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RESEARCH ARTICLE

Effects of reclaimed water irrigation and nitrogen fertilization on the chemical properties and microbial community of soil

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Abstract

The ecological effect of reclaimed water irrigation and fertilizer application on the soil environment is receiving more attention. Soil microbial activity and nitrogen (N) levels are important indicators of the effect of reclaimed water irrigation on environment. This study evaluated soil physicochemical properties and microbial community structure in soils irrigated with reclaimed water and receiving varied amounts of N fertilizer. The results indicated that the reclaimed water irrigation increased soil electrical conductivity (EC) and soil water content (SWC). The N treatment has highly significant effect on the ACE, Chao, Shannon (H) and Coverage indices. Based on a 16S ribosomal RNA (16S rRNA) sequence analysis, the Proteobacteria, Gemmatimonadetes and Bacteroidetes were more abundant in soil irrigated with reclaimed water than in soil irrigated with clean water. Stronger clustering of microbial communities using either clean or reclaimed water for irrigation indicated that the type of irrigation water may have a greater influence on the structure of soil microbial community than N fertilizer treatment. Based on a canonical correspondence analysis (CCA) between the species of soil microbes and the chemical properties of the soil, which indicated that nitrate N (NO_3^--N) and total phosphorus (TP) had significant impact on abundance of Verrucomicrobia and Gemmatimonadetes, meanwhile the pH and organic matter (OM) had impact on abundance of Firmicutes and Actinobacteria significantly. It was beneficial to the improvement of soil bacterial activity and fertility under 120 mg kg^{-1} N with reclaimed water irrigation.

Keywords: reclaimed water, nitrogen, soil chemical properties, 16S rRNA sequence, soil microbe community

1. Introduction

In urban areas, the demand for water has sharply increased due to increased population. Reclaimed water is a major resource for the augmentation of inadequate water supplies, especially in arid zones and urban areas. Irrigation with reclaimed water is one of the principal alternatives for the maintenance of existing water resources, and it has been encouraged by governments and official entities worldwide

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(Biggs and Jiang 2009; Becerra-Castro *et al.* 2015). Irrigation with reclaimed water can improve soil health when using suitable management practices (Martinez *et al.* 2011; Chen *et al.* 2013; Nicolás *et al.* 2016) and changes in the availability of soil N have the potential to drastically alter the soil carbon (SC) cycle (Cox *et al.* 2000; Cramer *et al.* 2001). However, the potential health risks and environmental concerns related to irrigation with reclaimed water cannot be ignored (Chen *et al.* 2015).

The impact on the environment of irrigation with reclaimed water and the long-term ecological effects has been the focus of people's attention for a long time. The research on ecological effect of irrigation with reclaimed water has mainly focused on investigating soil pollution (Blanchard *et al.* 2001; Hidri 2014), leaching of N and phosphorus (P) to ground and surface waters (Katz *et al.* 2009) as well as the diversity of the soil ammonifiers community (Li *et al.* 2005) and soil microbial functional groups (Thayanukul *et al*. 2013). Nevertheless, research on the structure of the soil microbial community and related soil properties is still relatively weak with respect to irrigation with reclaimed water with different N levels.

The reclaimed water contains high salts, potentially hazardous compounds like heavy metals and pharmaceutically active chemicals and pathogens (Liu *et al.* 2005; Xu *et al.* 2010). The microbial diversity may have been markedly changed following pesticide application despite unaltered metabolism, and such changes may affect soil fertility and the balance of the soil ecosystem (Johnsen *et al*. 2001). N is one of the major essential macronutrients for the biological growth and development of plants. Microorganisms play a central role in the natural biological cycle and for instance convert N_2 in the atmosphere to available N in soil. The introduction of bacteria involved in N cycling or other bacteria with the ability to remediate soil contaminants (such as pesticide residue, inorganic fertilizer or pathogens) may lead to an amendment in soil quality (Oved *et al.* 2001; He *et al.* 2007; Hanjra *et al.* 2012).

Recently, genetic and molecular methods have greatly enhanced the possibilities of gaining information on the diversity and structure of the soil microbial community compared to the cultivation of isolated microbes (Caporaso *et al.* 2011; Li *et al.* 2015). The hereditary characteristics of the soil microbial community in forests, grasslands, reclaimed mining areas and farmlands were reported in the literature (Dimitriu *et al.* 2010; Li *et al.* 2013). However the study of the microbial community diversity in soil with reclaimed water irrigation through high-throughput technology is still rare.

After reviewing the past research work, we conclude that the study of the bacterial community structure model and the corresponding dynamic response characteristics under irrigation by reclaimed water with a different range of N levels is necessary. Thus, the present article aims to explore the characteristics of microorganisms involved in the regulation of the soil micro-environment and the increase in N bio-availability, which are important aspects in relation to rational fertilization and minimization of agriculture's environmental footprint when using reclaimed water for irrigation. In this study, we investigated the effects of irrigation using different types of water and N treatments on the diversity and composition of the microbial community. We hypothesized that both the water quality and the application of N would produce significant effects on the structure of the soil microbial community. N was applied only once just prior to planting in this study, therefore we further predicted that the type of water used for irrigation would have a larger impact on microbial properties than the N treatment.

2. Materials and methods

2.1. Test materials and design

The study was conducted at the Agriculture Water and Soil Environment Field Science Research Station, China (35°19´N, 113°53´E), at an altitude of 73.2 m, in the continental monsoon climate area of the temperate zone. A greenhouse pot culture experiment was used to study the effects of reclaimed water and N fertilization on the composition of the soil microbial flora and soil chemical properties with clean water as the control. The tested soil was taken from the surface layer (0–20 cm) of a sandy loam from the experimental station. The air-dried soil samples were sieved to pass through a 2-mm sieve, then 6 kg air-dried soil was placed in each pot. The soil chemical properties of total nitrogen (TN), total phosphorus (TP) and organic matter (OM) were 1.20, 0.83 and 32.85 g kg^{-1}, respectively. pH was 8.26, electrical conductivity (EC) was 0.39 ds m^{-1}. The standard recommended dose of P (44 mg kg^{-1} of soil) and K (249 mg kg^{-1} of soil) was applied before planting of cabbage (*Brassica campestris* L. ssp. *chinensis* Makino) on 6 April. There were five fertilizer treatments: N_0 (0 mg kg^{-1}), N_1 (80 mg kg^{-1}), N_2 (100 mg kg^{-1}), N_3 (120 mg kg^{-1}), N_4 (180 mg kg^{-1}). Two types of water, clean water (C) and reclaimed water (R) were used for irrigation. The resulting 10 treatments had 6 replicates each, and thus a total of 60 pots were used. The reclaimed test water was taken from the Camel Bay sewage treatment plants after secondary treatment, a source of city sewage, and the water quality indicators were shown in Table 1. A total of 12.9 L water, corresponding to 226 mm, was applied to each pot during the experiment by irrigation every second day. The cabbage was harvested on 6 June by cutting the stem at the soil surface.