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Features of Metallic Ion Distribution in Non-Traditional Water Agricultural Applications in Sandy Loam in an Arid Area

Liang Pei [1,2,3,4]

[1] National Engineering Technology Research Center for Desert-Oasis Ecological Construction, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China; peiliang@ms.xjb.ac.cn
[2] Xinjiang Key Laboratory of Environmental Pollution and Bioremediation, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[3] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[4] University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: Sandy loam is the main soil in the arid area of North China, which leads to serious water shortage. Therefore, the utilization of non-traditional water is necessary. However, there are many metal mining areas in the northern arid area. The mining process of these metal mines causes the pollution of surrounding water sources. It is important to study the distribution of pollutants in the process of unconventional water utilization around metal mines. In view of the above problems, a field test area was established near a mining area in a northern province to carry out research on non-traditional agricultural water applications. The influence of non-traditional agricultural water on pollutant distribution in balsam pear and sandy loam irrigation areas around a loam metal mine was analyzed. By discussing the influence of non-traditional water output after secondary treatment on the content and distribution characteristics of heavy metals in balsam pear in the sandy loam irrigation area around the metal mine, the distribution rules of heavy metals in the soil crop system under different non-traditional hydroponics conditions in the sandy loam irrigation area around the metal mine were analyzed. The results show that under different non-traditional agricultural water consumption conditions, there is no significant difference in terms of the content of heavy metals in the sandy loam irrigation area around the metal mine. The non-traditional water used for short-term agricultural application does not cause pollution of the loam environment and crops, nor does it cause heavy metal accumulation in the sandy loam irrigation area around the metal mine. The input and output have a minimal impact on the balance of heavy metals in the sandy loam irrigation area around the metal mine. The presented research results provide a scientific basis for agricultural utilization of non-traditional water around mining areas in arid areas.

Keywords: non-traditional water; agricultural application; balsam pear; heavy metals; sandy loam; arid area

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1. Introduction

There is a shortage of water resources in the arid areas of northern China. The disparity between supply and demand of water resources can be effectively mitigated by coordinating the allocation of water resources between water sources and users and realizing the scientific allocation of water resources in arid areas. In view of these problems, the development and application of sewage and non-traditional water resources has become an inevitable development trend. Similarly, water sources are very important strategic and economic resources. Research on sewage recycling and non-traditional water resource application technology is an important basis for the scientific allocation of water resources. In 2021, China's agricultural water consumption accounted for more than 62% of total annual water consumption. From the perspective of resources, the uneven spatial and temporal distribution of water resources in China, the poor matching of cultivated land resources and imperfect engineering facilities highlighted the disparity between supply and demand of water resources in many regions. In the case of water shortages and the low application rate of agricultural water, it is urgent to find alternative water sources and propose feasible solutions. The development of non-traditional water resources and the comprehensive application of agriculture have become inevitable choices. Furthermore, the collaborative allocation of non-traditional water and conventional water resources represents an attempt to seek to coordinate the entire resource system [1,2].

The effects of non-traditional water (secondary treatment) on the physical properties of loam changes with characteristics of the irrigated loam. The effects of non-traditional water on the chemical properties of loam are mainly reflected in the changes in the contents of N, P and saline elements [3,4]. The contents of other elements does not differ significantly from those found in tap water. Non-traditional irrigations, which contains a large quantity of nutrient elements, helps to improve loam fertility. Because non-traditional water resources contain traces of saline elements, long-term irrational irrigation affects loam permeability, in particular via an excessive accumulation of saline elements in plant roots, which alters the loam composition, resulting in loam compaction. Some ions of the saline elements in loam are toxic and lead to changes in the loam physical environment. An increase in sodium ions reduces loam porosity, resulting in a decrease in the retention capacity of nutrient elements in loam. The negative and positive effects of non-traditional water resources on fertility and pollution determine the effects of sewage irrigation on the physical and chemical properties of loam. In particular, the effects of suage irrigation on the degree of loam fertility has become a hot research topic with respect to the process of non-traditional water agricultural applications [5]. However, the complexity of migration and transformation of non-traditional water resources in loam systems makes it difficult to investigate the effects of non-traditional water on loam fertility [6,7].

Water, loam and plants comprise a natural system of interconnected elements that interacted with each other. Non-traditional water contains nutrient substances, such as nitrogen, potassium, phosphor, etc. [8,9] that can be used as fertilizers for crops, promote crop growth, reduce the use of synthetic fertilizers and improve the cultivability of loam [10]. However, the system of water, loam and plants is an interrelated and interactional natural system that is also a complicated heterogeneous system. For economic and technical reasons, some pollutants in non-traditional water are not completely removed [10]. N and P, as well as high quantities of completely saline elements, different kinds of toxic traces and substances (heavy metals in sandy loam irrigation areas around metal mines, organic pollutants, etc.) and pathogens may represent new sources of pollutions. These harmful substances may exert negative effects on loam and crops. Therefore, heavy metals in sandy loam irrigation areas around metal mines could enter the loam via water through non-traditional water agricultural applications and be absorbed by crops in the process of crop growth, completing the transfer of water to loam and, eventually, to vegetables. Heavy metals in sandy loam irrigation areas around the metal mines that have entered into loam and crops do not harm the environment and crops for a limited period of time [11]. However, when they accumulate beyond the volume that can be supported by loam and crops, they can harm crops and human beings and cause serious ecological problems. This possibilty explains the fear of some people with respect to eating local vegetables in cities in arid areas, as they are concerned about the influence of heavy metals in sandy loam irrigation areas around metal mines. Therefore, it is important to understand the migration and transformation law of heavy metals in loam and crops around sandy loam ore areas. Both domestic and foreign scholars have conducted research on non-traditional water agricultural applications [12–14]. However, most researches has focused on physiological and biochemical effects on crops, with only few studies emphasizing the quality of crop fruits and metal ion contents in sandy loam [15,16].

Sandy loam is the main soil in the arid area of North China, which leads to serious water shortage. Therefore, the utilization of non-traditional water is very necessary. However, there are many metal mining areas in the northern arid area. The mining process of these metal mines causes pollution of the surrounding water sources. It is important to study the distribution of pollutants in the process of unconventional water utilization around metal mines. However, the research on agricultural utilization of non-traditional water in arid areas is just at the beginning, and no research has been conducted on agricultural utilization of non-traditional water around mining areas. The distribution of heavy metals in sandy loam is also less studied. Therefore, our results will help to fill the gap in this research field. In view of the above problems, a field test area was established near a mining area in a northern province to carry out research on agricultural application of non-traditional water. The influence of non-traditional agricultural water on pollutant distribution in balsam pear and sandy loam irrigation areas around loam metal mines was analyzed. By discussing the influence of non-traditional water output after secondary treatment on the content and distribution characteristics of heavy metals in balsam pear in the sandy loam irrigation area around a metal mine, we analyzed the distribution rules of heavy metals in the soil crop system under different non-traditional hydroponics conditions.

In this paper, we will provide a basis for evaluating the effects of non-traditional water agricultural application on sandy loam environments and establish an agricultural security quality standard for ore and sandy loam areas in arid regions.

2. Materials and Methods

2.1. Experimental Crops

This study was based on the "Action plan for the development of northern sandy loam area of Chinese Academy of Sciences" project by the Chinese Academy of Sciences. The study area is located near a metal mining area in an arid region of North China and is part of a semi-arid and semi-humid climate area. It has four distinct seasons, long winters and short springs. In spring, the temperature rises rapidly, with more rainfall in autumn and less rainfall and snowfall in winter. The temperature is moderate. The annual solar radiation was 103.8 kcal/cm^2, the physiological radiation was 50.4 kcal/cm^2 and the sunshine time was 1477.6 h. The annual average temperature was 13.3 °C, the extreme low temperature was −19.5 °C and the extreme high temperature was 40 °C. The annual accumulated temperature (≥10 °C) was 4479.5 °C. The frost-free period was 179 days per year. The average annual rainfall was 615 mm. The interannual precipitation changed considerably. The precipitation in flood season (from 1 June to 30 August) accounted for about 51% to 59% of the annual precipitation. The rainfall intensity was medium, the rainfall duration was short and the infiltration capacity was limited. Rainwater also easily rubs and erodes the sandy loam surface. The experimental sandy loam investigated in this study is a unique sandy loam in an arid area of northern China, with a unit weight of 1.05 to 1.21 g/cm^3.

In the test station, we used secondarily treated non-traditional water from a village in an arid ore area. The water quality was stable, and water was collected when it was ready for use.

2.2. Monitoring Items and Methods

The sandy loam and balsam pear sampling times were June 2020 and September 2021, respectively, corresponding to the balsam pear harvest. The sandy loam samples were taken from 0~30, 30~60, and 60~90 cm sandy loam layers in each small cell. Test indices included TN, $NO^-{}_3$–N, NH^{4+}–N, organic nitrogen, available potassium, available phosphorus, Ca^{2+}, Mg^{2+}, Na^+, $CO^{2-}{}_3$, HCO^{3-}, $SO^{2-}{}_4$, pH, EC, CEC, As, Cd, Cu, Cr, Zn and Pb. The sampling time for the crops was September 2020, corresponding to the balsam pear harvest, taken in the form of fruits. The test indices were as follows: seed and fruit dry weight, as well as TN, $NO^-{}_3$-N, TP, $NH^+{}_4$–N, As, Cr, Zn, Cd, Cu and Pb contents in fruit.

2.3. Instruments and Reagents

Instruments: an inductively coupled plasma emission spectrograph (ICP-AES), bath water kettle, PHs-11A model digital display ion meter, electric vibrating machine, analytical balance, electric dry oven, etc.

Reagents: analytically pure perchloric acid, nitric acid (guarantee reagent), analytically pure hydrofluoric acid, hydrogen peroxide, phenanthroline indicator, 1.55 mol·L^{-1} potassium dichromate standard solution, deionized water, 0.41mol·L^{-1} ferrous sulphate solution, paraffin vegetable oil and concentrated sulfuric acid.

2.4. Sample Determination Method

To determine the contents of contaminants of sandy loam and balsam pear in sandy loam irrigation areas around metal mines, we picked balsam pear fruit twice a week during the full productive period, and each measurement was repeated at each production process, taking the average as the final output. We picked 10 ripe balsam pear fruits from each small cell in the sandy loam irrigation area around the metal mines and determined the heavy metals contents in the fruit. We used an MDS28 microwave digestion instrument and an ELAN5200 inductively coupled plasma mass spectrometer to determine the heavy metal contents in balsam pears [16–18].

Determination method: cut balsam pear into pieces, place exactly 0.1200 g into the PTFE digestion pot, add 1 mL each of concentrated H_2O_2 and HNO_3, use an expander to expand of the packed piston seal and cover with a lid. Dry water drops on the outer wall of the inner pot. The inner pot was equipped with pads placed outside the pot, which had a cushion block inside. Place the pot on the pot shelf, cover with the lid and secure with two screws; then, select the microwave digestion process. Remove the pot after sufficiently cooling. Quantitatively transfer the solution to a 10 mL tube and add 20 mg/mL standard internal mixture to a 10 mL volume. Directly determine the mass concentrations of Pb, As, Cd and other elements under ICP2MS operating parameters.

Graphite furnace atomic absorption spectrometry was used to determined Pb and Cd contents in sandy loam, and flame atom absorption spectrometry was used to determine the contents of by heavy metals, such as Zn and Cu, in the sandy loam irrigation area around the metal mines.

2.5. Experimental Data Analysis

We analyzed data by using SPSS12 statistical analysis software.

3. Results

3.1. Heavy Metals Contents in Non-Traditional Water in the Sandy Loam Irrigation Area around the Metal Mines

As shown in Table 1, six heavy metals were found in non-traditional water of the sandy loam irrigation area around the metal mines. Pb contents were similar to those in normal water, whereas the contents of other heavy metals in non-traditional water of the sandy loam irrigation area around the metal mines were higher than those in normal test water in the experimental area. For example, As, Cr and Cd contents were about twice those in normal water, and Cu and Zn contents six and four times those in normal water, respectively. However, the heavy metals contents in non-traditional water of the sandy loam irrigation area around the metal mines were much lower than the upper limit of the standard for agricultural water applications (GB5084-08).

3.2. Effects of Non-Traditional Water of Different Periods on the Heavy Metals Content in Sandy Loam

The Table 2 shows the distribution of six heavy metals in sandy loam according to the non-traditional water agricultural application period. The table lists background values (test values in September 2019), as well as the sandy loam heavy metals contents following 12 months of non-traditional water agricultural application (test values in September

2020 with non-traditional water agricultural application), 18 months of non-traditional water agricultural application (test values in September 2019 with non-traditional water agricultural application) and 24 months of non-traditional water agricultural application (test values in September 2019 with non-traditional water agricultural application), all of which decreased increased sandy loam depth. These results prove that during the investigated period (≤24 months), non-traditional water agricultural application had no obvious effect on heavy metals distribution in sandy loam layers [19,20]. Compared with the sandy loam environmental quality standard (GB15618-2008), even with high heavy metals content in the surface layer (0~30 cm) of the sandy loam, the heavy metals contents in the sandy loam irrigation area around the metal mines were much lower than the upper limit prescribed by the standard, indicating that short-term non-traditional water irrigation (≤24 months) does not cause heavy metal accumulation pollution in sandy loam irrigation areas around metal mines. This result is consistent with the results reported by Adrien et al. and María et al. [21–23].

Table 1. Heavy metals in non-traditional water of the sandy loam irrigation area around the metal mines.

Water Quality	As /mg·L^{-1}	Cr /mg·L^{-1}	Cd /μg·L^{-1}	Cu /μg·L^{-1}	Pb /mg·L^{-1}	Zn /mg·L^{-1}
Underground water	0.0031	0.0194	0.041	0.062	0.0119	0.0312
Non-traditional water	0.0062	0.0343	0.075	0.292	0.0121	0.1190
Agricultural application water quality standard	0.05	0.1	0.5	1	0.1	2

Table 2. Sandy loam heavy metal contents non-traditional water irrigation period vs. background values.

Index	Depth/cm	Background Values	Irrigation Periods			Loam Quality Standard GB15618-2008		
			12 Months	18 Months	24 Months	First Grade	Second Grade	Third Grade
As /mg·kg^{-1}	0~30	8.1 ± 1.82 a	9.3 ± 0.32 a	6.7 ± 0.89 a	9.3 ± 1.19 b			
	30~60	8.2 ± 2.29 ab	8.6 ± 1.11 a	6.4 ± 1.33 b	8.3 ± 0.77 a	≤15	≤25	≤40
	60~90	6.3 ± 3.43 d	8.2 ± 3.86 d	6.7 ± 2.80 ab	6.7 ± 2.02 cd			
Cd /μg·kg^{-1}	0~30	58 ± 2.32 a	64 ± 1.03 a	63 ± 5.38 c	54 ± 4.91 ef			
	30~60	50 ± 6.17 c	58 ± 1.12 a	49 ± 1.76 a	52 ± 2.02 d	≤200	≤1000	≤infinite
	60~90	41 ± 3.13 bc	46 ± 0.82 a	40 ± 1.99 b	48 ± 1.31 ab			
Cu /mg·kg^{-1}	0~30	23 ± 1.12 b	76 ± 1.23 a	64 ± 1.71 b	70 ± 1.15 a			
	30~60	22 ± 0.32 a	71 ± 2.89 b	66 ± 4.82 b	67 ± 5.02 bc	≤35	≤100	≤400
	60~90	20 ± 2.11 bc	67 ± 1.33 b	63 ± 3.44 e	70 ± 3.99 c			
Cr /mg·kg^{-1}	0~30	34 ± 1.21 b	10 ± 1.95 de	9 ± 1.03 b	9 ± 1.73 b			
	30~60	34 ± 2.02 b	10 ± 0.32 a	9 ± 0.02 a	9 ± 1.89 bc	≤90	≤250	≤300
	60~90	35 ± 1.82	9 ± 1.82 de	7 ± 1.82 f	8 ± 1.82 ± 1.62 de			
Zn /mg·kg^{-1}	0~30	28 ± 1.14 b	28 ± 0.09 a	33 ± 3.02 b	26 ± 2.81 cd			
	30~60	33 ± 0.72 a	27 ± 1.13 ab	34 ± 1.19 ab	24 ± 1.41 b	≤100	≤300	≤500
	60~90	36 ± 1.02 bc	26 ± 1.77 b	26 ± 2.86 bc	24 ± 0.12 a			

Note: Data are presented as average values ± standard deviation. At the p = 0.05 level, the same letters indicate no significant difference, whereas different letters indicate significant differences.

A comparison of heavy metals contents in 2019 and 2020 in non-traditional water agricultural application with background values using multiple comparison (LSD method) analysis revealed some differences in As, Cu, Cr and Zn contents in the 0–30 cm loam layer, but no significant differences were observed at other depths with respect to the contents of these or other metals.

The cause of the above differences was probably the difference in sampling locations in different years. Due to the spatial variation of sandy loam properties, the sandy loam structure, clay particle contents, infiltration capacity and organic matter concentrations varied across sampling locations, resulting in fluctuations and differences in heavy metals contents in sandy loam depending on the year. Overall, the six investigated heavy metals do not accumulate in all the sandy loam layers as a result of multiple years of non-traditional water resource irrigation application. In addition, other factors, such as differences in irrigation and rainfall infiltration space, atmospheric dust, heavy metals content, crop uptake, etc., also contributed to these differences.

3.3. Effects of Different Volumes of Non-Traditional Water Agricultural Application on the Content of Heavy Metals in the Sandy Loam Irrigation Area around the Metal Mines

Depending on the circumstances of the experimental area, during the period of 2019–2020, different water resources were used to irrigate different test plots depending on the requirements of the specific plot. The plots were alternatively irrigated by a combination of clear and non-traditional water or by non-traditional water [24,25]. The latter two kinds of water quality are referred to as half-non-traditional water and non-traditional water. The heavy metals contents in the sandy loam irrigation area around the metal mines are shown in Table 3.

Table 3. Sandy loam heavy metals contents with different volumes of non-traditional water agricultural application.

Index	Depth/cm	Local Value	Underground Water	Half-Non-Traditional Water	Non-Traditional Water
As /mg·kg^{-1}	0~30	8.9 ± 0.29 b	8.8 ± 0.32 a	9.3 ± 1.19 c	9.8 ± 1.79 d
	30~60	8.1 ± 0.04 a	8.0 ± 0.88 b	8.3 ± 0.12 a	11.2 ± 1.33 c
	60~90	6.5 ± 0.43 b	8.1 ± 0.55 ab	6.8 ± 0.76 ab	8.2 ± 0.23 a
Cd /μg·kg^{-1}	0~30	62 ± 2.26 b	50 ± 3.27 b	58 ± 4.19 b	53 ± 5.11 ac
	30~60	51 ± 3.14 b	47 ± 3.59 b	64 ± 3.22 b	51 ± 3.52 b
	60~90	46 ± 1.45 b	47 ± 1.48 a	48 ± 1.19 a	44 ± 0.17 a
Cu /mg·kg^{-1}	0~30	23 ± 1.02 b	16 ± 1.00 c	21 ± 1.11 b	22 ± 0.21 a
	30~60	22 ± 1.24 b	18 ± 0.28 a	20 ± 0.22 a	25 ± 0.33 a
	60~90	19 ± 0.51 a	16 ± 0.99 b	18 ± 1.93 ab	23 ± 0.55 ab
Cr /mg·kg^{-1}	0~30	36 ± 2.01 b	27 ± 0.12 a	28 ± 2.03 ab	75 ± 1.98 ad
	30~60	34 ± 1.76 a	26 ± 0.66 b	23 ± 1.21 ab	32 ± 1.22 a
	60~90	33 ± 1.56 a	25 ± 0.69 a	27 ± 0.82 a	30 ± 3.01 c
Pb /mg·kg^{-1}	0~30	63 ± 0.98 a	14 ± 0.87 a	18 ± 1.09 c	22 ± 0.27 a
	30~60	64 ± 1.99 b	17 ± 2.54 c	18 ± 0.28 a	21 ± 0.36 a
	60~90	61 ± 3.24 b	14 ± 0.79 a	15 ± 0.71 b	19 ± 0.15 b
Zn /mg·kg^{-1}	0~30	7.3 ± 2.53 c	49 ± 0.66 a	58 ± 5.19 d	60 ± 3.77 ab
	30~60	7.9 ± 5.07 ab	40 ± 3.31 b	52 ± 0.89 a	62 ± 3.91 b
	60~90	7.1 ± 6.12 c	48 ± 1.12 a	50 ± 2.11 c	54 ± 1.24 a

Note: Data are expressed as average values ± standard deviation. For the p = 0.05 level, the same letters indicate no significant difference, whereas different letters indicate significant differences.

As shown in Table 3, there was no significant difference in the contents of most heavy in the sandy loam irrigation area around the metal mines relative to the volume of non-traditional water irrigation. With respect to the impacts of heavy metals on the environment, non-traditional water resources can substitute underground water as an irrigation water source. There was no significant difference in the heavy metals contents relative to the volume of non-traditional water irrigation, except Zn and Cd in 30–60 cm deep sandy loam, which may have been caused by the spatial variability in the sandy loam sampling locations. This result indicates that non-traditional water irrigation application in sandy loam areas does not cause heavy metals to accumulate in the balsam pear growing season.

3.4. Distribution Characteristics of Heavy Metals in Balsam Pear under Non-Traditional Water Agricultural Application

We analyzed the distribution of Cr, Cd, Pb, As, Cu and Zn metals, which have a major effect on crop growth and human health in the food chain. Analysis result of heavy metals contents in balsam pear fruits are shown Table 4. Statistical analysis revealed that the distribution characteristics of heavy metals in balsam pear fruits varied depending on the irrigation water quality and conditions [26–28]. The Cr, Cd, Pb, As and Cu contents increased with increased volume of non-traditional water irrigation. However, variance analysis, revealed that Cr content reached a significant level of 88% (F = 5.97, sig = 0.081 < 0.1), whereas Cd, Pb, As, Cu and Zn contents did not reach such significant levels. Zn was present in relatively small proportions in balsam pear fruit, so could not be detected in the present study. Although several kinds of ions showed an increasing trend in balsam pear fruit, their contents were far below the Safety Qualification for Agricultural Product national standard (GB2763-2012) and the pollution-free vegetable quality standard [29,30]. The above analysis and comparison indicate that irrigation with non-traditional water resources has a better safety profile than irrigation with sewage resources. In addition, compared with the use of underground water for irrigation, the use of non-traditional water for irrigation did not cause a significant increase in heavy metals contents in balsam pear fruit. This further indicates that short-term non-traditional water irrigation application has little effect on heavy metals contents in the crops of sandy loam irrigation areas around metal mines.

Table 4. Balsam pear fruit heavy metals contents under irrigation conditions with varying water quality (mg/kg).

Water Quality	As	Cd	Cr	Cu	Pb	Zn
Underground water	0.0026	0.021	0.062	0.019	0.055	No detected
Half- non-traditional water	0.0040	0.044	0.068	0.022	0.079	No detected
Non-traditional water	0.0033	0.060	0.092	0.0099	0.083	No detected
National standard	0.5	0.05	0.5	0.5	0.2	No detected

3.5. Analysis of Heavy Metals Contents in Sandy Loam and Balsam Pear under Non-Traditional Water Agricultural Application

We analyzed the heavy metals contents in sandy loam and balsam pear during the balsam pear growing season in 2019–2020 resulting from non-traditional water irrigation application (Figures 1 and 2). Six kinds of heavy metals were identified in the sandy loam irrigation area around the metal mines; the heavy metal contents absorbed by the above-ground portion of balsam pear plants were higher than those contributed by non-traditional water irrigation application. However, under all non-traditional irrigation conditions, the amount of As and Cd removed was 7 and 12 times higher than that contributed by irrigation, respectively. With respect to Pb, the amount removed was 23 times greater than that contributed by irrigation, and for Cu, Cr and Zn, the amount removed was 4.0, 2.0 and 2.0 times greater than that contributed by irrigation, respectively. Our analysis revealed that the use of non-traditional irrigation helped to discharge heavy metals in the sandy loam irrigation area around the metal mines to the same extent as the use of underground water and combined irrigation applications [31–33], which may have affected the heavy metals contents in sandy loam. However, as shown in Table 3, heavy metals contents in the sandy loam irrigation area around the metal mines did not significantly change (increase or decrease) after the balsam pear growth season. Therefore, despite the effect of irrigation water quality on the contents of heavy metals in sandy the loam irrigation area around the metal mines, heavy metals contents are also affected by precipitation, evaporation, fertilization, atmospheric and other factors.

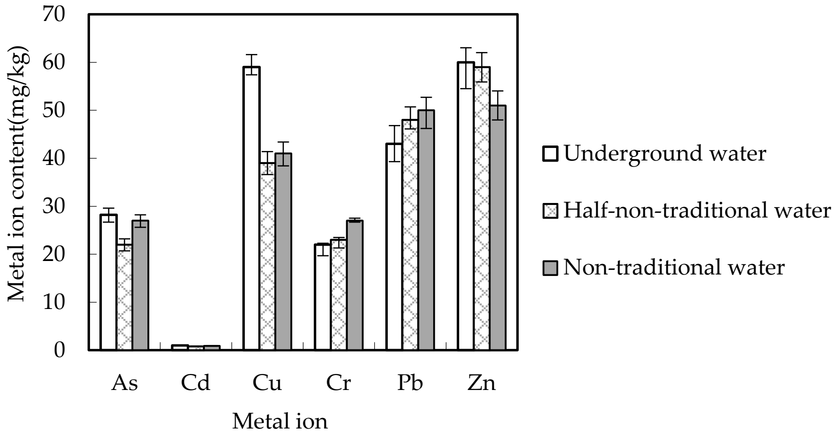

Figure 1. Metal ion absorption by the above-ground portion of balsam pear plants (mg/kg).

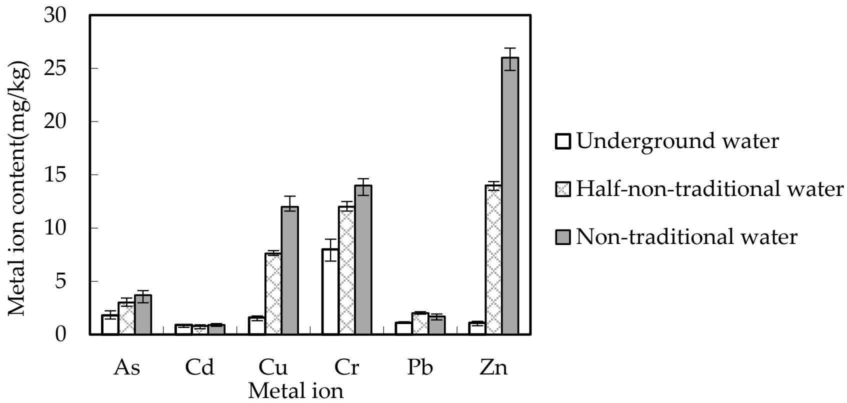

Figure 2. Metal ion removal by non-traditional irrigation (mg/kg).

The proportion of heavy metals removed and contributed to sandy loam at a depth of 0 to 90 cm is shown in Figures 3 and 4. A proportion of 0.88%~0.96% was removed, whereas Cr had the lowest removal proportion of 0.064%~0.092%. Zn accumulated was accumulated in the highest proportion, at 0.09%~0.43%, whereas Pb accounted for the lowest proportion of accumulation, at 0.0061%~0. 013%. These results show that both the accumulation and removal of heavy metals accounted for only small proportions of the total heavy metals contents in sandy loam at a depth of 0–90 cm. In conclusion, accumulation associated with non-traditional water irrigation and removal by above-ground crops have minimal effects on the total heavy metals contents in sandy loam.

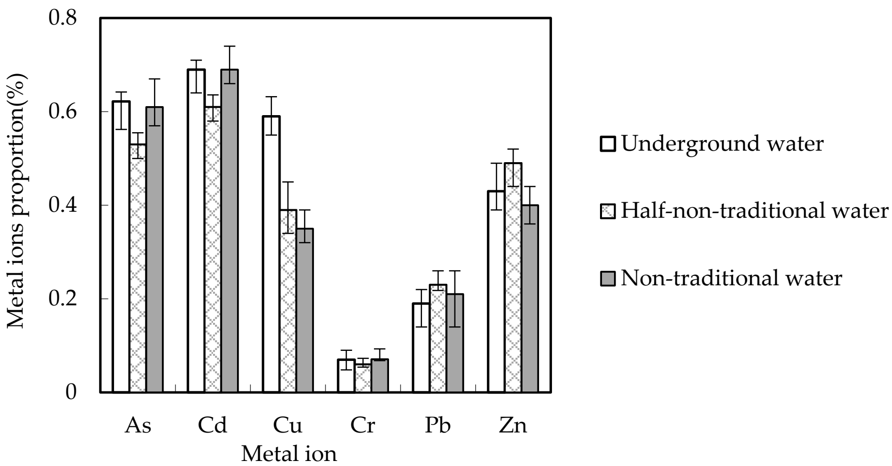

Figure 3. Metal ion removal proportions vs. total volume in sandy loam (%).

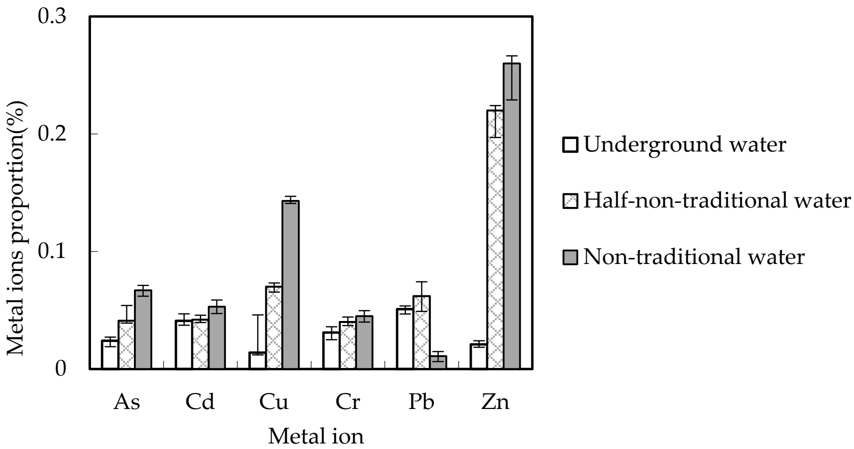

Figure 4. Metal ions accumulation proportions vs. total volume in sandy loam (%).

4. Conclusions

In view of the serious water shortage caused by the poor water-holding capacity of sandy loam in the arid area of northern China, as well as the water pollution around the mining area and the low utilization rate of non-traditional water, we established a field test base near the mining area in a northern province to investigate the use of non-traditional water for agricultural irrigation. We found that the geochemical behavior of heavy metals in sandy loam around metal mines is related to the physical and chemical properties of the sandy loam, the types of crops planted and the characteristics of the elements themselves. The contents, volume migration and accumulation rates of heavy metals in sandy loam and balsam pear were analyzed. The results show that the migration and accumulation rates of various heavy metals in sandy soil and balsam pair vary depending on conditions. The main conclusions are as follows:

The volume of non-traditional water had no significant effect on the heavy metal contents of sandy loam. With respect to the six heavy metals identified in the sandy loam irrigation area around the metal mines under investigation, the removal rate by crop harvest was higher than that contributed by irrigation with non-traditional water. Among all the heavy metals in sandy loam irrigation area around the metal mines, the removal rate was 7 and 12 times contribution rate of As and Cd, respectively. For Pb, the removal rate was about 23 times the accumulation rate, and for Cu, Cr and Zn, the removal rate was 4.0, 2.0 and 2.0 times greater than the accumulation rate, respectively. However, both accumulation and removal accounted for very small proportions of total heavy metals contents of the sandy loam at a depth of 0–90 cm. This demonstrates that non-traditional water agricultural application had little effect on the heavy metals pollution in the sandy loam irrigation area around the metal mines under investigation.

A field experiment involving the use of non-traditional water resources to irrigate balsam pear showed that heavy metals increased in the agricultural sandy loam environment, but there was no significant difference relative to baseline values. The heavy metals volumes in sandy loam and crops were far below the allowable food hygiene standard value and thee national sandy loam environmental quality standard. Therefore, the use of non-traditional water for agricultural irrigation does not cause accumulation of heavy metals in an agricultural sandy loam environment and crops.

Non-traditional water agricultural application is not the only decisive factor with respect to changes in heavy metals content in sandy loam and crops, which are also affected by climate change, fertilization, sandy loam self-purification capacity, sandy loam and crop types, and other factors. It is worth further studying the effects of non-traditional water agricultural application on crop nutrition, crop quality and morphologic change, the relationship between non-traditional water quality and crop yields and the safety of organic and hazardous substances relative to irrigation with non-traditional water.

This study provides a basis for future research on non-traditional water use in arid areas and mining areas. The results of this study provide a theoretical basis for agricultural utilization of non-traditional water around mining areas in arid regions. Future research should focus on the safety of the environment (soil, plant, water, air, human), similar research should be conducted to investigate various soil types. The bearing capacity of non-traditional water in various types of soil, as well as the rules, specifications and indicators of agricultural utilization, agricultural safety and quality standards, etc., should also be studied in the future. According to our research results, the selective removal and retention of non-traditional pollutants in water is another area of focus for future research. For example, how to remove harmful substances while retaining beneficial substances and how to control the absorption of beneficial and harmful substances by crops should be investigated in future research. Our research team will continue to conduct research in this field.

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