Experimental Study on the Heavy Metal Pollution in the Soil Irrigated by Reclaimed Water from Sewage Treatment Plant

Xing YAN[1*], Gang LUO1, Jian CAO[2], Jiawen XU[1], Shuang WANG[1], Weihai YE[1], Yicheng LIANG[1]

1. Guangzhou Sewage Purification Co., Ltd., Guangzhou 510163, China; 2. Vegetable Research Institute, Guangdong Academy of Agriculture Sciences, Guangzhou 510640, China

Abstract Reclaimed water irrigation is one of the potential ways of solving the shortage of water resources, and the pollution risk on migration behavior of heavy metals in the soil which are irrigated by reclaimed water and the related soil surface is still short of research. Through the experimental study of different kinds of water irrigation methods on vegetable, it can be concluded that compared with sewage irrigation and tap water irrigation, reclaimed water irrigation does not pollute the soil, and it greatly saves the cost of water resources, and even provides a large number of growth elements for vegetables. The results show that after leaching by reclaimed water for 60 days, Cr, Cd, As, Hg, Pb, Ni, Zn and Cu from reclaimed water are enriched in soil to a certain degree, but with the leaching time extending, concentrations of the heavy metal remain stable. The variation of heavy metal content in soil irrigated by reclaimed water is small in vertical depth, basically showing a horizontal trend. According to *Soil Environmental Quality Standards* (GB15618 – 1995), soil irrigated by reclaimed water does not exceed the standard, better than soil quality standard of planting vegetables.

Key words Reclaimed water, Soil, Vegetables, Accumulation

1 Introduction

There are dense rivers, abundant water resources and fertile lands in Guangzhou City which becomes an important base for the production of high quality and efficient vegetables[1]. However, with the industrial and agricultural development and population growth, the water pollution is becoming more and more serious[2–4]. The reclaimed water is the non-potable water reaching certain water quality standards and reused within a certain range after the municipal sewage treatment, so using reclaimed water for irrigation will be a potential way to solve shortage of water[5–7]. Zhou Lubo *et al.*[8] study the influence of reclaimed water irrigation in golf course on the groundwater, soil, landscape quality, maintenance cost and human health, and point out that the reclaimed water irrigation in golf course is safe and feasible. There are many foreign studies on farming irrigation by sewage. Lahaam *et al.*[9] research the impact of different mixing ratio of clean water and reclaimed water on tomato quality; Al-Nakshabandi *et al.*[10] use reclaimed water for drip irrigation on eggplant near Amman, Jordan; Pollice *et al.*[11] use the reclaimed water through tertiary sewage treatment for drip irrigation on fennel and tomatoes. The studies show that the reclaimed water as irrigation water is basically safe[12–13]. However, there is still a shortage of studies on the migration of heavy metals in the soil, the risk of contamination of shallow groundwater and heavy metal accumulation in soils in the process of using reclaimed water to irrigate vegetables[14–15]. On the basis of long-term wastewater treatment and application by Guangzhou Sewage Purification Co., Ltd., and Vegetable Research Institute of Guangdong Academy of Agriculture Sciences, we assess the vertical migration of heavy metals in the soil and pollution-related risks in the course of using reclaimed water from Guangzhou's municipal sewage treatment plant to irrigate vegetables, in order to provide the most effective irrigation water for the planting of vegetables in Guangzhou City.

2 Materials and methods

2.1 Materials

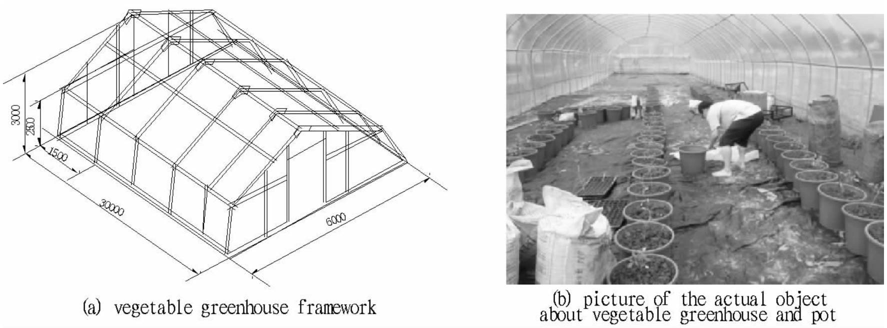
2.1.1 Greenhouses. Greenhouse uses galvanized steel frame, with length × width × height of 30000 mm × 6000 mm × 3000 mm. A 2000 mm × 2500 mm door is set at the side of greenhouse. Steel frame is fastened with rivets, and steel pipe is inserted into ground 500 mm deep. Greenhouse top is covered with transparent plastic film, to prevent rainwater interference. The airtight gauze net is used to enclose greenhouse to prevent pests. The greenhouse sets four fans for ventilation and heat dissipation, to make sure that the vegetables do not wither due to high temperature. The experimental equipment is shown in Fig. 1.

2.1.2 Vegetable pot. The vegetable pot is made of plastic material, with the volume of 20 L. Its diameter is 300 mm and its height is 400 mm, with a tray below, as shown in Fig. 2.

2.1.3 Experimental soil. 3.5 t of soil (sandy loam) with good texture is selected nearby, and the soil is dried in the air outdoors. After removing the grass roots, gravel and other impurities, the soil is sifted with a 20-mesh sieve. 500 kg of decomposed manure and right amount of inorganic fertilizers are mixed with the soil to form the experimental soil. After loading the tray with soil, the soil is fully watered, and the film is covered to preserve moisture. After the water never drips, it is placed in the vegetable

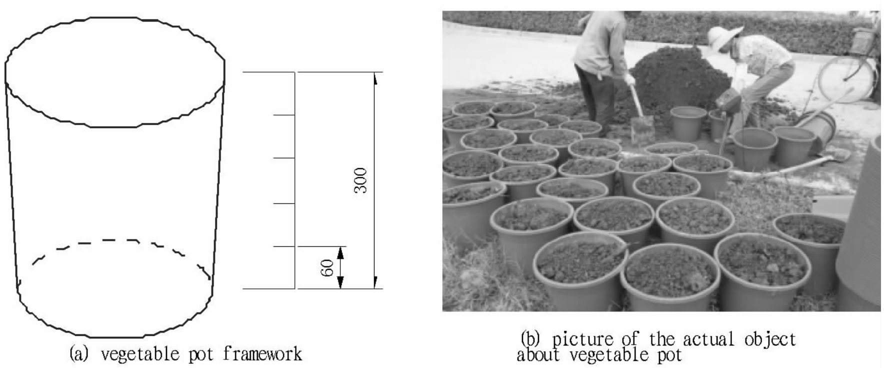
Received: March 26, 2015 Accepted: May 17, 2015
Supported by Key Science and Technology Project of Tianhe District, Guangzhou City, Guangdong Province (201205YG088).
* Corresponding author. E-mail: yanxing82001@163.com

greenhouse. At the same time, some soil samples are dried and weighed for testing and calculating the soil pH and heavy metals, as shown in Table 1. Except cadmium, all heavy metals can basically meet the secondary standard of Soil Environmental Quality Standards (GB15618 – 1995), as shown in Table 2.



(a) vegetable greenhouse framework (b) picture of the actual object about vegetable greenhouse and pot

Fig. 1 Experimental equipment



(a) vegetable pot framework (b) picture of the actual object about vegetable pot

Fig. 2 Vegetable pot

Table 1 Table 1 Heavy metal content Unit: mg/kg

Detection indicators	pH	Mercury	Arsenic	Chrome	Copper	Nickel	Lead	Zinc	Cadmium
Value	7.5	0.23	12.43	26.21	28.79	11.83	22.03	69.95	1.40

Table 2 The limit values of soil environmental quality Unit: mg/kg

Items	First level	Second level			Third level
	Natural background	pH < 6.5	6.5 < pH < 7.5	pH > 7.5	pH > 6.5
Mercury	0.15	0.30	0.50	1.0	1.5
Arsenic	15	40	30	25	40
Copper	35	50	100	100	400
Lead	35	250	300	350	500
Chrome	90	150	200	250	300
Zinc	100	200	250	300	500
Nickel	40	0	50	60	200
Cadmium	0.20	0.30	0.30	0.60	1.0

2.1.4 Experimental water. We select the sewage of Guangzhou Shijing Sewage Treatment Plant, reclaimed water and tap water as the experimental irrigation water. The water quality is shown in Table 3.

Table 3 Experimental water indicators Unit: mg/L

Detection indicators	pH	Mercury	Arsenic	Chrome	Copper	Nickel	Lead	Zinc	Cadmium
Tap water	7.1	<0.0010	<0.0010	<0.0100	<0.0100	<0.0100	<0.0500	0.0160	<0.0030
Reclaimed water	7.2	0.0001	0.0043	0.0160	0.0200	0.0210	<0.0500	0.0360	<0.0030
Sewage	7.5	0.0005	0.0056	0.0390	0.3180	0.0650	<0.0500	0.2990	<0.0030

2.2 Experimental methods The experiment sets two repeated irrigation plots, and we select the experimental pots in Plot I as the research object (Table 4). The distribution of experimental plot is shown in Fig. 3. Five pots of vegetables are planted in each group, and in vegetable growth process, it is watered once a day at 8:00 and 16:00, each about 1 L. The experiment started from September 1, 2013 to December 31, 2013. The samples are taken in the first day of each month. 100 g of mixed samples are taken from the pot irrigated with tap water; 100 g of samples 0 mm, 60 mm, 120 mm, 180 mm and 240 mm deep in the pots irrigated by reclaimed water and sewage, respectively.

Table 4 Experimental design and arrangement of irrigation water for vegetables

Plot I			Plot II		
Group I: tap water	Group I: reclaimed water	Group I: sewage	Group II: sewage	Group II: reclaimed water	Group II: tap water
Group I: reclaimed water	Group I: sewage	Group I: tap water	Group II: tap water	Group II: sewage	Group II: reclaimed water
Group I: sewage	Group I: tap water	Group I: reclaimed water	Group II: reclaimed water	Group II: tap water	Group II: sewage

Fig. 3 The distribution of experimental plot

2.3 Sample treatment The soil samples are first placed in the laboratory to be aired naturally, and then dried in an oven at 105 ℃. After sample grinding, digestion and other pretreatment processes, the samples are detected and analyzed. Chromium, cadmium, copper, zinc, nickel and lead are detected using atomic absorption spectrometry while mercury and arsenic are detected using atomic fluorescence spectrophotometry.

3 Results and analysis

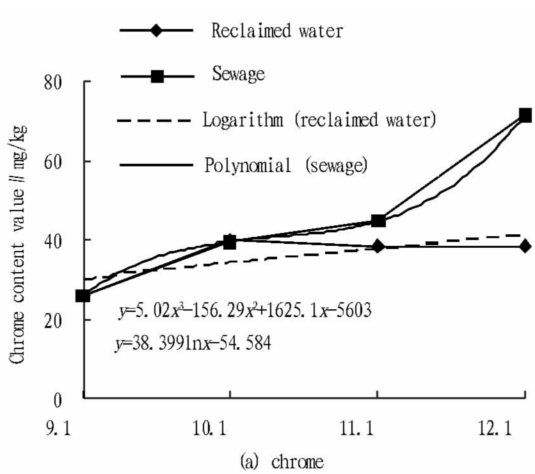
By experiment, it is found that the heavy metal content is low in the vegetable soil irrigated by reclaimed water while the heavy metal content is high in the vegetable soil irrigated by sewage. The experimental data are shown in Table 5.

Table 5 The content of heavy metal in the experimental vegetable soil

Date (month. day)	Sample name	Soil depth mm	Mercury mg/kg	Arsenic mg/kg	Chrome mg/kg	Copper mg/kg	Nickel mg/kg	Lead mg/kg	Zinc mg/kg	Cadmium mg/kg
9.1		Original sample	0.23	12.43	26.21	28.79	11.83	22.03	69.95	1.40
10.1	Tap water	Average sample	0.23	12.43	33.63	17.38	14.51	18.51	62.50	1.44
11.1	Tap water	Average sample	0.30	12.58	35.21	17.22	14.00	18.58	60.60	1.48
12.1	Tap water	Average sample	0.30	13.41	35.97	13.62	14.90	20.92	59.62	1.54
10.1	Reclaimed water	0	0.14	10.30	32.96	23.37	15.03	22.93	74.53	1.84
11.1	Reclaimed water	0	0.50	12.11	44.93	14.85	28.60	24.55	59.46	1.77
12.1	Reclaimed water	0	0.86	60.68	42.74	24.88	28.61	25.71	82.77	2.10
10.1	Reclaimed water	60	0.28	10.80	48.40	25.32	39.87	25.75	80.30	1.97
11.1	Reclaimed water	60	0.18	12.19	34.90	25.12	24.28	26.08	78.06	1.97
12.1	Reclaimed water	60	0.24	11.22	35.04	21.59	24.86	23.26	68.95	1.94
10.1	Reclaimed water	120	0.38	12.69	42.70	19.99	25.83	21.56	80.17	1.46
11.1	Reclaimed water	120	0.16	13.03	41.42	19.83	26.83	19.18	65.74	1.46
12.1	Reclaimed water	120	0.17	10.47	42.79	21.76	27.07	17.94	69.84	1.38
10.1	Reclaimed water	180	1.14	10.30	43.07	22.29	27.43	19.70	88.62	1.63
11.1	Reclaimed water	180	0.33	10.62	33.27	24.12	23.30	18.28	75.86	1.50
12.1	Reclaimed water	180	0.40	11.40	32.10	20.61	22.72	21.49	69.27	1.46
10.1	Reclaimed water	240	0.23	15.30	33.50	20.30	23.47	19.86	68.75	1.37
11.1	Reclaimed water	240	0.55	10.39	38.81	24.80	32.40	23.42	67.73	1.59
12.1	Reclaimed water	240	0.32	11.72	39.38	14.26	26.51	19.80	60.83	1.47
10.1	Sewage	0	0.62	10.60	30.16	34.38	13.90	15.90	90.78	1.69
11.1	Sewage	0	0.46	12.52	50.99	18.27	22.50	17.69	61.36	1.44
12.1	Sewage	0	0.41	12.84	57.77	24.69	23.02	20.94	74.15	1.97
10.1	Sewage	60	0.25	7.70	62.34	26.71	28.33	23.86	77.66	1.98
11.1	Sewage	60	0.18	11.92	50.69	27.47	23.40	23.03	76.22	2.10
12.1	Sewage	60	0.19	12.48	88.84	18.86	38.22	18.43	69.51	1.47
10.1	Sewage	120	0.36	12.76	37.97	16.31	17.24	23.75	62.63	1.56
11.1	Sewage	120	0.25	15.71	38.54	10.38	18.13	14.69	55.57	1.82
12.1	Sewage	120	0.92	12.23	77.92	22.36	34.17	15.54	70.92	1.50
10.1	Sewage	180	0.57	12.02	33.47	23.98	15.06	24.95	69.38	1.48
11.1	Sewage	180	0.14	12.84	48.31	17.83	22.17	15.48	64.43	1.51
12.1	Sewage	180	0.47	14.09	72.21	19.08	31.63	17.36	72.44	1.80
10.1	Sewage	240	0.34	12.38	34.76	23.02	15.18	16.96	72.37	1.53
11.1	Sewage	240	0.71	11.91	35.98	21.47	15.28	20.66	72.95	1.51
12.1	Sewage	240	0.36	12.66	62.31	18.16	28.07	18.74	66.57	1.42

Based on the value of soils irrigated with tap water, we choose the representative chrome and nickel as the research object for data analysis, and get the average values of chrome and nickel in 0 mm, 60 mm, 120 mm, 180 mm and 240 mm deep soils in the same time period, with the time as the abscissa and chromium and nickel concentrations as vertical axis (Fig. 4a). From the curve in Fig. 4a, it is found that the content of heavy metals in the soil irrigated with sewage gradually increases over time, and the increasing trend basically meets the increment mode of simple cubic equation. The content of heavy metals in the soil irrigated with reclaimed water slightly increases, and the accumulation of heavy metals in soil basically meets the logarithmic function trend, and the content of heavy metals basically tends to be at a stable level over time, indicating that the accumulation of heavy metals in soil is a dynamic balance process, because the content of heavy metals in reclaimed water is low, and in the process of using reclaimed water to irrigate soil, part of accumulated heavy metals seep with water flow. The concentration of heavy metals in sewage is high, the accumulated heavy metals are more than the heavy metals seeping out over time, and the heavy metal content shows an increasing trend. The content of heavy metals in the soil in Fig. 4a is significantly lower than in Fig. 4b. Based on Table 1 and Table 3, it can be found that the content of heavy metals in soil is closely related to the background value of the original soil, and the irrigation water has a small impact. The content of nickel in the soil irrigated by reclaimed water and sewage is lower than 40 mg/kg, and the content of heavy metals in the soil irrigated by reclaimed water tends to be at a stable level.

The samples at different depths are taken and the concentration of chrome and nickel is detected. With the depth as abscissa and concentration as vertical axis, we get Fig. 5. From the curves in the figure, it is found that in the vegetable soil irrigated with reclaimed water, the heavy metal content shows a substantially horizontal trend, and with the change of time and depth, the changes in the concentration of heavy metals become small. The content of heavy metal in reclaimed water is low, and the accumulation in soil follows the laws of dynamic equilibrium; the accumulation amount is basically equal to desorption amount, and the concentration value is close to the background value of soil, so the heavy metal content is higher than the original level and always shows a steady state. The soil irrigated with sewage shows a quadratic polynomial decreasing trend. The heavy metal content presents the maximum value at 60 mm, and then the concentration gradually decreases with the increasing depth, indicating that in the soil surface, the amount of heavy metals absorbed by soil is far greater than the desorption amount, but with the increasing depth of the soil, the heavy metal content of the water decreases, leading to decreasing adsorption amount and increasing desorption amount, so the content of heavy metals in soil gradually decreases. As can be seen from the figure, the heavy metal content gradually increases over time, which is consistent with the case in Fig. 4. LEC risk assessment method is used for the risk assessment on the soil irrigated by reclaimed water. The sewage treatment plant detects and analyzes the reclaimed water every day to ensure that the water meets the vegetable irrigation standards, and through the experiments, it is found that the content of heavy metal in the soil irrigated with reclaimed water is not increased obviously, and remains stable to meet the standard requirements of vegetable cultivation, so the possibility of accidents is "very unlikely", and L value is 0.5. After using the reclaimed water for the irrigation of vegetables, whether the heavy metal in soil is adsorbed by vegetables is to be studied in the further experiment. Assuming the vegetables come into contact with irrigation water, and human body is indirectly put in the risk environment through the consumption of vegetables; human will eat vegetables every day, so the frequency of exposure to the risk environment is at the highest level "continuous exposure", and E value is 10. The content of heavy metal in reclaimed water is low, and the heavy metal accumulated in soil is also low, meeting the needs of growing vegetables, so there is basically no risk of harm, and the consequence of an accident is "minor injuries", with C value of 1. The risk score D ($D = L \times E \times C$) is calculated at 5, less than 20, a little dangerous, so the soil irrigated with reclaimed water is at the level of tolerable risk (safe, no need to take action).



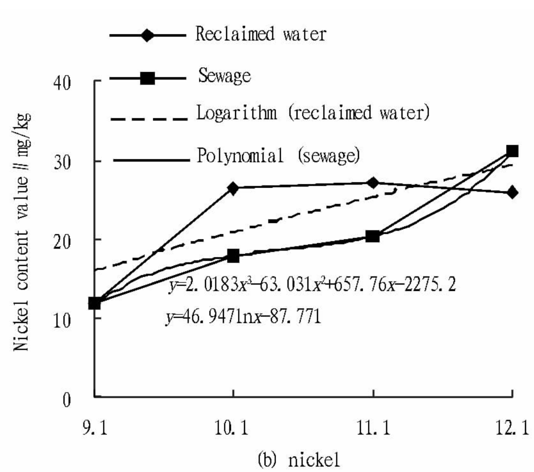


Fig. 4 The accumulation of chrome and nickel in the vegetable soil

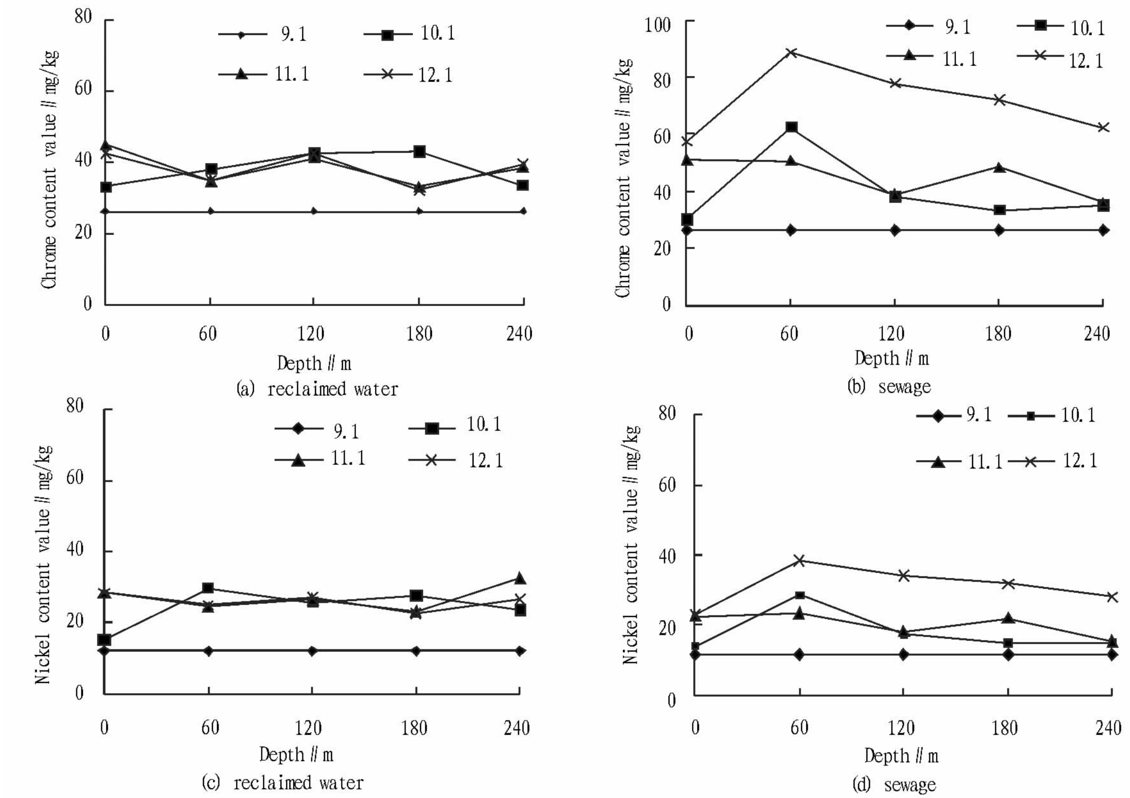


Fig. 5 The changes in the concentration of heavy metals in the vegetable soil irrigated by reclaimed water or sewage with soil depth

4 Conclusions and discussions

From the experimental study, it is found that compared with the vegetable soil irrigated with sewage, the content of heavy metal in the soil irrigated with reclaimed water basically meets the secondary standard of *Soil Environmental Quality Standards* (GB15618 – 1995). There is accumulation of heavy metal in soil during irrigation, but over time, the heavy metals accumulated in soil gradually realize desorption and show dynamic balance, and the topsoil for vegetable cultivation is in full compliance with the requirements of environmental quality. LEC risk assessment method is used for the risk assessment on the soil irrigated by reclaimed water, and it is at the level of tolerable risk (safe, no need to take action). The study clears the migration of heavy metal in soil, the risk of contamination of shallow groundwater and heavy metal accumulation in soil during the irrigation of vegetables with reclaimed water, improves the theoretical researches in areas of reclaimed water, and further corroborates the conclusion of Lahaam *et al.* that the reclaimed water is basically safe to be irrigation water. Based on the actual situation of water pollution in Guangzhou City, this study aims to provide the most effective irrigation water for the planting of vegetables in Guangzhou City. The cadmium in the used soil slightly exceeds the secondary standard of *Soil Environmental Quality Standards* (GB15618 – 1995), but it has little effect on the studies of migration of migration in soil irrigated with reclaimed water. Findings confirm that the reclaimed water is basically safe to be irrigation water, but there is a need to refine the reclaimed water use practices to ensure the safety of reclaimed water in the use process. Before the use of reclaimed water, it is necessary to test the reclaimed water quality to ensure that the water reaches the standard and further study incidental and uncertain risks.

References

[1] FENG SY. Introduction of the sustainable utilization of water resource and management[M]. Beijing: Science Press, 2003. (in Chinese).
[2] ZOU JW, LIU SW, QIN YM, *et al.* Sewage irrigation increasedmethane and nitrous oxide emissions from rice paddies in southeast China[J]. Agriculture, Ecosystems and Environment, 2009(129): 516 – 522.
[3] ZHANG YL, DAI JL, WANG RQ, *et al.* Effects of long-term sewageirrigation on agricultural soil microbial structural and functional characterizations in Shandong, China[J]. European journal of soil biology, 2008(44): 84 – 91.
[4] WANG GL, LAN WL. Contamination of soil from sewage irrigation and its remediation[J]. Journal of Agro – Environment Science (J. Agro – Environ. Sci.), 2003, 22(2): 163 – 166.
[5] Anikwe MAN, Nwobodo K CA. Long term effect of municipal waste disposal on soil properties and productivity of sites used for urban agriculture in Abakaliki, Nigeria[J]. Bioresource Technology, 2002, 83(3): 241 – 250.
[6] LI GX, YAN CZ, LI QZ. Improvement and development trend of wastewater reuse technology[J]. Environmental Science and Technology, 2009, 32(1): 79 – 83. (in Chinese).
[7] HU XF, ZHU Q. On environmental quality and agriculture reuse of water from sewage treatment plant[J]. Agro – Environmental Protection, 2002, 21(6): 530 – 534. (in Chinese).
(To page 74)

detrimental to health, and will consider mixed application of chemical and organic fertilizers.

Table 4 Model regression results

Variables	Regression coefficient	t value
Constant	337.752***	3.49
Char1	-130.194**	2.28
Char2	-112.326***	-5.26
Oper1	0.001	-0.31
Oper 2	-101.425**	-2.21
Oper 3	64.053	0.88
Oper 4	152.515***	3.01
Oper 5	-14.523	-0.50
CTC	-9.622	-0.26
SFA1	17.878	0.32
SFA2	3.325	0.10
SFA3	-59.477	-1.19
Number of samples	340	
A-R2	0.12	
F value	4.13	

Note: ***, ** and * signify that variable is significant at 1%, 5% and 10% respectively.

3.3.4 Scientific fertilizer application ability. All three variables of scientific fertilizer application ability, SFA1, SFA2 and SFA3, fail to pass the significance test. This is possibly because farmers seldom participate in agricultural technological training and extension of scientific fertilizer application technologies, and professional level of agricultural technological personnel is to be improved.

4 Conclusions

Improper use of chemical fertilizers is an essential reason for diffused pollution of agriculture. Therefore, finding out influence factors of farmers in application of chemical fertilizers will play a significant role in controlling the diffused pollution of agriculture. Based on survey data of 340 farmers in Chongqing, we made empirical analysis on influence factors of farmers' application of chemical fertilizers, including basic characteristics of farmer householder, farmer family and production characteristics, agricultural product trading characteristics, and farmers' scientific fertilizer application ability. Results show that application of chemical fertilizers is negatively correlated with age and education level of farmer householder, while women labors are more likely to apply more chemical fertilizers. Besides, low soil fertility will lead to more application of chemical fertilizers. Family annual income, proportion of agricultural production population, commodity trading characteristics, and whether organic fertilizers used or not fail to pass the significance test. Finally, the influence of scientific fertilizer application ability on farmers' application of chemical fertilizers is not significant.

References

[1] WU XL. The study of farm household behavior and agricultural non-point source pollution [D]. Nanchang: Jiangxi Agricultural University, 2011. (in Chinese).

[2] SHI HT, ZHAO MJ, HUO XX. Farmer's fertilizer input structure and its influencing factors --An empirical analysis on survey data of growers in seven apple main producing provinces [J]. Journal of Huazhong Agricultural University (Social Sciences Edition), 2013(2): 1-7. (in Chinese).

[3] ZHANG WW. Control and management of agricultural non-point source pollution [D]. Hangzhou: Zhejiang University, 2006. (in Chinese).

[4] HE HR, ZHANG LX, LI Q. Rational fertilization and reduction of large-scale farmland pollution by rationalized fertilizer usage [J]. Journal of Agrotechnical Economics, 2006(6): 2-10. (in Chinese).

[5] ZENG WJ, HOU MM. Empirical research on the impact factors of farmers' reducing use of fertilizer --A case study of Eryuan County, Yunnan Province [J]. Journal of Anhui Agricultural Sciences, 2014, 42(5): 1489-1494. (in Chinese).

[6] GONG QW, ZHANG JB, LI J. Empirical analysis on the influencing factors for farmers decision-making on the fertilizer application quantity: Based on the investigation data in Hubei Province [J]. Problems of Agricultural Economy, 2008(10): 63-68. (in Chinese).

[7] Smith VH, Goodwin BK. Crop insurance, moral hazard and agricultural chemical use [J]. American Journal of Agricultural Economics, 1996, 78(2): 428-438.

[8] Dercon S, L Christiaensen. Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia [J]. Journal of Development Economics, 2011, 96(2): 159-173.

[9] Clare M. Managing nonpoint source pollution in western Washington: landowner learning methods and motivations [J]. Environmental Management, 2009(43): 1122—1130.

(From page 70)

[8] ZHOU LB, HAN LB, ZHOU J, *et al*. Using reclaimed water for golf course irrigation [J]. Water Saving Irrigation, 2005(4): 7-9. (in Chinese).

[9] O AI-Lahhaln, N M EI Assi, M Fayyad. Impact of treated wastewater irrigation on qua]ity attributes and contamination of tomato fruit. [J]. Agri. Water Management, 2003(61): 51-62.

[10] G A AI-Nakshabandi, MM Saqqar, MR Shatanawi, *et al*. Some environmental problems associated with use of treated wastewater for irrigation in Jordan [J]. Agri. Water Manage, 1997(34): 81-94.

[11] A. Pollice, A. LoPez, G. Laera, *et al*. Filtered munieipal wastewater as alternative water source inagrieulture: a field investigation in Southern Italy [J]. Seienee. 1998, 40: 160-167.

[12] Moller A, Muller HW, Abdullah A, *et al*. Urban soil pollution in Damascus, Syria: concentrations and patterns of heavy metals in the soils of the Damascus [J]. Ghouta Geoderma, 2005, 124(1-2): 63-71.

[13] LIU F, CHENG B, ZHANG ZM, *et al*. The research on health risks of heavy metal in farmland from the city epigenetic irrigated area [J]. Chinese Agricultural Science Bulletin, 2008, 24(4): 445-449. (in Chinese).

[14] XING LZ, KONG J. Technical and economical analysis of reusing municipal wastewater in agriculture: A case study in Israel [J]. Environmental Science and Technology, 2003, 26(5): 23-24. (in Chinese).

[15] LI GX, YAN CZ, LI QZ. Improvement and development trend of wastewater reuse technology [J]. Environmental Science and Technology, 2009, 32(1): 79-83. (in Chinese).