The Response and Repairing of Three Kinds of Crops on Xi'an's Sewage Irrigation Area Soil

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Abstract. This paper focuses on the XiChaZhai village’s vegetable soil which is located in the northern suburbs of Xi’an and on its vegetables, thus analyzes the quality of sewage irrigation region soil and its influence on vegetables through the measurement of Cu, Zn, Pb, Cd’s content in samples. The results show that the research area soil contains apparently excessive heavy metals, and there exists significant differences of different elements’ integrated intensity in soil, the content declines in sequence from Cd, Zn, Pb to Cu. The four heavy metals’ contents in sewage irrigation region soil vary greatly from that in non-sewage irrigation region soil (P<0.01) . *Raphanus sativus* and *Ottelia acuminate* have favorable effects on Cd and Cu’s accumulation. Three crops having repairing effects on Xi’an sewage irrigation region soil are *Raphanus sativus*, *Ottelia acuminate* and *Brassica chinensis*, in that order. Different crop tissues differ in the accumulation of heavy metal, the order according as roots, stem and leaves, fruits. Therefore, based on differences of various crops on heavy metals’ absorption and translocation, appropriate crops should be scientifically planted in heavy metal contaminated area soil.

1. Introduction

It has been nearly one hundred years since the usage of industrial wastewater and domestic sewage on agricultural irrigation appeared around the world. In the increasingly mature process of wastewater irrigation technology development, especially in America, Japan and Israel are most representative. At present, in China’s farmland Irrigation, about 7.3% of which is at sewage irrigation level, and the proportion is increasing.

Long-term wastewater irrigation not only nourishes but also changes the property of soil, and turns the common soil into sewage irrigated soil. In the spirit of saving water, people irrigate farmland with sewage, while at the same time some environmental issues begin to show especially out. Research of heavy metals in sewage irrigation area carried out by Sun Libo et al found that, when heavy metals Cr, As, Hg etc. accumulated in the soil, combined with long-term wastewater irrigation, these contaminants will damage the biotic environment through underground water and food chain, and then threaten human health. For example, wastewater irrigation turns wheat color into black and rots the vegetables which become harder to store.

In recent years, research has found that repairing efficiency can be improved through enhanced measure. While as a kind of assistance measure, enhanced measure does not bring high repairing efficiency, on the contrary, it increases the pollution risk. Several scholars including Wang Fenghua et al pointed out that, Cr’s toxicity and bio-availability in soil can be effectively reduced by means of microorganism’s reduction and bio-sorption etc., which points out a new way for repairing Cr-
contaminated soil. Dai Yunchao et al. found that, ameliorant addition can furthest reduce Cd content in pakchoi cabbage and in soil. Although people have found more than 400 kinds of hyper-accumulator, the majority of them focus on repairing Ni-pollution in the soil. In addition, ramie can well repair heavy metal contaminated soil. On the repairing of Zn and Cd, Baker and Brown et al found that Thlaspi caerulescens has a higher efficiency. In phytoremediation technology studies, Yang Xiao-er and Wei Shuhe et al. respectively studied Zn-hyperaccumulator Sedum alfredii and Solanum nigrum which can well repair Cd-contaminated soil. Liu Jiali et al. found that heavy metals’ content of vegetables in sewage irrigation area is related to various factors, including vegetable kinds, air mass and water quality. It refers not only to kinds of vegetable planted, but also to air pollution status, wastewater quality and property of sewage irrigation area. This paper focuses on the XiChaZhai village’s farmland which is located in the northern suburbs of Xi’an, studies heavy metals content respectively in roots, stems, leaves and fruits of various crops planted here, and contrastively analyzes the accumulation and repairing effects of different crops and the potential ecological hazard evaluation. In order to understand the crops’ response regularity on heavy metals, and provide theoretical foundation for evaluating soil environmental quality of Xi’an’s sewage irrigation area and choosing crops for planting in sewage irrigation area.

2. The research area and method

2.1. General situation of the research are
Sewage irrigation has a long history and a relatively larger scale in Xi’an. Xi’an’s sewage irrigation area are mainly including Fenghui sewage irrigation area, which is located in Weiyang District ——a suburb northeast of the city of Xi’an, and is located at 108 degrees, 47 minutes and 8 seconds to 109 degrees, 2 minutes and 21 seconds east longitude, and 34 degrees, 14 minutes and 50 seconds to 34 degrees, 26 minutes and 22 seconds north latitude, covers an area of 251 km2. And its soil belongs to loess parent material.

2.2. Sample collection and treatment
We choose Xichazhai Village vegetable garden and clean soil apple garden as the research area, which is located in Shihua Road, Weiyang District, northern suburbs, Xi’an. For its long-term sewage irrigation history and a certain scale. In August 2015, the soil and crops of research area were gathered respectively, they are in the same area and they were irrigated by commensurate wastewater at the same time, without going through fertilizer and pesticide treatment, (Therein, the gathered background apple garden soil is from the same area which was irrigated by underground water, and without going through pesticide spraying.) the surface layer (0 - 20 cm) of soil was taken and mixed to constitute the mixed soil sample. In the same sampling plot, roots, stems, leaves and fruits of three kinds of crops ——including Ottelia acuminata, Raphanus sativus and Brassica chinensis (from 5-10cm in diameter) were respectively gathered to constitute the composite sample, which separates the aboveground part from underground part. Then let the samples dry and grind them, sifting through a 100mm nylon sieve and keeping them under seal in a polyethylene bag.

2.3. Experimental method
The soil heavy metals adopts the resolution method of HCl-HNO3-HF-HClO4 full-decomposition, and the roots, stems, leaves and fruits of crops adopt the resolution method with the ratio of nitric acid/perchloric acid being 9:1, then make them into solutions and measure four heavy metals——including Cu, Zn, Pb and Cd’s contents through atomic absorption spectrometry method.

2.4. Data Processing
Heavy metals’ contents in soil and their differences among sewage irrigation area, non-sewage irrigation area and background soil were analyzed through SPSS 11.0 software calculation. Takes soil background value of Shaanxi province as the background soil standard. (See Table 1)
Assessment of potential ecological risk method: Nemerow pollution index method. The Nemerow pollution index evaluation criteria of soil can be seen in Table 2.

### Table 1 Soil background value of Shanxi province (mg/kg)

| Project | Cu  | Zn  | Pb  | Cd  |
|---------|-----|-----|-----|-----|
| Background value of soil element | 32  | 74.2| 29.5| 0.15|

### Table 2 The Nemerow pollution index evaluation criteria of soil

| Grad | Nemerow | Pollution index (PN) | Class pollution |
|------|---------|----------------------|-----------------|
| I    | PN≤0.7  | Clean (Safe)         |                 |
| II   | 0.7<PN≤1.0 | Slight clean level   |                 |
| III  | 1.0<PN≤2.0 | Mild pollution      |                 |
| IV   | 2.0<PN≤3.0 | Medium pollution    |                 |
| V    | PN>3.0  | Heavy pollution      |                 |

3. Results and analysis

3.1. The heavy metals content of experimented

The heavy metals content of experimented soil is shown in Table 3. Taking the heavy metal background value in Shanxi as the evaluation standard, the result reveals that the average contents of Cu, Zn, Pb, Cd in soils planted with *Ottelia acuminata*, *Raphanus sativus* and *Brassica chinensis* are all higher than the background value with the maximum value of Cu, Zn, Pb, Cd being respectively 1.25, 1.11, 1.15 and 3.82 times of the background value; In the soil of the apple orchard, only the content of Cu slightly exceeds the standard and the contents of other 3 heavy metals are all within the background value.

### Table 3 The heavy metals content of experimental soil (mg/kg)

| Index | Cu    | Zn    | Pb    | Cd    |
|-------|-------|-------|-------|-------|
| Soil A| 36.160±3.110 | 78.364±5.001 | 22.621±4.081 | 0.452±0.089 |
| Soil B| 26.721±7.333 | 77.382±8.191 | 24.624±4.060 | 0.492±0.081 |
| Soil C| 22.324±3.202 | 75.437±6.533 | 20.235±1.623 | 0.457±0.083 |
| Soil D| 34.240±2.500 | 59.334±9.912 | 28.723±6.942 | 0.145±0.019 |
The soil A represents _Ottelia acuminata_ soil, soil B for _Raphanus sativus_ soil, soil C for _Brassica chinensis_ in soil, soil D for in apple orchard soil, soil E for background soil, the data is presented as mean plus or minus standard deviation, The same below.

From the table above, it can be learned that the content of Cd in the experimented soil severely exceeds the standard, and that of Cu, Zn, Pb also exceeds slightly.

3.2 Studies on the difference of the heavy metal content in experimented Soils

By taking F test, this paper studies on the difference of heavy metal content in the area of the sewage irrigation and the non-sewage irrigation area and the background soil. The result shows that the contents of 3 heavy metals (Zn, Pb, Cd) in the sewage irrigation area planted with _Ottelia acuminata_ differ a lot with that in the non-sewage irrigation area and the soil background value (P<0.05). The contents of 4 heavy metals in the sewage irrigation area planted with _Raphanus sativus_ are all obviously higher than that in the non-sewage irrigation area and the background value; the contents of Zn and Cd in soils planted with _Brassica chinensis_ are significantly higher than that in the non-sewage irrigation area, but the contents of other 2 heavy metals have no remarkable difference between these two areas.

| Index | Heavy metal | Soil D Cu | Soil D Zn | Soil D Pb | Soil D Cd | Soil E Cu | Soil E Zn | Soil E Pb | Soil E Cd |
|-------|-------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Soil A | Pb | - | 0.050* | - | - | 0.027* | - | 0.000* |
| Cd | - | - | 0.000** | - | - | 0.049* | - | 0.000** |
| Cu | 0.008* | - | - | - | - | - | - | - |
| Soil B | Zn | - | 0.000** | - | - | 0.000** | - | 0.000** |
| Pb | - | - | 0.002 | - | - | 0.004 | - | - |
| Cd | - | - | 0.000** | - | - | 0.000 | - | - |
| Cu | 0.057* | - | - | 0.086 | - | - | - | - |
| Soil C | Zn | - | 0.001** | - | - | 0.000** | - | 0.000** |
| Pb | - | - | 0.232 | - | - | 0.000 | - | - |
| Cd | - | - | 0.000** | - | - | 0.000 | - | - |

*P<0.05; **P<0.01.

From above data, it can be concluded that _Raphanus sativus_ can well accumulate the 4 heavy metals and _Ottelia acuminata_ can accumulate 3 of these heavy metals (Z, Pb, Cd).

3.3 The effect of different parts of plants on the accumulation of heavy metals

From Figure a, we can see that the roots and stems of these three plants absorb nearly the same content of Cu, the maximum reaching 5.234 mg/kg by the roots of _Ottelia acuminata_; the leaves of _Brassica chinensis_ comparatively absorb less Cu than that of the other two plants; the fruits of _Ottelia acuminata_ and _Brassica chinensis_ absorb almost the same amount of Cu; the fruits of _Raphanus sativus_ absorb relatively less Cu than that of the other 2 plants, reaching the minimum of 0.926 mg/kg; therefore, the accumulation of Cu in soils planted with different plants can be ranked as as _Ottelia acuminata, Raphanus sativus, Brassica chinensis_ (from high to low); the distribution in tissues of different plants can be ranked from high to low as root, stem, leaf and fruit.
From Figure. b, we can know that the accumulation of Zn in soils planted with different plants is *Ottelia acuminate*, *Raphanus sativus*, *Brassica chinensis* (from high to low); the accumulation amount of Zn by the roots of the three plants is *Ottelia acuminate*, *Brassica chinensis*, *Raphanus sativus* (from high to low), and the maximum reaches 30.568 mg/kg by the roots of *Ottelia acuminate*; the stems and fruits of the three plants absorb nearly the same amount of Zn; the leaves of the three plants absorb relatively less Zn than the stems and roots do; therefore, the accumulation of Zn in different parts of different plants can be ranked as root, fruit, stem, leaf (from high to low); the repair effect on Zn is *Raphanus sativus*, *Ottelia acuminate*, *Brassica chinensis* (from high to low).

From Figure. c and Figure. d, we can see that the accumulation of Pb and Cd by the roots, stems, leaves and fruits of these three plants is relatively low. The amount of Cd absorbed by these three plants is slightly greater than that of Pb.

![Figure 1](image)

**Figure 1** Distribution of heavy metals in different tissues of plants

3.4 The potential ecological hazard
From table 5, it can be learned that the Nemerow Pollution Index of Cd in soils planted with *Ottelia acuminate* is higher than 3, which is heavy pollution, and the indexes of Cu, Zn and Pb are between 0.98 and 1.24, being at the level of clean but already at the edge of the warning line. In soils planted with *Raphanus sativus*, the pollution indexes of Cu and Zn are both higher than 1, reaching the level of mild pollution; the pollution index of Pb is between 0.82 and 1, which is at the level of clean but is still at the edge of the warning line; the index of Cd is, however, higher than 4, reaching the level of heavy pollution. In soils planted with *Brassica chinensis*, the index of Cd is higher than 3, which is heavy pollution; the other 3 are at the level of mild pollution. Besides, the heavy metal pollution indexes in the apple orchard are all lower than 1, which means they are stable and will not threaten the environment.

In this soil sampling, the soils of *Ottelia acuminate*, *Raphanus sativus* and *Brassica chinensis* are collected from the sewage irrigation area and the soils of apple orchard from tap water irrigation area with a cleaner environment. According to Nemerow comprehensive
pollution index, the soils of *Ottelia acuminate*, *Raphanus sativus* and *Brassica chinensis* are all suffered from heavy pollution; the heavy metal pollutants are mainly resulted from the irrigation using industrial and sanitary wastewater, which intensifies non-point sources pollution in soils. The soils in the apple orchard, however, are safe. In this soil sampling, the soils of *Ottelia acuminate*, *Raphanus sativus* and *Brassica chinensis* are collected from the sewage irrigation area and the soils of apple orchard from tap water irrigation area with a cleaner environment. According to Nemerow comprehensive pollution index, the soils of *Ottelia acuminate*, *Raphanus sativus* and *Brassica chinensis* are all suffered from heavy pollution; the heavy metal pollutants are mainly resulted from the irrigation using industrial and sanitary wastewater, which intensifies non-point sources pollution in soils. The soils in the apple orchard, however, are safe.

**Table 5** Pollution index of heavy metals in the study area

| Index | Heavy metals | Pollution index | Pollution situation |
|-------|--------------|----------------|--------------------|
| Soil A | Cu           | 1.172±0.0230   | Mild pollution     |
|       | Zn           | 1.061±0.098    | Mild pollution     |
|       | Pb           | 1.005±0.045    | level of clean     |
|       | Cd           | 3.423±0.076    | heavy pollution    |
|       | Cu           | 1.070±0.045    | Mild pollution     |
| Soil B | Zn           | 1.278±0.020    | Mild pollution     |
|       | Pb           | 0.912±0.0431   | level of clean     |
|       | Cd           | 4.230±0.0234   | heavy pollution    |
|       | Cu           | 1.211±0.0789   | Mild pollution     |
| Soil C | Zn           | 1.472±0.067    | Mild pollution     |
|       | Pb           | 1.162±0.056    | Mild pollution     |
|       | Cd           | 3.53±0.043     | heavy pollution    |
|       | Cu           | 0.890±0.076    | level of clean     |
| Soil D | Zn           | 0.685±0.024    | Clean (Safe)       |
|       | Pb           | 0.32±0.01      | Clean (Safe)       |
|       | Cd           | 0.19±0.02      | Clean (Safe)       |
4. Conclusion and discussion

(1) The content of heavy metals in soils of the experimented area remarkably exceeds the standard. The content of Cd exceeds severely and that of Zn and Cu also exceeds slightly. The accumulation of different elements in soils differs a lot and can be ranked as Cd, Zn, Pb, Cu (from high to low).

(2) The content of the four heavy metals in the sewage irrigation area is significantly different from that in the non-sewage irrigation area. Raphanus sativus can well accumulate Cd and Ottelia acuminata can enrich and accumulate Cu.

(3) The soils of Ottelia acuminata, Raphanus sativus and Brassica chinensis are all heavily polluted areas, but the soil of apple orchard is currently within a safe range.

(4) The accumulation amount of heavy metals in different parts of plants is root, stem, leaf, and fruit (from high to low). The repair effect on the soil of the studied area is Raphanus sativus, Ottelia acuminata, Brassica chinensis (from high to low), therefore, more Raphanus sativus and Ottelia acuminata should be planted in Xi’an’s sewage irrigation areas since they are able to repair the heavy metal-contaminated soil and their fruits, with a relatively lower accumulation of heavy metals, are safe to eat.

(5) The heavy metals in Xi’an’s sewage irrigation area have obviously accumulated in vegetables but have not yet influence the appearance of vegetables. It is similar to the study result of this paper. The impact of the accumulation of heavy metal on vegetables and its physicochemical property still remain to be further studied.

References

[1] Liu Runtang, Xu Jianzhong. Sewage water irrigation problems and solutions in China[J]. China Water Resources, 2002, 10(1): 123-125.

[2] Pang Jiangli, Huang Chunchang, Sun Gennian. Heavy metal elements content of sewage irrigated soil in Xi’an and its influence to quality of vegetable[J]. Journal of Shaanxi Normal University, 2000, 22(3): 55-57.

[3] Sun Libo, Guo Guanlin, Zhou Qixing. Assessment of heavy metals and POPs contamination in a sewage irrigation area[A]. Chinese Journal of Ecology, 2006, 25(1): 29-33.

[4] POCIECHA M, LESTAN D. Novel EDTA and process water recycling method after soil washing of multi-metal contaminated soil [J]. Journal of Hazardous Materials, 2012, 20(2): 273-279.

[5] Wang Fenghua, Luo Xiaosan, Lin Aijun. Remediation of Chromium-Contaminated Soil[A]. Asian Journal of Ecotoxicology, 2010, 5(2): 153-161.

[6] Dai Yunchao, Lv Jialong, Diao Zhan. Effects on Soil Amendments on Cd Bioavailability to and Uptake by Brassica chinensis in Different Dd-contaminated Soil[A]. Journal of Agro-Environment Science, 2015, 34(1): 80-86.

[7] Liu Jianv, Zhou Qixing, Sun Ting. Feasibility of applying ornamental plants in contaminated soil remediation[A]. Chinese Journal of Applied Ecology, 2007, 18(7): 1617-1613.

[8] Wang Kairong, Gong Huijun. Absorption and the effect of cleaning up of ramie on soil cadmium[J]. Acta Scientiae Circumstantiae, 1998, 18(5): 510-516.

[9] She Wei, Jie Yucheng, Xing Hucheng. Uptake and Accumulation of Heavy Metal by (Boehmeria nivea) Growing on Antimony Mining Area in Lengshuijian City of Hunan Province[J]. Journal of Agro-Environment Science, 2010, 29(1): 91-96.
[10] Baker AJM, McGrath SP, Sidoli CMD, et al. The possibility of in situ heavymetal decontamination of polluted soils using crops of metal-accumulating plants [J]. Resources Conservation and Recycling, 1994, 11(1): 41-49.

[11] Brown SL, Chaney RL, Angle JS, et al. Zinc and cadmium uptake by hyper accumulator Thlaspi caerulescens and metal tolerant Silene vulgaris grown on sludge-amended soils [J]. Environmental Science and Technology, 1994, 29(6): 1581-1585.

[12] Yang Xiaoe, Long Xinxian, Ni Wuzhong. Sedum alfredii H - A new zinc hyperaccumulator [J]. Chinese Science Bulletin, 2002, 47(13): 1003-1006.

[13] Wei Shuhe, Zhou Qixing, Wang Xin. A newly discovered cadmium hyperaccumulator - Solanum nigrum L [J]. Chinese Science Bulletin, 2005, 50(1): 33-38.

[14] Lv Jiali, Liu Xiaojuan, Wang Zhentao. Study on Available Contents of Cd and Pb in Sewage-irrigated Soils in Taiyuan [A]. Journal of Shanxi Agricultural Sciences, 2015, 43(12): 1632-1637.

[15] Wang Mei, Jiang Lihua, Liu Zhaohui. Impacts of petroleum pollutants on microbial population and enzyme activity in three different types of soils in Shandong Province [A]. Acta Pedologica Sinica, 2010, 47(2): 200-208.

[16] Li Peijun, Gong Fanqiang, Zhang Hairong. Bioremediation of petroleum-contaminated soil and its relationship with soil enzyme activities [A]. Chinese Journal of Ecology, 2005, 24(10): 100-104.

[17] Pang Jiangli, Huang Chunchang, Sun Gennian. Heavy metal content of sewage irrigated soil in Xi’an and its influence to tomato [J]. Soil and Environmental Science, 2001, (02): 94-97.