Ecol Manag 480:118664

Liu J, Chang Z, Huang Y (2011) Research process on influence of reclaimed water irrigation on green space soil. J Irrig Drain 30:111–114 (**in Chinese**)

Liu QY, Wang HM, Xu XL (2020) Root nitrogen acquisition strategy of trees and understory species in a subtropical pine plantation in southern China. Eur J Forest Res 139:791–804

Lu S, Li J, Bai X et al (2020) Analysis of standard accounting method of economic compensation for ecological pollution in watershed. Sci Total Environ 737(11):138157

Lu S, Wang J, Pei L (2016a) Study on the effects of irrigation with reclaimed water on the content and distribution of heavy metals in soil. Int J Environ Res Public Health 2016(13):298

Lu S, Zhang X, Pei L (2016b) Influence of drip irrigation by reclaimed water on the dynamic change of the nitrogen element in soil and tomato yield and quality. J Clean Prod 139(8):561–566

Lu S, Zhang X, Peng H et al (2020b) The energy-food-water nexus: Water footprint of Henan-Hubei-Hunan in China. Renew Sustain Energy Rev 133:110417

Lu S, Lian Z, Sun H et al (2021) Simulating trans-boundary watershed water resources conflict. Resources Policy 73(21):102139

Lyu SD, Chen WP, Qian JP et al (2019) Prioritizing environmental risks of pharmaceuticals and personal care products in reclaimed water on urban green space in Beijing. Sci Total Environ 697:133850

Lyu SD, Chen WP (2016) Soil quality assessment of urban green space under long-term reclaimed water irrigation. Environ Sci Pollut Res 23:4639–4649

Martinez-Piernas AB, Plaza-Bolan P, Aguera A (2021) Assessment of the presence of transformation products of pharmaceuticals in agricultural environments irrigated with reclaimed water by wide-scope LC-QTOF-MS suspect screening. J Hazard Mater 412:125080

Martinez-Piernas AB, Plaza-Bolaños P, Fernández-Ibáñez P et al (2019) Organic microcontaminants in tomato crops irrigated with reclaimed water grown under field conditions: occurrence, uptake, and health risk assessment. J Agric Food Chem 67:6930–6939

Marupakula S, Mahmood S, Clemmensen KE et al (2021) Root associated fungi respond more strongly than rhizosphere soil fungi to N fertilization in a boreal forest. Sci Total Environ 766:142597

Meng Y, Liu WY, Fiedler H et al (2021) Fate and risk assessment of emerging contaminants in reclaimed water production processes. Front Environ Sci Eng 15:104

Moazeni M, Nikaeen M, Hadi M et al (2017) Estimation of health risks caused by exposure to enteroviruses from agricultural application of wastewater effluents. Water Res 125:104–113

Moller A, Muller H, Abdullah A et al (2005) Urban soil pollutionin Damascus, Syria: Concentrations and patterns of heavy metals in the soils of the Damascus Ghouta. Geoderma 124(1–2):63–71

Rosabal A, Morillo E, Undabeytia T et al (2007) Long-term impacts of wastewater irrigation on Cuban soils. Soil Sci Soc AM J 71(4):1292–1298

Pablos MV, Rodriguez JA, Garcia-Hortiguela P et al (2018) Sublethal and chronic effects of reclaimed water on aquatic organisms. Looking for relationships between physico-chemical characterisation and toxic effects. Sci Total Environ 640:1537–1547

Rachmadi AT, Azizkhan ZM, Hong PY (2021) Enteric virus in reclaimed water from treatment plants with different multi-barrier strategies: Trade-off assessment in treatment extent and risks. Sci Total Environ 776:146039

Rivero-Huguet M, Marshall W (2011) Scaling up a treatment to simultaneously remove persistent organic pollutants and heavy metals from contaminated soils. Chemosphere 83(5):668–673

Romero-Trigueros C, Cabanero JJA, Tortosa PAN et al (2019) Medium-long term effects of saline reclaimed water and regulated deficit irrigation on fruit quality of citrus. J Sci Food Agric 100:1350–1357

Rytter RM, Rytter L (2020) Changes in soil chemistry in an afforestation experiment with five tree species. Plant Soil 456:425–437

Singer R, Brown S (2018) Impact of soil filtration on metals, nutrients, and estrogenic activity of reclaimed water. J Environ Qual 47:1504–1512

Solaiman S, Micallef SA (2021) Aeromonas spp. diversity in US mid-Atlantic surface and reclaimed water, seasonal dynamics, virulence gene patterns and attachment to lettuce. Sci Total Environ 779:146472

Urbano V, Mendonça T, Bastos R et al (2017) Effects of treated wastewater irrigation on soil properties and lettuce yield. Agr Water Manag 181:108–115

Wang G, Jin J, Xu M et al (2006) Effects of plant, soil and soil management on soil microbial community structure. J Ecol 25(5):550–556 (**in Chinese**)

Wang SY, Li XO, Wu WY et al (2019) Sorption and desorption behavior of 4-nonylphenol and a branched isomer on soils with long-term reclaimed water irrigation. Environ Eng Sci 36:1100–1111

Wang Z, Li J, Li Y (2017) Using reclaimed water for agricultural and landscape irrigation in China: A review. Irrig Drain 66:672–686

Wu WY, Liao RK, Hu YQ et al (2020) Quantitative assessment of groundwater pollution risk in reclaimed water irrigation areas of northern China. Environ Pollut 261:114173

Xiao Y, Gu XM, Yin SY et al (2017) Investigation of geochemical characteristics and controlling processes of groundwater in a typical long-term reclaimed water use area. Water 9:800

Xie E, Zhao XH, Li K et al (2021) Microbial community structure in the river sediments from upstream of Guanting Reservoir: Potential impacts of reclaimed water recharge. Sci Total Environ 766:142609

Zalacain D, Bienes R, Sastre-Merlin A et al (2019a) Influence of reclaimed water irrigation in soil physical properties of urban parks: A case study in Madrid (Spain). CATENA 180:333–340

Zalacáin D, Martínez-Pérez S, Bienes A et al (2019b) Salt accumulation in soils and plants under reclaimed water irrigation in urban parks of Madrid (Spain). Agric Water Manag 213:468–476

Zhang J, Wang Y (2009) Influence of irrigation with reclaimed water on soil peculiarity and microbes quantity of plant rhizosphere. Water Sav Irri 28(3):5–8 (**in Chinese**)

Zhang S, Yao H, Lu Y et al (2018) Reclaimed water irrigation effect on agricultural soil and maize (Zea mays L.) in northern China. Clean Soil Air Water 46:1800037

Zhang X, Ma L, Gilliam F et al (2012) Effects of raised-bed planting for enhanced summer maize yield on rhizosphere soil microbial functional groups and enzyme activity in Henan Province China. Field Crop Res 130:28–37

Zhu FF, Dai LM, Hobbie EA et al (2019) Uptake patterns of glycine, ammonium, and nitrate differ among four common tree species of Northeast China. Front Plant Sci 10:799