Influence of drip irrigation by reclaimed water on the dynamic change of the nitrogen element in soil and tomato yield and quality

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ABSTRACT

This paper carries out an analysis of the influence of the dynamic change pattern of soil in every crop growth period and irrigation by reclaimed water on yield and quality of fruit and vegetables comparative to drip irrigation by groundwater under the condition of drip irrigation by reclaimed water based on a field experiment. The results show the variation of peak value of concentration of NH₄⁺-N in topsoil is: drip irrigation by reclaimed water > drip irrigation by 50% reclaimed water > drip irrigation by groundwater, the concentration of NH₄⁺-N is higher at the depth of 0–40 cm with almost no accumulation of NH₄⁺-N below the depth of 40 cm NO₃-N presence in soil slightly increases across the entire growth period with irrigation by reclaimed water. Irrigation by reclaimed water increases tomato yield and irrigation water use efficiency, and has an improved taste index indicated by an improved soluble sugar and titratable acidity content of the fruit without any obvious adverse influence on the nutritive indexes such as Vc soluble solid. The shortening of the irrigation period and increase in buried depth of drip irrigation tape are to promote an increase in tomato yield and irrigation water use efficiency to carry out drip irrigation by reclaimed water under the condition of having a shorter irrigation period and a greater depth of drip irrigation tape and to yield a higher rate of water conservation.

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1. Introduction

Reclaimed water irrigation reduces serious nonpoint source pollution as a result of waste water irrigation and provides important nutrients for plant growth and promotes plant growth and development and increases yield, however, the excessive nutrients, poisonous chemical substances and pathogens in reclaimed water flow into ecological systems in the environment and result in environmental pollution to a certain extent of which may jeopardize the environment and human health (Ivanov et al., 2013; Velvizhi and Venkata Mohan, 2012). Drip irrigation is able to adjust soil moisture and nutrients based on the characteristics of irrigation time, irrigation quantity, soil infiltration range and height control point as well as physical properties (Shibao et al., 2016a; ShibaoLu et al., 2015a; Shibao et al., 2016b), root system distribution and water consumption

of crops so as to ensure that the crop is high in quality and yield and reduce nonpoint source pollution at the same time. The drip irrigation technique has been adopted to reclaim domestic sewage in rural areas to enhance the utilization efficiency of nutritive substances such as nitrogen and phosphorus in reclaimed water, saved fertilizer and water, increase yield and reduce surplus pollutants introduced into the environment and ecological system, which is of great significance for China as it needs to alleviate its water resource crisis, prevent nonpoint source pollution and promote the development of a cyclic economy (ShibaoLu et al., 2015b; Del Campo and Perez, 2014; Lu et al., 2016a). This paper performs a study of and compares the dynamic change pattern of nitrogen elements in soil in every crop growth period after drip irrigation by reclaimed water and groundwater by conducting an experiment on the premise that the other conditions are identical.

Reclaimed water utilization is one of key measures to substantially alleviate the shortage of agricultural water taken both here and abroad, being the development trend for environmental protection by waste water reclamation to mitigate secondary pollution

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by the reduction of waste water discharge which has been widely adopted in many developed countries (Lu and Liang, 2016a, 2016b; Venkata Mohan et al., 2008). Irrigation by reclaimed water is used as a means to reduce nonpoint source pollution due to irrigation by waste water and offer important nutrients necessary for plant growth as well as promote plant growth and development and improve yield. However, the excessive nutrients, poisonous chemical substances and pathogens in reclaimed water flow into ecological systems in the environment and result in environmental pollution to a certain extent of which may jeopardize the environment and human health. As an important component of life, the nitrogen element is the main factor that generates water body pollution and eutrophication (Daniel David et al., 2009; Zoltan Boboescu and Daniel Gherman, 2014; Karra et al., 2013). In addition, human activities, such as the application of agricultural nitrogen fertilizer in quantities and the willful discharge of daily waste water create a large quantity of nitrogen elements in the form of NO_3^- -N and NH_4^+ -N unabsorbed by the crop in soil flow in the process of volatilization and leaching and run-off, have brought actual and potential pollution into the environment. Therefore, in theory, it is valuable and instructive in operation to conduct a study on the nitrogen element present in soil, especially the dynamic change of NO_3^- -N and NH_4^+ -N in terms of prediction and control of nonpoint source pollution in agriculture.

In addition, drip irrigation is able to adjust soil moisture and nutrients based on the characteristics of irrigation time, irrigation quantity, soil infiltration range and height control point as well as physical properties, root system distribution and water consumption of the crop so as to ensure that the crop is high in quality and yield and to ensure the reduction of nonpoint source pollution simultaneously (Feng et al., 2015; Lu et al., 2013, 2016b). The drip irrigation technique is adopted to reclaim domestic sewage in rural areas to enhance the utilization efficiency of nutritive substances such as nitrogen and phosphorus in reclaimed water, save fertilizer and water, increase yield and reduce surplus pollutants introduced into the environment and ecology systems, of which is of great significance for China as it needs to alleviate its water resource crisis, prevent nonpoint source pollution and promote the development of a cyclic economy.

Research on yield and quality of vegetables subjected to irrigation by reclaimed water both here and abroad are inadequate. Vegetable moisture, content, crude protein, amino acid content, total soluble sugar, vitamin C, crude ash, nitrate nitrogen and nitrite nitrogen are important nutritive indexes or quality indexes, and there are few research reports on the influence of irrigation and fertilization on yield and quality of greenhouse crops (Wu and Zhang, 2015; Yang et al., 2015a; Lam et al., 2015). This paper conducted a study of and compared the dynamic change patterns of the nitrogen element in every crop growth period after drip irrigation by reclaimed water and groundwater as well as the influence of irrigation by reclaimed water on yield and quality of vegetables to offer a technical basis for the selection of crops suitable for irrigation by reclaimed water.

2. Experiment material and method

2.1. Brief introduction to the experiment, irrigation and fertilization

The experiment field is located in the comprehensive demonstration zone of nonpoint source pollution control in water source area for the middle route of the South to North Water Diversion Project jointly built by the Institute of Geographical Sciences and Natural Resources Research, CAS and the Northern Water Diversion Office under State Council, and is in the mountainous area of the southern part of Maojian District, Shiyan City, Hubei Province in a

northern subtropical monsoon climate region, in which annual solar radiation is 106.6 kcal/cm^2 , physiological radiation is 50.4 kcal/cm^2 , annual average sunshine duration is 1925.8 h, perennial mean temperature is 15.3°C , extreme minimum temperature is -14.9°C and the extreme maximum temperature is 41°C . The accumulated temperature of the days whose temperature $\geq 10^\circ\text{C}$ in the year is 4936.5°C , the frost-free period in the year is 246 days, the multi-year mean precipitation is 855 mm with a significant inter-annual variation in the amount of precipitation and the amount of precipitation in the flood period (May 1 – Oct. 20) accounting for 58%–62% of the annual amount of precipitation. The soil in the study area is yellow-brown soil with a unit weight varying from 1.56 to 1.71 g/cm^3 . The water for irrigation has been subjected to testing for 15 quality indicators, the statistical results of which are shown in Table 1.

All operations are subject to the same irrigation and fertilization system (Shao et al., 2013; Cui and Ouyang, 2015), irrigation quantity shall be determined according to the evaporation capacity of an evaporation dish with a diameter of 20 cm placed in a position as high as a tomato with irrigation carried out 11 times in a growth period with the irrigation quantity up to 272 mm in which fertilization and irrigation have been performed 4 times with the same amount of fertilizer applied every time and carbamide selected as the fertilizer. The amount of fertilizer applied in every operation is 180 kgN/hm^2 .

2.2. Experiment layout

The operation was carried out from Sept. 20 to Dec. 10 in the growth period for tomatoes in 2014. Tomato growth is based on ridge culture with the ridge shoulder being 60 cm in width, center-to-center spacing between ridges being 140 cm, and the ridge being 15 cm in height with two rows planted on the ridge and plant spacing being 40 cm. Prior to tomato growing, 20 kg of diammonium phosphate compound fertilizer was applied to every mu of field. There are three types of water for irrigation, namely T1 (irrigation by reclaimed water), T2 (irrigation by reclaimed water and groundwater, in which reclaimed water accounts for 50% of total irrigation quantity) and C (irrigation by groundwater), as shown in Table 2. Every operation was repeated for 3 plots; every plot contains 3 ridges with a length of 4 m, and every plot is $4 \text{ m} \times 4 \text{ m}$ in area. Irrigation is carried out in the form of gravity drip irrigation with a drip irrigation tape laid in the center of every ridge; dripper spacing is 20 cm, being identical with plant spacing, dripper flow rate is 2.7 L/h, and every tomato plant root has a

Table 1
Testing result of reclaimed water and groundwater quality indicators.

Test item	Reclaimed water		Groundwater
	Average value	Standard deviation	
Calcium ion	59.12	31.01	24.30
Magnesium ion	29.65	12.27	21.90
Sodium ion	138.50	16.19	75.00
Chlorine ion	181.32	86.58	26.70
Bicarbonate ion	381.89	310.53	240.00
Carbonate ion	42.12	24.04	36.70
Sulfate ion	94.87	12.82	50.00
Ion	0.16	0.08	0.13
Manganese	0.04	0.02	Not detected
BOD	40.32	8.79	11.60
COD	79.63	26.87	15.10
Total salt	720.20	136.48	334.00
Total nitrogen	28.10	19.85	1.36
Total phosphorus	1.04	0.87	0.04
TSS	70.75	24.77	Not detected

Table 2

Reclaimed water drip irrigation experiment operation.

No.	Operation	Water for irrigation
1	T1	Reclaimed water
2	T2	Reclaimed water accounts for 50% of total irrigation quantity
3	C	Groundwater

dripper for water supply. Every operation (of which includes 3 repeated plots) has 1 bucket (volume is 240 L) for water supply with a bucket placed in a position about 1.2 m above the ground. A set of negative pressure meters are installed at the depth of 20 cm below the dripper in the second experiment plot, just in case the soil water potential indicated by the negative pressure meter is lower than -25 kPa, and irrigation was initiated.

2.3. Item to be determined and experiment method

Soil was sampled on the third day, sixth day and tenth day after irrigation. The sampling depth was 0–20 cm, 20–40 cm, 40–60 cm, 60–90 cm and 90–100 cm. NO_3^- -N in the soil was determined by a $1 \text{ mol} \cdot \text{L}^{-1}$ KCl extraction-flow analyzer, and NH_4^+ -N in the soil was determined by a $2\% \text{K}_2\text{SO}_4$ extraction-flow analyzer (Tachikawa and Yamanak, 2014; Smol et al., 2015).

In addition, rural domestic waste water was subjected to filtration via a multi-layer soil infiltration system so as to obtain reclaimed water for the experiment. Groundwater, domestic waste water and reclaimed water are shown in Table 3. It was observed that the simple multi-layer soil infiltration system is not so good at domestic waste water treatment, with upper limits for many indexes in reclaimed water slightly exceeding the national standard limit.

Tomato fruit yield was determined at fruit maturing stage with the time interval for picking from 3 days to 5 days. In the full bearing period (July 9), tomato fruit with the same development status in every operation are selected to determine the quality. The determination indexes include: Vc (2,6-DCPIP titration), soluble solid (refractometer), soluble sugar (Anthrone colorimetry) and total water soluble acid (acid-based titration). After harvest, 3–5 plants were sampled from every plot (above the ground) to determine dry matter mass and the plant's total nitrogen (H_2SO_4 -mixed accelerator-distillation). After the tomato was uprooted, 24 irrigators were selected from every plot so as to determine flow quantity of the irrigator under the pressure of 0.10 MPa (GB/T 17188-1997) (Verlicchi and Zambello, 2014; Saumya et al., 2015) and also determine the flow quantity of the new irrigator and evaluate the blocking degree of the irrigator by the flow quantity reduction percentage.

Table 3

Water quality index, determination method and their comparison with relevant national standards.

Item	Ground water	Domestic waste water	Reclaimed water	Analysis method	Farmland irrigation water quality standard (GB5084-2005)-vegetable (GB5084-2005, 2005)
COD_{Cr} ($\text{mg} \cdot \text{L}^{-1}$)	3.21–5.83	450–730	68–112	Determination by dichromate titration	100
$\text{NH}_3\text{-N}$ ($\text{mg} \cdot \text{L}^{-1}$)	0.08–0.17	73–108	14–29	Determination by sodium reagent	-
Turbidity	0.4–2	20–113	21–98	Determination by turbidity meter	-
SS ($\text{mg} \cdot \text{L}^{-1}$)	2–10	60–190	30–60	Gravimetric method	60
Temperature	10–20	14–38	14–38	Determination by temperature meter	-
pH	7–8	6–9	6–9	Determination by glass electrode method	6–9
BOD_5 ($\text{mg} \cdot \text{L}^{-1}$)	1.2–2.33	179–271	28–47	Dilution inoculation method	40
DO ($\text{mg} \cdot \text{L}^{-1}$)	0.21–0.14	2.9–5.7	2.0–4.8	Portable dissolution instrument	≥ 0.5
TN ($\text{mg} \cdot \text{L}^{-1}$)	0.99–2.03	53–79	17–37	Ultraviolet spectrophotometry	≤ 30
TP ($\text{mg} \cdot \text{L}^{-1}$)	0.08–0.22	4.9–10.4	4.1–9.3	ammonium aluminate spectrophotometry	≤ 30

$$R_q = \frac{q_{\text{new}} - q}{q_{\text{new}}} \times 100 \quad (1)$$

where: R_q — flow quantity reduction percentage, %; q — average flow quantity of the irrigator after operation, L/h; q_{new} — average flow quantity of the new irrigator, L/h.

3. Results and discussion

3.1. Dynamic change of ammonium nitrogen in the soil in every crop growth period

The dynamic change of NH_4^+ -N in the soil in every crop growth period is shown in Fig. 1. Given the same water quality, NH_4^+ -N concentration in top soil (0–40 cm in soil layer) is up to the maximum within three days after irrigation. At the initial stage after irrigation, higher soil moisture offers favorable conditions for the mineralization of the nitrogen element in the soil in addition to the inhibition of nitrification of NH_4^+ -N, and the mineralization rate at this point is likely to be much higher than the nitrification rate of NH_4^+ -N, resulting in the accumulation of NH_4^+ -N over a short period. Given the same irrigation quantity, the peak value change pattern of NH_4^+ -N in top soil after irrigation is: drip irrigation by reclaimed water > drip irrigation by 50%, reclaimed water > drip irrigation by groundwater. During the crop growth period, the concentration of NH_4^+ -N in the soil at the depth of 0–20 cm is only to maintain it at a high level within a short period of time (3 days) after fertilization and irrigation. It shall be below $0.5 \text{ mg} \cdot \text{kg}^{-1}$ in other periods by and large. In addition to a higher content of NH_4^+ -N in the soil profile at the depth of 20 cm–40 cm in Sept. 22, Oct. 4, Nov. 6 and 18, Dec. 4 due to irrigation, NH_4^+ -N in the soil profile at the depth of 20 cm–100 cm at other times was below $0.5 \text{ mg} \cdot \text{kg}^{-1}$. Such a changing pattern of NH_4^+ -N indicates that soil is favorable for nitrification, as a general rule, and no NH_4^+ -N has accumulated in the soil.

3.2. Dynamic change of nitrate nitrogen in soil in every crop growth period

The change trend of NO_3^- -N in soil subjected to every operation in every growth period is as shown in Fig. 2, in which Sept. 25 shows the content of NO_3^- -N in the soil in the tomato growth period and Dec. 4 shows the content of NO_3^- -N in the soil during the tomato harvest. The change pattern of NO_3^- -N in the soil during the growth period is on the increase along the soil profile (Lu et al., Skitmore). NO_3^- -N in the soil increased from Sept. 20 to Oct. 10, due to the application of a large amount of carbamide and diammonium phosphate as a base fertilizer for tomato growth. Later, the change of NO_3^- -N in the soil was primarily subjected to the influence of

Fig. 1. Dynamic change chart for $\text{NH}_4^+\text{-N}$ in soil in every crop growth period.

irrigation and fertilization.

3.3. Yield analysis

Reclaimed water irrigation is more likely to increase tomato

yield, being the most effective under the condition of having a shorter irrigation period and deeper position in which a drip irrigation tape is located (Pang et al., 2013; Yang et al., 2015b). It is observed from Table 4 that when the irrigation period is 4 days, the yield under reclaimed water irrigation is 1.4% and 10.3% higher than

Fig. 2. Dynamic change chart of $\text{NO}_3^-\text{-N}$ in soil in every crop.

that under mixed water irrigation and groundwater irrigation, respectively. With the shortening of the irrigation period, the yield is on the increase, being the most noticeable under the condition of reclaimed water irrigation and mixed water irrigation. Reclaimed water irrigation is taken as an example, compared with an irrigation period of 8 days and 16 days, the yield under the condition whereby the irrigation period is 4 days increased by 2.9% and 7.6%, respectively. The yield under the condition that reclaimed water is used for irrigation and that irrigation period is 4 days is up to the maximum, being 76.6 t/hm², with the increase in the buried depth of drip irrigation tape, yield was on the increase, being the most notable under the condition of reclaimed water irrigation, for example, if the buried depth is 30 cm, the yield shall be increased by 13.5% and 16.7% compared with the condition whereby the buried depth is 15 cm. In 2011, the yield was up to the maximum, namely 66.1 t/hm² under the condition that reclaimed water is adopted for drip irrigation and the buried depth is 30 cm, compared with reclaimed water irrigation, the yield under such a condition whereby reclaimed water is used for irrigation is slightly on the decrease, being decreased by 1.0% and 0.1%, respectively.

It was observed from the statistical analysis of the tomato yield given in Tables 4 and 5 that water quality exerts a consistent influence on yield and that reclaimed water irrigation under the condition of a shorter irrigation period and greater depth for drip irrigation tape is favorable for an increase in yield. The influence of water quality, irrigation period and buried depth has exerted no obvious influences on tomato yield, without significant interaction among various factors. Compared with irrigation period and buried depth of drip irrigation tape, water quality has a greater influence on tomato yield. Although irrigation by reclaimed water and mixed water is to significantly inhibit crop water consumption, crop yield is higher (Lu et al., 2016c; Wang et al., 2016).

3.4. Quality analysis

It was observed from the statistical analysis results of tomato

fruit quality (Table 4 and Table 5) that soluble sugar, titratable acidity and soluble solid under the condition of irrigation by reclaimed water are higher than those by groundwater, indicating that irrigation by reclaimed water improves the taste of tomatoes to a certain extent and that irrigation by reclaimed water significantly decreases reduction type Vc, without a significant difference indicating that irrigation by reclaimed water has no obvious influence on the nutritive index of tomatoes. Irrigation period has no significant influence on soluble sugar and titratable acidity. With an increase in irrigation period, there was an obvious trend of an increase in reduction type Vc and soluble solid, in which, the difference between 4 days and 6 days in the irrigation period is up by a significant level, indicating that the extension of the irrigation period is conducive to the improvement in the nutritive index of tomatoes. In the case whereby the buried depth is 30 cm, various quality indexes are higher than those in other operations, indicating that the buried depth of 30 cm is able to improve the fruit quality of tomatoes in an effective way.

4. Conclusion

- (1) When given drip irrigation by reclaimed water, the peak value change pattern of concentration of NH₄⁺-N in top soil is: drip irrigation by reclaimed water > drip irrigation by 50% reclaimed water > drip irrigation by groundwater, NH₄⁺-N concentration is higher at the depth of 0–40 cm, there is almost no NH₄⁺-N accumulated below the depth of 40 cm. In the whole growth period, NO₃-N in the soil is on the slight increase along the soil profile.
- (2) Irrigation by reclaimed water has a tendency to increase tomato yield and irrigation water productivity, being more obvious under the condition of shorter irrigation periods and greater depth for the drip irrigation tape. Irrigation by reclaimed water improves taste indexes such as soluble sugar and titratable acidity of fruit to a certain extent, and has no significant adverse influences on nutritive indexes

Table 4
Tomato yield and quality.

Operation	Soluble sugar/%	Titratable/acidity %	Reduction type Vc/(mg·(100 g) ⁻¹)	Soluble solid/%	Yield/(t·hm ⁻²)
Reclaimed water	3.56a±0.06	0.30a±0.01	8.25a±0.76	3.93a±0.22	74.04a±2.73
Mixed water	3.36a±0.13	0.29a±0.02	8.64a±1.14	3.92a±0.27	74.13a±2.23
Groundwater	3.40a±0.22	0.29a±0.03	8.49a±1.11	3.75a±0.11	69.53a±1.79
4 d irrigation period	3.48a±0.09	0.30a±0.02	7.37b ± 0.09	3.88a±0.26	73.59a±4.26
8 d irrigation period	3.29a±0.18	0.30a±0.03	8.82 ab ± 0.06	3.74a±0.10	73.77a±1.96
16 d irrigation period	3.55a±0.09	0.27a±0.01	9.20a±0.64	3.97a±0.21	70.34a±1.77
Reclaimed water	3.22a±0.15	0.32a±0.04	7.82a±0.76	3.65a±0.14	67.76a±5.69
Mixed water	3.13a±0.04	0.26a±0.02	7.66a±1.56	3.49a±0.06	64.53a±2.41
Groundwater	3.21a±0.09	0.30a±0.04	8.25a±1.44	3.53a±0.13	63.32a±4.45
0 cm buried depth of drip irrigation tape	3.17a±0.12	0.28a±0.01	7.18a±1.79	3.56a±0.15	63.51a±4.67
Buried depth of drip	3.15a±0.10	0.29a±0.05	6.23a±0.79	3.51a±0.04	64.76a±1.28
30 cm buried depth of drip irrigation tape	3.24a±0.10	0.31a±0.05	7.75a±1.79	3.61a±0.16	67.33a±6.24

Note: The same letters denote significant difference ($P = 0.05$) between layers in operation; the same below.

Table 5
Source of variance in yield and quality.

Operation	Soluble sugar/%	Titratable/acidity %	Reduction type Vc/(mg·(100g) ⁻¹)	Soluble solid/%	Yield/(t·hm ⁻²)
Water quality	NS($P = 0.335$)	NS($P = 0.823$)	NS($P = 0.897$)	NS($P = 0.493$)	NS($P = 0.25$)
Irrigation period	NS($P = 0.184$)	NS($P = 0.169$)	NS($P = 0.097$)	NS($P = 0.393$)	NS($P = 0.46$)
Mutual influence	NS($P = 0.900$)	NS($P = 0.201$)	NS($P = 0.963$)	NS($P = 0.361$)	NS($P = 0.96$)
Water quality	NS($P = 0.747$)	NS($P = 0.183$)	NS($P = 0.851$)	NS($P = 0.398$)	NS($P = 0.45$)
Buried depth of drip	NS($P = 0.746$)	NS($P = 0.592$)	NS($P = 0.668$)	NS($P = 0.696$)	NS($P = 0.56$)
Mutual influence	NS($P = 0.699$)	NS($P = 0.380$)	NS($P = 0.823$)	NS($P = 0.584$)	NS($P = 0.34$)

Note: NS indicates insignificant difference; the same as below.

such as Vc and soluble solid. Shorter irrigation periods increase tomato yield and irrigation water productivity and a prolonged irrigation period is conducive to the improvement of the nutritive index of tomato.

- (3) Increase in buried depth enhances tomato yield and irrigation water productivity. Irrigation water productivity is up to the maximum under the condition that the buried depth is 30 cm, which is able to improve various quality indexes of tomato. For tomato plants in solar greenhouses, shorter irrigation periods and greater depth for a drip irrigation tape are able to increase yield to a great extent and have no adverse influence on fruit quality.

Conflict of interests

The authors declare that they have no conflict of interests in this work.

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