Effects of Reclaimed Water Irrigation On The Soil Characteristics And Microbial Populations of Plant Rhizosphere

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Research Article

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Abstract

In this paper, the effects of irrigation with different water quality 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 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, showing increasing trend with the increasing content of reclaimed water from 0%, 50–100%. Moreover, the number of bacteria and fugus is closely related with the content of soil organic matter, available potassium and effective phosphorus. However, the number of *Actinomycetes* is determined by the content of available potassium.

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 (Zhou 2002;Al-Nakshabandi et al. 1997). 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(Al-Lahham et al. 2003;Oron et al.1999). It was reported that the reuse of reclaimed water for farmland had reached 20 million, and the amount is supposed to be increasing greatly due to the water crisis(Zhang et al. 2018).

However, the hazards from substandard industrial wastewater 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)(Smith et al.1996;Wang et al.2003). Toxic elements and organic pollutions may be transferred to soils by reclaimed water irrigation(Gu et al. 2018;Hong et al. 2014;Jin et al.2014). The influences of reclaimed water irrigation on the microbial health risks were also reported(Moazeni et al.2017;Farhadkhani et al.2018;Mok et al.2014). The population of microorganisms is affected by the quality of reclaimed water, method of irrigation and the type of plant(Cameron and McLaren 1997). For example, the reclaimed lawn irrigation could increase the population of root microbe, while have no significant effects on the microbial community in the root layer(Guo and Gong 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 (Manta et al.2002;Moller et al.2005;Zhao et al. 2006;Barry et al.1995;Al et al. 2008;Morillo et al. 2007;Gwenzi and Munondo 2008). Therefore, standards for reclaimed water 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 (Wang et al. 2011;Smith and Cook 1996;Bouwer and Idelovitch 1987;Rattan et al. 2005). 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, S., Wang, J., & Pei, L. 2016;Lu, S., Zhang, X., & Pei, L. 2016)). 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 quality on soil physical and chemical properties of several common garden plants, with comparison with contract treatment irrigated by Tap water. Potted experiments in 8 kinds of plants 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 belonging to the extreme water shortage area. Hence, alternative water resources are significant for the regional sustainability. Meanwhile, surface water suffers serious pollution. The river with water quality worse than V standard was approximately 147 km long in 2010s, according to China environmental quality standard for surface water (GB3838-2002), which means the water is too polluted to be used in these rivers. The main pollution source of surface water is COD, ranging at 34–89 mg L^{-1} in serious polluted river, and the average COD in the polluted river is approximately 50 mg L^{-1}, 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 were 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 and nitrogen content was much higher in reclaimed water than that in tap water. The suspended sediment concentration was also much higher in reclaimed water. pH did not show significant differences between reclaimed water and tap water. We put the flowchart (Fig. 1) here to assist the comprehension of the research process in this study.

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
Note: TW indicates Tap water irrigation; RW indicates reclaimed water irrigation; SS is suspended sediment.					

1.1 The test materials plants

In this experiment, we selected 8 potting soil of garden plants, namely *Oriental plane (OP), Sophora japonica (SJ), Pinus tabulaeformis (PT), Pinus bungeana (PB), Ginkgo biloba (GB), Magnolia denudate (MD), Hemerocallis fulva (HF), and Euonymus japonicas (EJ)*.

1.2 Soil sample collection

The experimental soil was collected from the potted plant with reclaimed water irrigation in Hebei agricultural university, Baoding City, Hebei province. 3 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.

1.3 Analysis methods of soil samples

(1) 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 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).

(2) 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

2.1 Analysis of soil physical and chemical properties

You can see from Table 2, the amount of salt in the soil of the 4 plants (*OP*, *PT*, *PB*, *GB*) irrigated by reclaimed water was significantly increased, compared with the contrast treatment. 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 attention to the salt accumulation caused by reclaimed water irrigation in green space to avoid the harm of salinization. Chlorides ion content ranged at 71.25–103.60 mg kg^{-1} after 5-year reclaimed water irrigation. Under two kinds of irrigation water quality, chlorides 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 plants (*SJ*, *PT*, *PB*, *GB*, *MD*, *HF*), compared with contrast treatments, 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 increased 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 enhanced soil salinization (Zalacáin et al. 2019;Chen et al. 2013;Wang et al.2017). For example, Zalacáinet al. (2019) 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. Compared with tap water resources, the reclaimed water is much easier to increase the risk of salinization due to its high saline content, as reported from 600 to 1700 μS cm^{-1} (2017).

Table 2
Soil data analysis under different water quality irrigation conditions

Index	Irrigation water	OP	SJ	PT	PB	GB	MD	HF	EJ
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

Note: * indicates significant difference ($p < 0.05$); ** indicates extremely significant difference ($p < 0.01$); RW indicates reclaimed water irrigation; TW indicates Tap water irrigation; *OP* indicates *Oriental plane*; *SJ* indicates *Sophora japonica*; *PT* indicates *Pinus tabulaeformis*; *PB* indicates *Pinus bungeana*; *GB* indicates *Ginkgo biloba*; *MD* indicates *Magnolia denudate*; *HF* indicates *Hemerocallis fulva*; and *EJ* indicates *Euonymus japonicas*.

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 contrast treatments, soil pH did not show significant changes after 5-year reclaimed water irrigation, but showed a bit decrease trend in reclaimed water. This is similar with the previous results, which also showed no significant differences in soil pH after years of reclaimed water irrigation, comparing with the tap 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 types of plants. As shown in Table 2, the content of soil organic matter only showed significant increasing trend in the plant of *PB* with the increase rate at approximately 55%. However, no significant differences were found in other kinds of plants.

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

Compared with the tap water irrigation, the content of available potassium in soil showed significant increases in 3 kinds of plants (*PB, GB, HF*), with the average increasing rate at 34.1% after 5-yearreclaimed water irrigation.

Compared with tap water, 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 in soil varied with the types of plants, which are mainly related with the taken-up capacity of different plants. Previous studies have found that different plants have different absorption efficiency to different substances under different tree ages. Some plants are more efficient at absorbing certain substances when the fruit is growing, while others are more efficient at absorbing certain substances when the root is growing. We will continue to explore this area in the future (Chen et al. 2013).

2.2 Analysis of soil microbial quantity

2.2.1 Soil bacteria content in different water quality irrigation

Contrary results were found in the previous researches. For example, the total number of soil bacteria and *Actinomycetes*, 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. 2(a),(b),(c)). Figure 2(d) 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 kinds of plants in 2015 was higher than soil bacteria number in 2014 and 2013 except for the *OP*, 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).

2.2.2 Soil fungus content in different irrigation water quality

Soil fungus is a common soil microorganism, which is suitable for acidity, and the number of fungi 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%, 50–100% in the most plants in 2013 (Fig. 3 (a)), although this increasing trend was weaken with the irrigation years. However, the number of fungus demonstrated different trends with the irrigation time with reclaimed water depending on the types of the testing plants. As shown in Fig. 3 (d), soil fungus content showed increasing trend with the irrigation years (2013–2015) in 4 kinds of plant (*OP*, *GB*, *MD*,*PB*), decreasing trend in 2 kinds of plants (*SJ* and *EJ*), and fluctuations in other plants. Specifically, the content of soil fungus increased in 2014 and then decreased in 2015 in 2 kinds of plants (*PT* and *HF*). During 2015, the differences of soil fungus content reduced in three kinds of irrigation water qualities in *SJ*, *EJ*, *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, and the root secretion causes the number of rhizosphere microorganisms to exceed the number of non-rhizosphere soil microorganisms. The number of rhizosphere microorganisms depends largely on the amount of sugar, organic acids and amino acids in the root secretions. 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. The results of the study suggest that the role of plants varies from plant community structure diversity, plant species, genotypes of the same plant, and even the different root regions of the same plant (Wang et al. 2006).

2.2.3 Soil *Actinomycetes* content in different irrigation water quality

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). In addition the *Actinomycetes* can fix nitrogen by the genus Frankia group and their symbiotic relations with plant roots (Hozzein et al. 2019;Zhang et al. 2012). 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. 4(a), (b), (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. 4(d)).

2.3 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 in soil 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 groups, 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 nutritions 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 a class of bacteria which are 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 elements (such as N, P, S) bioconversion, but also deeply influenced soil physical and chemical properties, such as the formation of soil aggregate structure, pH changes, etc.. For example, the increasing number of *Actinomycetes* help to decompose 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 too much, 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 equations (1), (2) and (3), where soil organic matter (x1), available potassium (x2), effective phosphorus (x3) and alkali solution nitrogen (x4) 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,

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

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

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

The regression equation of the total number of soil bacteria (Eq. (1)) showed that the soil organic matter, effective phosphorus and alkali solution nitrogen 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. (2)) showed that the content of available potassium had great influence on the total number of *Actinomycetes*.

Conclusions

The influences of irrigation water qualities on the soil physiochemical properties and microorganism were examined in 8 kinds of potted plants 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 content of soil total salinity (0.199-0.501 g kg^{-1}), water soluble sodium (52.33-80.21 mg kg^{-1})and chloride ions(71.25-103.60mg kg^{-1}) were higher after reclaimed water irrigation than that of tap water irrigation. In terms of soil nutrient, the content of alkaline nitrogen, effective phosphorus and available potassium in soil after reclaimed water irrigation was highly dependent on the types of potted plants. Because the water quality is the most direct factors affecting soil microbial (no significant interactions between plants and water quality), the content of different indices in irrigation water quality is different and the total number of soil bacteria also has a significant impact. The number of microorganism in soil, including bacteria, fungus and *Actinomycetes* were increased with the content of reclaimed water when irrigated, which is also closely related with the changing of soil nutrient. Also, the number of bacteria and *Actinomycetes* may increase with the irrigation years by reclaimed water. The content of soil organic matter kept unchanged in different irrigation water qualities, which may be attributed to the increasing number of *Actinomycetes* in soil. 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. We will analyze soil characteristics and seasonal changes in microbial populations. Moreover, the soil microbial community structure and diversity should be studied in depth.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Availability of data and materials The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests The authors declare that they have no competing interests" in this section.

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Authors' contributions Pei Liang analyzed and interpreted the 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.

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Figures

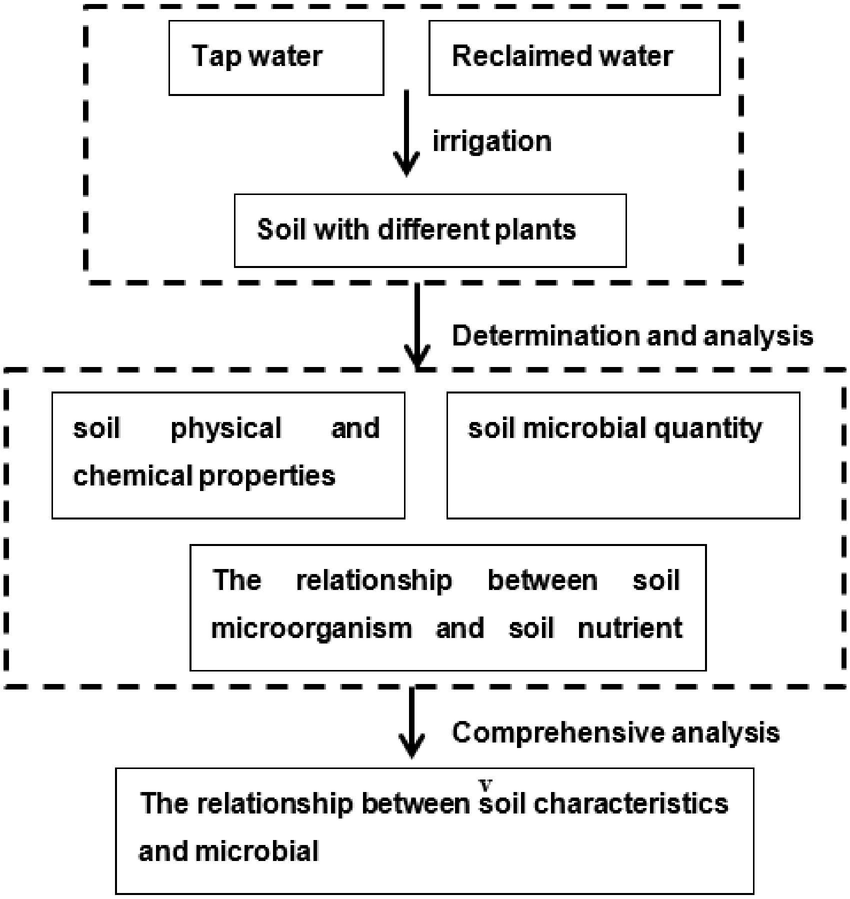

Figure 1

Flowchart of the research process in this study

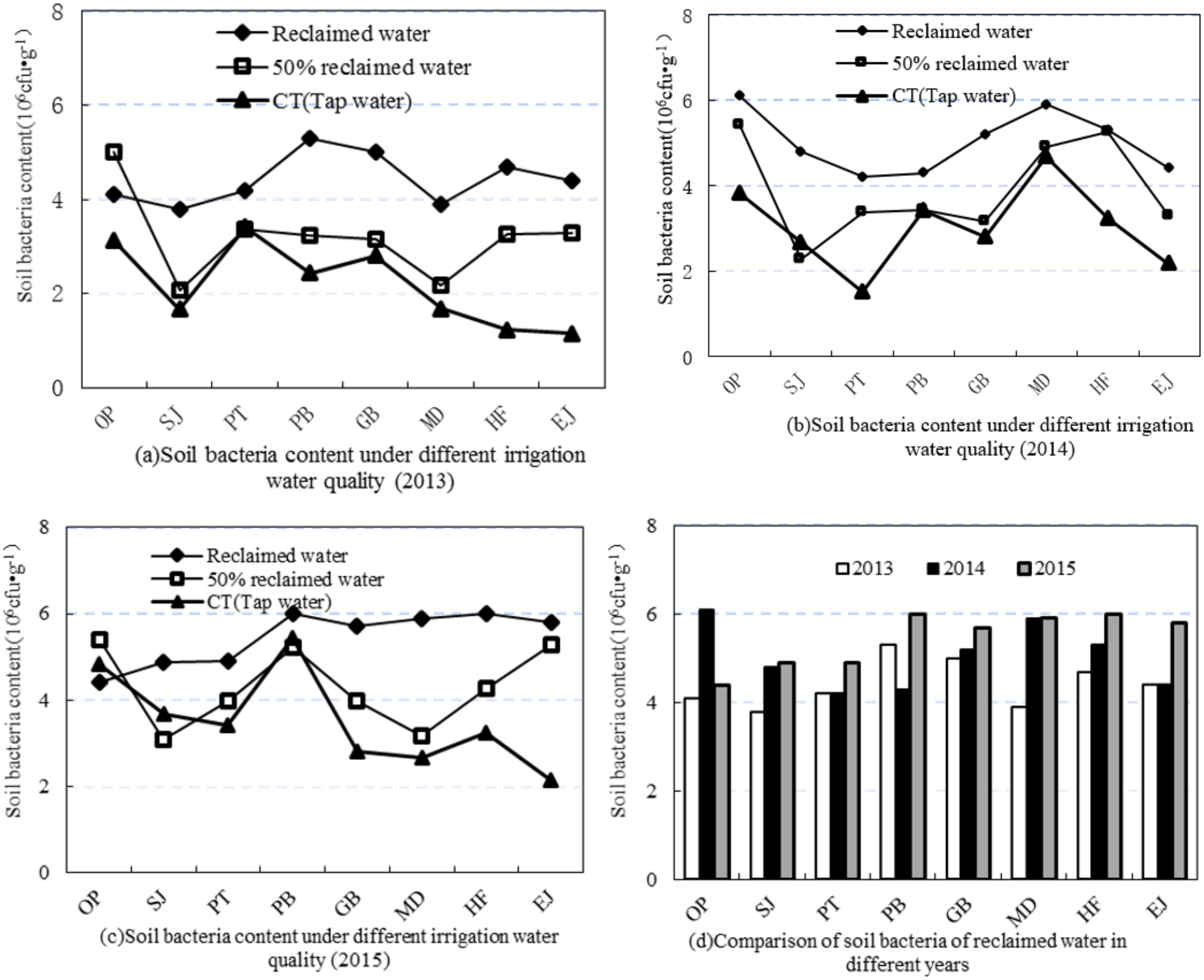

Figure 2

(a,b,c,d)Changes in the number of bacteria in different plants

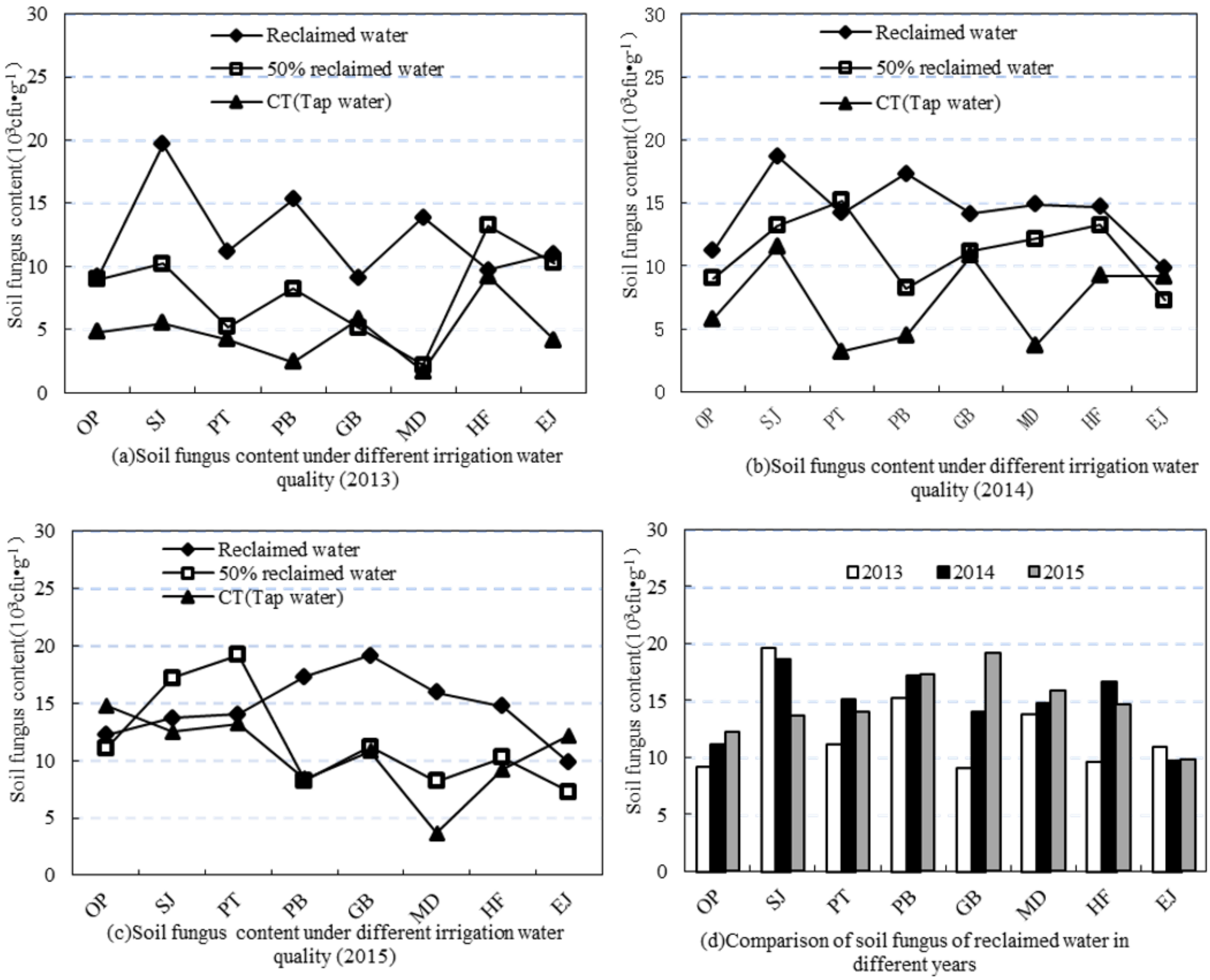

Figure 3

(a,b,c,d) Changes in the number of fungus in different plants

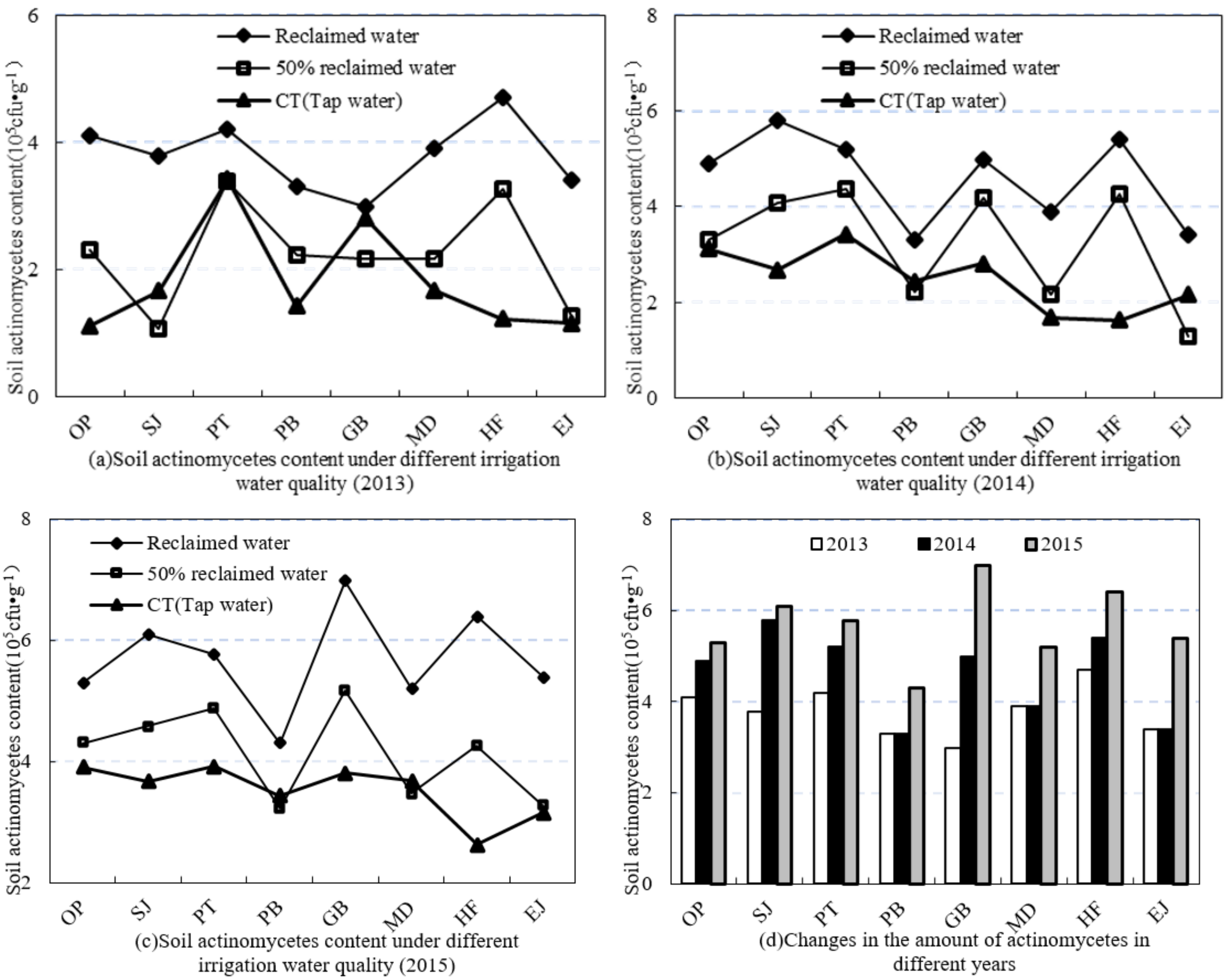

Figure 4

(a,b,c,d) Changes in the number of Actinomycetes in different plants