Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.22662

122 (2018) 100–105
August

The responses of soil function to reclaimed water irrigation changes with soil depth

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Received 24 February 2018; Accepted 25 June 2018

ABSTRACT

The effect of reclaimed water irrigation on soil microenvironment and nitrogen economy in soil profiles was studied by monitoring different plots with nitrogen fertilization rate that had been irrigated with effluents in 2014 and 2015. The tap water irrigated plot with nitrogen topdressing 270 kg/ha served as the control and provided reference "background" values. Soil temperature, organic matter (OM), pH, electrical conductivity (EC), total nitrogen (TN), and mineral nitrogen at different soil depths were analyzed by data logger and lab test, and soil microbes were analyzed by agar plate dilution method. The results indicated that soil average temperature gap value between rhizosphere and bulk soil was elevated for all three reclaimed water treatments, while microbes amount was significantly higher in rhizosphere soil compared with control. OM, TN, EC, and mineral nitrogen increased in the top 10-cm soil layers with reclaimed water irrigation, while average pH decreased in 0–60 cm soil layers compared with control. Irrigation with reclaimed water also significantly increased both the yield, biomass, partial factor productivity from applied N, and nitrogen-supplying capacity in the fields. It showed that reclaimed water irrigation could be of agricultural reuse due mainly to its OM concentrations and nutrients input, furthermore, nitrate-nitrogen content could be improved, which may eventually reduce amount of chemical fertilizer, thus, we recommend irrigation with reclaimed water in semi-arid areas, however, EC was elevated and pH was decreased in 0–60 cm soil layers, which may eventually lead to deterioration of soil and disposal of the cation ions of effluent.

Keywords: Reclaimed water; Soil microenvironment; Rhizosphere soil; Partial factor productivity from applied N; Nitrogen-supplying capacity

1. Introduction

Reclaimed water (RW) from sewage disposal plants has been extensively employed for various purposes around the world, including crop irrigation, urban landscaping, water spraying dust, ecological river water, industrial recovered water, etc. [1–3]. RW was reused for crop irrigation starting in the 1950s in China, the application and practice of RW irrigation have been implemented in Beijing, Tianjin, Dalian, and other places [4–6]. The RW irrigation is now recognized as an important part of water resources, which also have both positive and negative consequences. It could provide the soils with mineral nutrients and organic matter (OM) [7], and

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Presented at the 3rd International Conference on Recent Advancements in Chemical, Environmental and Energy Engineering, 15–16 February, Chennai, India, 2018.

1944-3994/1944-3986

also serves as an alternative for agricultural irrigation and food safety [8]. In the recent years, soil environment effect of RW irrigation has developed regarding the advantages and disadvantages from various practices to use agriculture for safe utilization municipal sewage. However, as a result of irrigation with municipal sewage, many questions have been presented with regards to changes in soil properties, and accumulation of environmental contaminants in soil profiles of the irrigation area, which may consequently degrade the soil quality and accumulate the contaminants in the foods. Most of studies concerning the introduction of effluent-associated contaminants to soils were focused on trace heavy metals, persistent organic pollutants (POPs), and pathogenic microorganism accumulation in reclaimed wastewater irrigated soils [9–11]. Excessive inputs of some elements would also have adverse impact on the plants. For instance, overconsumption of total nitrogen (TN) from wastewater irrigation has resulted in a marked increase in soil acidity since the 1980s [12,13]. For the irrigation of *Lycopersicon esculentum* Mill., the employing of RW may enrich the plants and fresh fruits with nutrients [14]. The accumulation of NO_3^--N, POPs, and microbes was observed in groundwater where sewage was employed for irrigation of the area [15–17]. It is generally concluded, however, that the accumulation of nutrients and POPs is seem to constitute a constraint for the reuse of reclaimed sewage for the irrigation of plants, although levels of contaminants in treated plant issues were lower than national standards [18].

The objective of the study is to ascertain the effect of effluent irrigation on soil microenvironment including soil temperature, electrical conductivity (EC), pH, OM, microbes amount, TN, and mineral nitrogen by monitoring plots. The most commonly used method to study the effect of reclaimed wastewater on soil properties and utilization of carbon and nitrogen is to compare soil parameters indexes and nitrogen use efficiency between effluent irrigation and tap water irrigation plots.

2. Materials and methods

2.1. Experimental design

In this study, we selected a research area irrigation with RW from Luotuo Wan Reclamation Plant in Xinxiang city (latitude 35°15′09″N, longitude 113°55′05″E, and altitude 73.2m), under treatment process of anaerobic-anoxic-oxic denitrification biofilter and ozone oxidation. The plots employed with the RW and tap water irrigation, and the typical factors of RW met for the Farmland Irrigation Water Quality National Standard (GB5084-2005).

The field trial was a fully randomized design with three replicates of five treatments (ReN1, ReN2, ReN3, ReN4, and contrast treatment [CK]) using effluent and tap water irrigation with the same subsurface drip irrigation systems and fertilization. Base fertilizers included dried chicken manure, nitrogen, phosphorus, potassium fertilizers, rated at 8,000, 180, 180, and 180 kg/hm^2, respectively. Irrigation scheduling was based on soil water content, as measured by a time-domain reflectometer. Tomato plants were evaluated at the developmental stages consisting of five clusters and topdressing with nitrogen was performed at the first, second, and fourth cluster fruit expanding stage. There are two types of water for irrigation, namely RW (irrigation by reclaimed wastewater) and CK (irrigation by tap water), and the amount of irrigation water is equal. There are three topdressing schedule with three times during transplanting to maturity period, namely N1 (topdressing nitrogen fertilizer at 90 kg/hm^2), N2 (topdressing nitrogen fertilizer at 72 kg/hm^2), N3 (topdressing nitrogen fertilizer at 63 kg/hm^2), N4 (topdressing nitrogen fertilizer at 45 kg/hm^2), and CK (topdressing nitrogen fertilizer at 90 kg/hm^2). That is, the ReN1, ReN2, ReN3, ReN4, and CK treatments consisted of nitrogen rate at 270, 216, 189, 135, and 270 kg/hm^2, respectively. Other management practices during the whole growth season were completely standard.

2.2. Soil sampling

Soil strongly adhering to the roots was considered to belong to the rhizosphere [19] and was collected for analysis. Bulk soils were sampled from a location approximately 15 cm from the root at the first, second, and fourth cluster fruit expanding stage and late growth stage [20]. Soil samples were collected at depth of 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–60 cm with a standard 3.5 cm Ø soil auger at tomato transplanting and post-harvest stages, five samples were collected per plot and stored at room temperature for determination. The NO_3^--N was measured in 1M KCl extraction, NH_4^+-N was measured in 2% K_2SO_4 extraction, total N was analyzed with auto flow analyzer (BRAN+LUEBBE, AA3, Germany). The pH was determined by a 0.01 M $CaCl_2$ (1:1 soil to solution ration). The EC was determined by an extracts of soil pastes (1:5 soil to water ratio). The OM content was determined by dichromate titration. The microbes amount in soil samples was analyzed by agar plate dilution method. The soil temperature in rhizosphere and bulk soil was measured in temperature meter [1,14,21,22].

2.3. Plant sampling

Five plant samples per plot were taken at maturity period of tomato, stored at room temperature, fresh samples were analyzed for dry matter, NO_3^--N, NH_4^+-N, and total N in root, stem, leaf, and fruit. In order to reduce the potential of developing evaporation conditions, fresh samples were sent to lab in 2 h. Dry matter weight was determined by oven-drying method, with temperatures set at 0.25 h 105°C: 20 h 70°C, dehydration: oven drying. The determined method of NO_3^--N, NH_4^+-N, and total N in plant was similar to soil samples.

2.4. Yield and nitrogen supplying capacity

Forty plants per plot were taken as yield statistics. During the tomato maturity stage, yield per lot was recorded separately and accumulated.

$$\mathrm{PFP} = \frac{\mathrm{TY}}{\mathrm{NR}} \tag{1}$$

where PFP is partial factor productivity from applied N, kg/kg; TY is tomato yield, kg/hm^2; and NR is nitrogen fertilizer ratio, kg/ hm^2.

$$\mathrm{NSC} = \mathrm{N}_{\mathrm{min-BT}} - \mathrm{N}_{\mathrm{min-PH}} \tag{2}$$

where NSC is N_{min} variation in 0 to 30 cm soil horizon depth, kg/hm^2; N_{min-BT} is N_{min} residual in 0 to 30 cm soil horizon depth before transplanting stage of tomato, kg/hm^2; and N_{min-PH} is N_{min} residual in 0 to 30 cm soil horizon depth post harvest stage of tomato, kg/hm^2.

2.5. Data analysis

Statistical analyses were conducted with DPS software (V.14.50) [23]. The Duncan's new multiple range test was used to determine the probability ($p < 0.05$) for significant differences. The graphs were generated using Microsoft Excel 2013, and the standard error of the mean was calculated and presented in the graphs as error bars.

3. Results and discussion

3.1. Effect of RW on rhizosphere and bulk soil average temperature

Effect of RW irrigation on rhizosphere and bulk soil temperature is shown in Fig. 1. It could be presented that average rhizosphere soil temperature during the tomato whole growth stage of ReN1, ReN2, ReN3, ReN4, and CK was 22.59°C, 22.47°C, 22.32°C, 22.23°C, and 21.32°C, while average bulk soil temperature during the tomato whole growth stage of ReN1, ReN2, ReN3, ReN4, and CK was 22.46°C, 22.18°C, 22.20°C, 22.12°C, and 21.28°C, respectively. The gap value between rhizosphere and bulk ($Gap_{rhi/\ bulk}$) of ReN1, ReN2, ReN3, ReN4, and CK was 0.13°C, 0.29°C, 0.12°C, 0.11°C, and 0.04°C. Compared with CK, ReN1, ReN2, ReN3, and ReN4 elevated soil temperature at rhizosphere and bulk, with highest $Gap_{rhi/bulk}$ level value in ReN2. Dynamics in rhizosphere and bulk soil temperature occurred as an indictor of soil biotic activity and nitrogen cycling [24]. In the present study, irrigation caused the rise of rhizosphere soil temperature values in the irrigated plots, while by contrast an increase of $Gap_{rhi/bulk}$ value was present in the irrigated plots where the irrigation effluents were improved the content of OM which primed soil microbes activity [25].

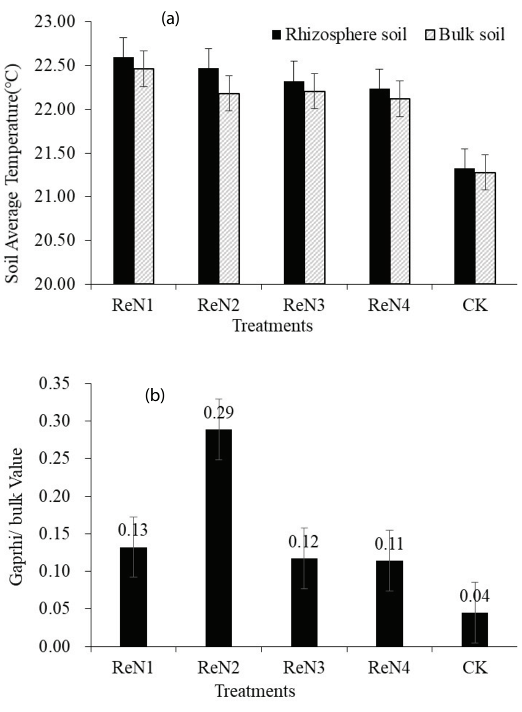

Fig. 1. Soil average temperature and gap value in rhizosphere and bulk soil during whole growth stage of tomato.

3.2. Effect of RW on soil microbes amount in rhizosphere and bulk soil

Results from microorganism biomass measurements of rhizosphere and bulk soil showed that irrigating the plots with effluent has caused an increase in microbes amount at all sampled, and the microbes amount in rhizosphere was significantly higher than in bulk soil (Fig. 2). The average rhizosphere soil microbes amount during the tomato whole growth stage of ReN1, ReN2, ReN3, ReN4, and CK was 1,392,500, 1,229,583, 790,417, 693,750, and 748,750 CFU/g in 2014, and 3,232,500, 2,733,333, 2,052,917, 1,896,591, and 1,298,333 CFU/g in 2015, while the average bulk soil microbes amount during the tomato whole growth stage of ReN1, ReN2, ReN3, ReN4 and CK, was 362,917, 394,583, 357,500, 319,812, and 315,417 CFU/g in 2014, and 484,167, 512,500, 576,667, 320,250, and 310,833 CFU/g in 2015, respectively. Both in 2014 and 2015 soil microbes amount in rhizosphere soil were significantly ($p < 0.05$) higher as compared with bulk soil both in 2014 and 2015. Generally, higher microbes amount was existed in the rhizosphere than in the bulk, which might be due to OM and mineral nutrient in the RW as well as root exudate [26]. Moreover, soil microbes amount in rhizosphere soil of ReN1 and ReN2 was significantly ($p < 0.05$) higher as compared with CK both in 2014 and 2015, the analogous results were observed that soil microbes amount in rhizosphere soil of ReN3 and ReN4 was significantly ($p < 0.05$) higher as compared with CK both in 2015. Considering the fertilizer rates that RW has been employed on the different plots, and nitrogen use efficiency to crops [14], it seems likely that microbes will promote rhizosphere soil microenvironment as long as effluent irrigation is used with suitable topdressing rate.

3.3. Effect of RW on soil OM content

The OM contents in examined soil layers ranged between 1.34% and 0.16% from top to subsoil layers (Fig. 3). In comparison with content in the control soil layers, results showed that RW employed caused increased soil OM to the depths of 10–60 cm profiles. Compared with its original content, soil OM in the 10–40 cm profiles was increased by 0.83%–2.75% with

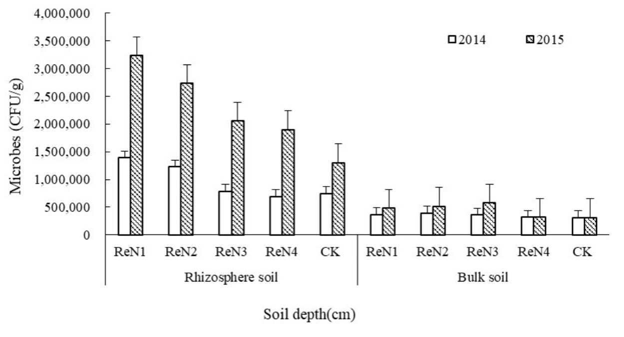

Fig. 2. Microbes amount in rhizosphere and bulk soil in every operation in 2014 and 2015.

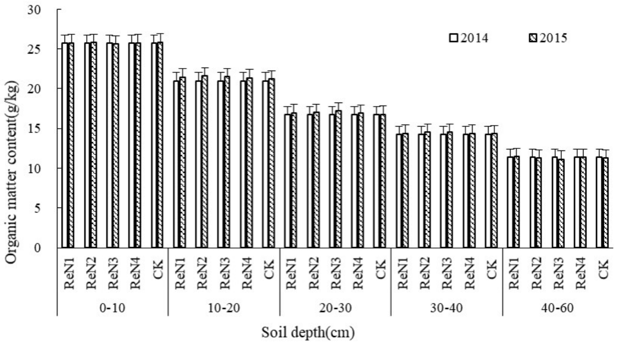

Fig. 3. Organic matter content in 0 to 60 cm soil layers in every operation in 2014 and 2015.

RW irrigation. Compared with tap water irrigation, average soil OM in the 0 to 60cm profiles was increased by 0.62%, 0.89%, 0.61%, and 0.39% with effluent irrigation and fertilizer rate of 270, 216,189, and 135 kg/hm^2, respectively. The elevation of OM in effluent irrigated fields could improve soil buffer ability and acts as a nutrient reserve [5,27]. Undoubtedly, RW application caused appreciable increased OM content in soils, which may improve the soil quality, and the OM values elevated with increasing irrigation years [1].

3.4. Effect of RW on soil pH and EC

Effect of RW irrigation on soil pH is shown in Fig. 4(a). The background value of pH in the 0 to 60cm layer was 8.70 in 2014, the average pH values in the 0 to 60cm layer irrigated with ReN1, ReN2, ReN3, ReN4, and CK was 8.73, 8.72, 8.65, 8.62, and 8.73 in 2015, respectively. Compared with control, average pH values have been slightly affected, showing no significant difference ($p < 0.05$). Noteworthy, effluent application caused slightly decreased pH values in soils, which may cause inefficient utilization of nutrient and lead to crop failure [28].

The EC contents in soil layers ranged between 0.219% and 0.077% from top to subsoil layers (Fig. 4(b)). Compared with control soil profiles, results showed that RW irrigation caused increased soil EC to the depths of 0–60 cm layers. In comparison with content in the control soil profiles, the average EC value in the 0–60 cm layer irrigated with effluent was increased by 13.19%, 5.46%, 12.74%, and 17.97%, respectively. In the present study, irrigation caused the raise of EC values in the plots, which may cause soil secondary salinization, soil degradation, and vegetable tolerance to salinity [29,30].

3.5. Effect of RW on soil TN

The distribution of TN in the examined soil layers is shown in Fig. 5. Compared with control soil profiles, results showed that RW irrigation caused increased soil TN to the depths of 0–60cm layers. In comparison with content in the control soil profiles, the average TN content the 0–60 cm layer irrigated with effluent was increased by 12.12%, 19.30%, 10.02%, and 14.34%, respectively. One of the benefits of effluent reused is that serves as "nutrient water," and this increase of TN in the root layer soil is due to RW irrigation [8].

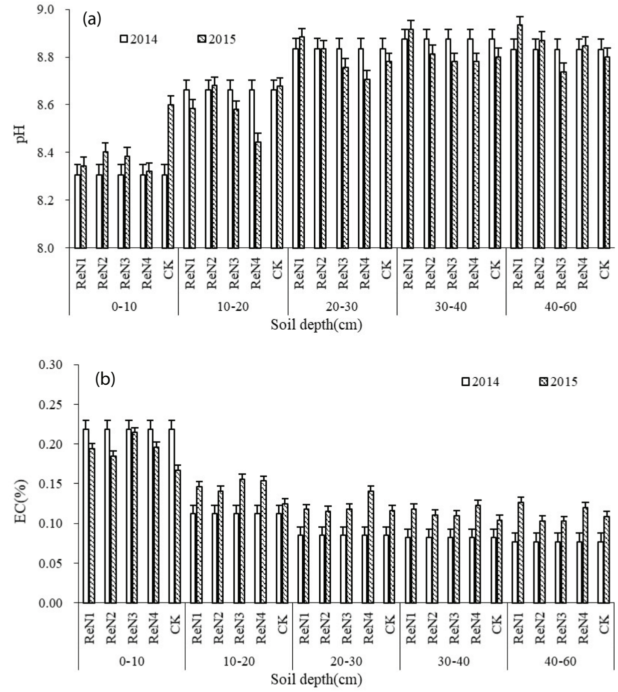

Fig. 4. pH and EC values in soil profiles in every operation in 2014 and 2015.

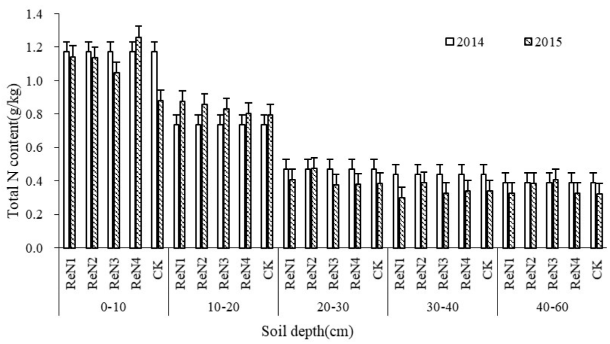

Fig. 5. TN content dynamic in 0–60 cm soil layers in every operation in 2014 and 2015.

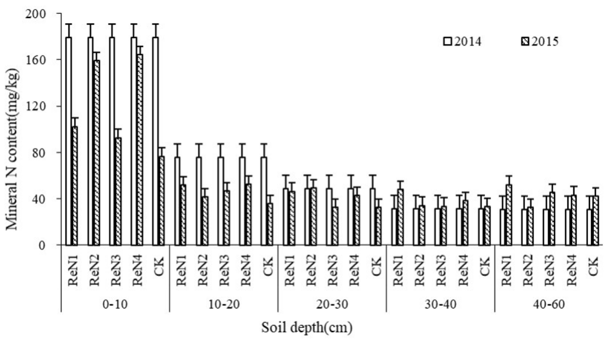

Fig. 6. Mineral nitrogen content dynamic in 0–60 cm soil layers in every operation in 2014 and 2015.

Table 1
Tomato biomass, yield, and soil nitrogen-supplying capacity

Year	Operation	Nitrogen rate/(kg/hm^2)		Nitrogen in irrigation water (kg/hm^2)	Biomass (t/hm^2)	Yield (t/hm^2)	Nitrogen in plant and fruit (kg/hm^2)	Nitrogen in fruit (kg/hm^2)	PFP (kg/kg)	NSC (kg/hm^2)
		Base fertilizer	Topdressing							
2014	ReN1	310.4	270	87.34	7.76a	139.80c	146.76a	41.88a	240.87c	225.13a
	ReN2	310.4	216	87.34	6.90bc	153.65a	146.79a	43.16a	291.88b	226.73a
	ReN3	310.4	189	87.34	7.00b	146.70b	122.64b	29.43b	293.75b	222.27a
	ReN4	310.4	135	87.34	6.74c	140.70c	112.58bc	23.56d	315.89a	203.02b
	CK	310.4	270	30.83	6.35d	140.48c	109.10c	26.56c	242.05c	209.20b
2015	ReN1	310.4	270	80.26	7.58a	142.09b	147.44c	42.57a	244.82c	231.30a
	ReN2	310.4	216	80.26	7.00b	156.44a	147.56a	43.93a	297.19a	232.42a
	ReN3	310.4	189	80.26	6.92bc	139.16bc	121.08b	28.64b	278.65b	216.90b
	ReN4	310.4	135	80.26	6.63c	134.74c	111.59c	22.57d	302.51a	204.04c
	CK	310.4	270	20.00	6.24d	133.35c	108.27c	24.84c	226.31d	220.22b

Note: Values followed by different letters of the same column show significant differences ($p < 0.05$) among treatments.

3.6. Effect of RW on soil mineral nitrogen

The distribution of TN in the examined soil layers is shown in Fig. 6. On 10 and 20cm layers, mineral N contents in soil with RW irrigation were significantly ($p < 0.05$) higher as compared with contents in soil from control plot. To a lower depth of 30, 40, and 60 cm, higher TN were only found in soils with RW irrigation and fertilizer rate 270 kg/km^2. The accumulation of mineral N in effluent plots could elevate soil nitrogen bioavailability and soil nitrogen-supplying capacity (NSC), and soil mineral N content was reported to be able to represent soil fertility [31,32].

3.7. Effect of RW on yield, soil NSC

Results from tomato biomass, yield, nitrogen in plant and fruit, and nitrogen use efficiency are shown in Table 1. It was observed that biomass and yield had the similar trend. That is, both biomass and yield with RW irrigation were significantly ($p < 0.05$) higher as compared with biomass and yield from control plot. To nitrogen in plant and fruit, higher nitrogen was found in RW irrigation and fertilizer rate 270 kg/km^2 and 216g/km^2. Average PFP from applied N of ReN1, ReN2, ReN3, ReN4, and CK was 242.84, 294.54, 286.20, 309.20, and 234.18 kg/kg, respectively. In comparison with PFP in the control plots, results showed that RW employed improved nitrogen agronomy productivity [33]. To NSC, higher values were only found in RW irrigation and fertilizer rate 270 kg/km^2 and 216g/km^2 ($p < 0.05$) [34–36]. In the present study, compared with control, RW irrigation and fertilizer rate 216g/km^2 improved yield, PFP, and NSC, because under the irrigation with RW of nutrient and OM there would contribute to increase in the total C and total N, both C and N contents may impact soil microbial amount, in particular the activity associated with cycling of nutrient elements [37].

4. Conclusion

This plot experiment evaluated the effects of RW on soil microenvironment and utilization of carbon and nitrogen in facilities habitat. The results showed that RW irrigation increased rhizosphere and bulk soil temperature, TN, mineral N content, and EC, while significantly increased microbes amount in 0–60 cm soil layers. Correspondingly, RW irrigation significantly enhanced the PFP from applied N and NSC in two-season plot trial. This result indicates that RW elevate soil ecological service function. In conclusion, RW promotes soil microbes activities and temperature, which may inevitably improve soil mineral nitrogen supplying. RW irrigation with traditional nitrogen rates had an opposite influence on pH and EC, which may eventually lead to deterioration of soil microenvironment. Thus, we recommend irrigation with RW in arid and semi-arid areas unless irrigation quality should be strictly monitored, along with appropriate amount of fertilizer.

Acknowledgments

The authors acknowledge the National Key Research and Development Program of China (Grant no.: 2017YFD0800403), National Natural Science Foundation of China (Grant no.: 51679241, 51479201), the Agricultural Science and Technology

Innovation Program of Chinese Academy of Agricultural Sciences (Grant no.: CAAS-ASTIP-FIRI-03), and the Chinese Academy of Agricultural Sciences Basal Scientific Research Fund (Grant no.: FIRI2017-10).

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