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

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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; Martínez-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 recycle 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; Abadía 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 on the plant root.
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 contrast 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 refrigerator. 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-613 acidity 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
measured by flame photometry (FP6410 flame 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 NaHCO₃ leaching molybdenum blue colorimetry (752 spectrophotometers). The available potassium was measured using NH₄OAc 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 contrast 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*| 60.21**| 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 Dess.; HF Hemerocallis fulva 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.
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

| Year          | Soil fungus content (10^3 cfu g^-1) |
|---------------|------------------------------------|
| 2013          |                                    |
| PA            |                                    |
| SJ            |                                    |
| PT            |                                    |
| PB            |                                    |
| GB            |                                    |
| MD            |                                    |
| HF            |                                    |
| IC            |                                    |
| 2014          |                                    |
| PA            |                                    |
| SJ            |                                    |
| PT            |                                    |
| PB            |                                    |
| GB            |                                    |
| MD            |                                    |
| HF            |                                    |
| IC            |                                    |
| 2015          |                                    |
| PA            |                                    |
| SJ            |                                    |
| PT            |                                    |
| PB            |                                    |
| GB            |                                    |
| MD            |                                    |
| HF            |                                    |
| IC            |                                    |
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
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 N₂ 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 (y1), the total number of fungus (y2), and the total number of actinomycetes (y3) as the dependent variable:

\[ y_1 = 19092.743x_1 - 20401.654x_2 + 60315.622x_3 + 297855.112 \]  
\[ y_2 = -1496.243x_1 + 281.403x_2 + 36.511x_3 + 5960.143 \]  
\[ y_3 = -2015.214x_2 + 504811.654 \]

The regression equation of the total number of soil bacteria (Eq. (1)) showed that the soil organic matter and effective phosphorus were 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 N₂ 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.

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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 Lijing 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.

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

Declarations

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