

Phytoextraction Ability of *Amaranthus mangostanus* L. from Contaminated Soils with Cs or Sr

Wang Dan^{1,2*}, Zhang Xiaoxue¹, Luo Xuegang² and Tang Yunlai^{1,2}

¹College of Life Science and Engineering, Southwest University of Science and Technology, China

²Defense Key Laboratory of the Nuclear Waste and Environmental Security, China

Abstract

The uptake, distribution, and accumulation of ¹³³Cs and ⁸⁸Sr with its antioxidant responses in *Amaranthus mangostanus* L plants was studied during cultivation in outdoor potted-soil. The results showed that the uptake capacity of *Amaranthus* for ¹³³Cs was higher than that for ⁸⁸Sr at the same molarity treatment where the concentration of ⁸⁸Sr or ¹³³Cs in the soil was from 0.1 mmol/kg to 5 mmol/kg. The maximum ¹³³Cs and ⁸⁸Sr uptake of total plant was 3535.2 mg/kg dw and 639.4 mg/kg, respectively. Amaranth had much stronger capacity for absorbing ¹³³Cs than for ⁸⁸Sr. The ¹³³Cs BCF of amaranth above-ground part and its total plant at the different concentration treatments in the soil was higher than for the ⁸⁸Sr BCF except at the 0.1 mmol/kg treatments. The TF was lower in the lower concentration (0.1 and 0.5 mmol/kg) than that in the higher concentration of ¹³³Cs and ⁸⁸Sr in the soil (1 and 5 mmol/kg). Amaranth could be used as a potential candidate plant for phytoremediation of ¹³⁷Cs and ⁹⁰Sr. The MDA content under ⁸⁸Sr stress was higher than that under ¹³³Cs stress, and the activities of CAT under ⁸⁸Sr stress were less than that under ¹³³Cs stress.

Keywords: Amaranth; Uptake; Accumulation; ¹³³Cs; ⁸⁸Sr; Phytoextraction

Introduction

The radionuclides coming from nuclear test or nuclear accident are the main potential nuclear pollutants for environment and are widely paid attention to the phytoremediation technology of radioactive pollution can achieve the goal of clearing radionuclides, remediating or controlling contaminated soils. It has many merits, such as low investment, low maintenance cost, convenient manipulation, no the second-time contamination, safety and the function of beautifying the environment [1-4]. The phytoextraction and remediation technology of contaminated soils with low-radioactive nuclides is the popular issues now, and it is considered to be cost-effective for cleaning up sites contaminated with low levels of long half-life radionuclides [5-7]. The selection of hyper accumulators for the different nuclides or metals, their uptake ability and accumulation capacity for the radionuclides is the most important factors which influence the remediation efficiency. Problems such as how to screen a series of plants with appropriate biological characteristics that can rapidly accumulate significant quantities of radionuclides, and how to find a way to enhance the bioavailability of radionuclides to the plants, should be addressed [8-11]. The contamination of soil with ⁹⁰Sr and ¹³⁷Cs has long-term radiological and health impacts due to their long half-lives and chemical similarities with two essential elements required for plant growth, Ca²⁺ and K⁺, respectively [12-14]. Some research reported that the ⁸⁸Sr and ¹³⁴Cs uptake ability of plant from the soil was the same with their ⁹⁰Sr and ¹³⁷Cs uptake ability as the stable isotopes of ¹³⁷Cs and ⁹⁰Sr. ¹³³Cs and ⁸⁸Sr can imitate the migration and distribution of ¹³⁷Cs and ⁹⁰Sr in the plant soil system very well [15,16]. *Amaranthus mangostanus* L. was chosen as the research material in this experiment to investigate its characteristics of uptake, transportation, and accumulation and its physiological mechanism in ¹³³Cs and ⁸⁸Sr polluted soils, and also to lay some theoretical foundations for phytoremediation of soil contamination with radionuclides.

Materials and Methods

Plant material and treatment

The experiment was carried out with outdoor potted plants in

the lab block of life science in Southwest University of Science and Technology (SWUST) in Mianyang, Sichuan (E=104°42', N=31°32', elevation: 462 m). The soil in the experiment was yellow earth, coming from the nursery in the garden center of SWUST. The pH of the soil in H₂O and KCl were measured with a pH meter. The soil organic matter was measured by using the Tyurin's method; each gram of grinded and sieved soil was mixed even with 5 ml deionized water, and the electrical conductivity of the soil was measured with a conductivity meter after it was static. The main physical and chemical characteristics of the soil were: pH in H₂O:7.06, pH in KCl: 6.18, Organic matter: 1.35%, Electrical conductivity: 1.25 ms/cm.

Each pot (diameter 25 cm, height 20 cm) was put into 4.5 kg of soil and some calcium superphosphate and clean water was sprayed before sowing. The plants of *Amaranthus mangostanus* L were transplanted into each treatment group when the plant had 5-6 leaves. There were 3 plants for each pot, 3 pots for each treatment, with three replications. Since the radionuclides were set on the soil surface by sedimentation and enters the inside with the time being, ¹³³CsCl or ⁸⁸Sr(NO₃)₂ solution was sprayed separately and evenly on the soil surface of each pot based on the concentrations in Table 1 in the next day after transplanting. The treatments of ¹³³Cs and ⁸⁸Sr were divided into two groups.

The plants were watered regularly during the experiment and maintained a field water capacity of 70%. The management level for each treatment field was the same when maturation the plants were harvested to be measured.

***Corresponding author:** Wang Dan, College of Life Science and Engineering, Southwest University of Science and Technology, China, Tel: +86-816-6089126; E-mail: wangdan@swust.edu.cn

Received December 29, 2014; **Accepted** February 24, 2015; **Published** February 27, 2015

Citation: Dan W, Xiaoxue Z, Xuegang L, Yunlai T (2015) Phytoextraction Ability of *Amaranthus mangostanus* L. from Contaminated Soils with Cs or Sr. J Bioremed Biodeg 6: 277. doi:10.4172/2155-6199.1000277

Copyright: © 2015 Dan W, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Treatment elements	Treatment				
	0	1	2	3	4
¹³³ Cs mmol/kg	0	0.1	0.5	1	5
¹³³ Cs mg/kg	0	13.29	66.45	132.91	664.50
⁸⁸ Sr mmol/kg	0	0.1	0.5	1	5
⁸⁸ Sr mg/kg	0	8.762	43.81	87.62	438.10

Note: 0 is the control. Each treatment consisted of three replications.

Table 1: Concentration of ¹³³Cs and ⁸⁸Sr in the soil.

Measuring the physiological and biochemical indexes

The leaves from the plants were taken away and each physiological index was measured after harvesting. The MDA content was measured with the TBA colorimetry [17]. The total chlorophyll content was measured at 652 nm with 95% ethanol colorimetry and calculated [17]. The activity of CAT was measured with the ultraviolet absorption method [17]. The activity of the POD and SOD was measured with Li's method [17]. The experiment results were the average values of three repeated tests.

Measuring the ¹³³Cs and ⁸⁸Sr contents

The plants of *Amaranthus mangostanus* L were harvested after maturation and divided into two parts, viz. roots or above-ground parts. The weeds and stones in the air-dried amaranth plant sample were removed and passed through 2 mm sieve, then rinsed in deionized water. They were dried to a constant weight in an oven and then measured for dry weight. Different parts of plants were pulverized with a stainless steel blade. The sample plants were washed with distilled water, weighed exactly 0.5 g after-sample and placed in the conical flask, in addition, 10 mL acid mixture (volume ratio of nitric acid: perchloric acid was 3:1) was added to it. Having been covered for an overnight, the liquid samples were washed into the Kjeldahl flask and dispelled on the electric stove until it began to give out white smoke. The digestive juice was colorless and transparent. It was kept into the constant volume of 50 ml with 0.5 mol/L nitric acid. The graphite furnace atomic absorption spectroscopy (AA700, Perkin Elmer Company, USA) was used to measure the content of ¹³³Cs and ⁸⁸Sr.

Measuring the biomass

The whole plants were used for biomass measurement after harvesting. The plant samples were washed with distilled water and separated into the above-ground parts and the root parts with scissors. Firstly, samples were air-dried in cool and well-ventilated places, then were oven dried (68°C ± 2°C, 24 h). The dry weight of each part was weighed to calculate the biomass.

Determination of the TF value and CF

TF (transfer factor) refers to nuclide content in the above-ground parts/nuclide content in the root parts. BCF (concentration factor) refers to nuclide content in the above-ground parts or total plant/nuclide content in the soil.

Data analysis

Microsoft Excel 2003 (U.S, Microsoft), DPS3.1 Software (China), and the Origin 6.0 mapping software (U.S., Microcal) were used for data analysis. All detecting data were repeated three times, and results were expressed in the mean ± standard deviation (Mean ± SD) form.

Results

The ¹³³Cs or ⁸⁸Sr absorption and distribution in amaranth

The ¹³³Cs or ⁸⁸Sr contents in the plants were measured after harvesting and the results were shown in Table 2.

It can be found from the Table 2 that the content of ¹³³Cs and ⁸⁸Sr in the control plants was smaller than the minimum detectable amount. The total contents of ¹³³Cs in the plant rose with the increase of the ¹³³Cs concentration in the soil and there were very significant differences between all the treatments (p<0.01). The highest ¹³³Cs content of total plant was 3535.2 ± 150.5 µg.g⁻¹ dw, which was in the 5 mmol/kg treatment. The ¹³³Cs content in the above-ground parts of the plant was rising with the increase of the ¹³³Cs concentration in the soil and there were also very significant differences between all the treatment (p<0.01), too. The ¹³³Cs content in the 5 mmol/kg treatment was the highest, which was 1820.1 ± 170.1 µg.g⁻¹ dw. The variation trend of the ¹³³Cs content in the root part was the same with as that in the above-ground part. It showed that ¹³³Cs concentration in the soil was the most important factor which affected the ¹³³Cs content in the plant of *Amaranthus*. The ⁸⁸Sr distribution and transportation were the same trend as they were in the ¹³³Cs treatment. The highest ⁸⁸Sr contents of all the plant was 639.4 ± 21.9 µg.g⁻¹ dw, which was in the 5 mmol/kg treatment, too.

The ¹³³Cs or ⁸⁸Sr contents in the above-ground part was lower than it in the root in 0.1mmol/kg and 0.5mmol/kg treatment and the number of their transfer factor (TF) were lower than 1. In the high level treatment (1mmol/kg and 5mmol/kg), however, the situations were opposite and the number of their TF was higher than 1. It showed that the ¹³³Cs or ⁸⁸Sr could be transported easily from the root to the above-ground parts when the ¹³³Cs concentration in the soil was high. The TF of ¹³³Cs or ⁸⁸Sr in amaranth was similar.

BCF (concentration factor) can reflect the nuclide or heavy metal phytoextraction ability of plant from the soil. The Table 2 showed that the amount of ¹³³Cs or ⁸⁸Sr BCF trend of amaranth above-ground and its total plant was similar, which declined with the rise of ¹³³Cs or ⁸⁸Sr concentration in the soil, which indicated that it was more difficulty to extract ¹³³Cs or ⁸⁸Sr from the soil in the higher concentration treatment by the amaranth than in the lower concentration. Except in the 0.1 mmol/kg treatment, ¹³³Cs BCFs of above ground and total plant was higher than the BCFs of ⁸⁸Sr which means the ¹³³Cs phytoextraction ability were higher than ⁸⁸Sr phytoextraction ability of amaranth in the higher ¹³³Cs or ⁸⁸Sr concentration in the soil. But in the 0.1 mmol/kg ¹³³Cs or ⁸⁸Sr treatment, the ¹³³Cs or ⁸⁸Sr CF of total plants was 21.69 and 28.29, respectively. The ¹³³Cs phytoextraction ability was lower than ⁸⁸Sr phytoextraction ability of amaranth.

Effects of ¹³³Cs or ⁸⁸Sr on the growth and biomass distribution of amaranth

The biomass of the amaranth plants was measured after harvesting, and the results were showed in Table 3. It can be found from the Table 3 that the difference of total biomass was not significant to the control in the low ¹³³Cs concentration treatments (0.1 and 0.5 mmol/kg), while in the high concentration treatments (above 1 mmol/kg), it was significantly lower than the control and the low concentration treatments. The treatments of different ¹³³Cs concentrations had the same trends of effects on the above-ground and root biomass of the amaranth plants.

For different concentrations of ⁸⁸Sr treatments, the above-ground,

	Treatment (mmol)	Treatment mg/kg	Contents of above ground $\mu\text{g/g dw}$	Contents of roots $\mu\text{g/g dw}$	Contents of total plant $\mu\text{g/g dw}$	TF	BCF of aboveground	BCF of total plant
⁸⁸ Sr	0	-	-	-	-	-	-	-
	0.1	8.76	119.2 \pm 4.3dD	128.6 \pm 2.1dD	247.8 \pm 3.3dD	0.93	13.61	28.29
	0.5	43.81	158.4 \pm 12.1cC	161.4 \pm 36.3cC	319.8 \pm 24.2cC	0.98	3.62	7.30
	1	87.62	217.6 \pm 13.4bB	201.4 \pm 18.6bB	419.0 \pm 15.5bB	1.08	2.48	4.78
	5	438.1	382.7 \pm 25.2aA	256.7 \pm 16.4aA	639.4 \pm 21.9aA	1.49	0.87	1.46
¹³³ Cs	0	0	-	-	-	-	-	-
	0.1	13.92	128.4 \pm 24.1dD	173.5 \pm 6.9dD	301.9 \pm 15.0dD	0.74	9.22	21.69
	0.5	66.45	455.3 \pm 22.3cC	473.2 \pm 11.6cC	928.5 \pm 17.6cC	0.96	6.85	13.97
	1	132.91	913.6 \pm 32.7bB	753.4 \pm 29.7bB	1667.0 \pm 31.1bB	1.21	5.67	12.54
	5	664.50	1820.1 \pm 170.1aA	1715.1 \pm 130.8aA	3535.2 \pm 150.5aA	1.06	2.74	5.32

Note: Results represent means \pm SD. Different small letters represents significant difference at p=0.05 level. Different capital letters represents significant difference at p=0.01 level. "-" means the item could not be detected.

Table 2: The uptake and distribution of ¹³³Cs or ⁸⁸Sr in amaranth.

Treatment (mmol/kg)	¹³³ Cs treatment(g dw plant ⁻¹)			⁸⁸ Sr treatment(g dw plant ⁻¹)		
	Above-ground part	Root part	Total biomass	Above-ground part	Root part	Total biomass
0	11.28 \pm 0.30a	1.83 \pm 0.18a	13.11 \pm 0.22a	11.28 \pm 0.30a	1.83 \pm 0.18a	13.11 \pm 0.24a
0.1	11.32 \pm 0.38a	1.89 \pm 0.06a	13.21 \pm 0.22a	11.03 \pm 0.09a	1.57 \pm 0.13ba	12.60 \pm 0.11b
0.5	11.52 \pm 0.48a	1.83 \pm 0.06a	13.35 \pm 0.25a	9.66 \pm 0.40b	1.32 \pm 0.13b	10.98 \pm 0.27c
1	9.88 \pm 0.41b	1.73 \pm 0.07b	11.61 \pm 0.24b	8.78 \pm 0.23bc	1.27 \pm 0.12bc	10.05 \pm 0.18c
5	8.58 \pm 0.42b	1.71 \pm 0.06b	10.29 \pm 0.24b	7.63 \pm 0.20c	1.14 \pm 0.05c	8.77 \pm 0.13d

Note: Different lowercase letters represents significantly different (p<0.05).

Table 3: Effects of ¹³³Cs and ⁸⁸Sr stresses on the biomass and the biomass distribution in amaranth.

Treatment (mmol/kg)	¹³³ Cs Treatment						⁸⁸ Sr Treatment					
	concentration in the soil(mg/kg)	concentration in the plant (mg.kg ⁻¹ dw)	Biomass of total plant g/ plant	Contens in the plant (mg)/plant	Contents in a pot (mg)/pot	Ratio of Contens in the plant\ Contents in a pot (%)	concentration in in the soil(mg/kg)	concentration in in the plant (mg.kg ⁻¹ dw)	Biomass of total plant g/ plant	Contens in the plant (mg)/ plant	Contents in a pot (mg)/pot	Ratio of Contens in the plant\ Contents in a pot (%)
0	0	-	13.107	-	-	-	-	-	13.107	-	-	-
0.1	13.29	300.21	13.210	3.97	59.81	19.91	8.762	250.26	12.600	3.15	39.429	23.97
0.5	66.45	930.34	13.347	12.42	299.02	12.46	43.81	320.13	10.983	3.51	197.145	5.35
1	132.91	1660.15	11.613	19.29	598.10	9.68	87.62	420.47	10.047	4.22	394.29	3.21
5	664.50	3540.32	10.293	36.45	2990.25	3.66	438.10	570.35	8.770	5.00	1971.45	0.76

Table 4: The ¹³³Cs and or ⁸⁸Sr extraction efficiency of amaranth.

root and total biomass all decrease with the increase of the ¹³³Cs concentration in the soil and there were significant difference (p<0.05) except between the 0.5 and 1 mmol/kg treatment. It could be found that high concentrations of ⁸⁸Sr had stronger effect on the biomass of amaranth than that of ¹³³Cs stress.

Table 3 also demonstrates the biomass distribution of the above-ground and root parts of amaranth. The results showed that the ¹³³Cs or ⁸⁸Sr treatment had no significant influence on the proportion of biomass of above-ground parts and root parts to the total biomass. The biomass of above-ground parts took up 82-88% of the total biomass. The biomass of root parts took up 12-18% of the total biomass. It was universal that the biomass of the roots was lower than that of the above-ground parts.

The ¹³³Cs or ⁸⁸Sr extraction efficiency of the amaranth

The ¹³³Cs or ⁸⁸Sr extraction efficiency of amaranth in ¹³³Cs or ⁸⁸Sr treatments was calculated and the results are showed in Table 4. The Table 4 shows that the ¹³³Cs or ⁸⁸Sr concentration in the soil, concentration in the plant, contents in the plant and contents in a pot were rising gradually with the increasing concentration in the soil, but the biomass of total plant and the ratio of contents in the plant with the contents in a pot were fall gradually. The ratio of ¹³³Cs or ⁸⁸Sr contents

in the plant with the contents in a pot was the highest in the 0.1 (mmol/kg) treatments, which was 19.91% and 23.97%, respectively. When in 5(mmol/kg) treatment, the ratio was lowest, which was 3.66% or 0.76%, respectively. That means it was more difficult to uptake ¹³³Cs or ⁸⁸Sr from the soil when ¹³³Cs or ⁸⁸Sr concentration in the soil was high and it would take more time to apply amaranth to remediate high ¹³³Cs or ⁸⁸Sr concentration contaminated soil. In this test, when the ¹³³Cs concentration in the soil was 0.1mmol/kg or 13.29 mg/kg and the ratio of content in the plant with contents in a pot was the same every time, it needed to grow amaranth plants approximately 5 times (if to grow amaranth plants 2 seasons in a year, it needed 2.5 years) theoretically to uptake all the ¹³³Cs from the soil. But when the ¹³³Cs concentration in the soil is 5 mmol/kg or 664.5 mg/kg, it needed to grow amaranth plants approximately 28 times (if to grow amaranth plants 2 seasons in a year, it needed 14 years). When the ⁸⁸Sr concentration in the soil is 5mmol/kg or 438.10mg/kg it needed to grow amaranth plants approximately 132 times (if to grow amaranth plants 2 seasons in a year, it needed 66 years).

Physiological response of amaranth to ¹³³Cs or ⁸⁸Sr stress

The effect of ¹³³Cs or ⁸⁸Sr on the chlorophyll and MDA content of amaranth: The chlorophyll and MDA content of amaranth under

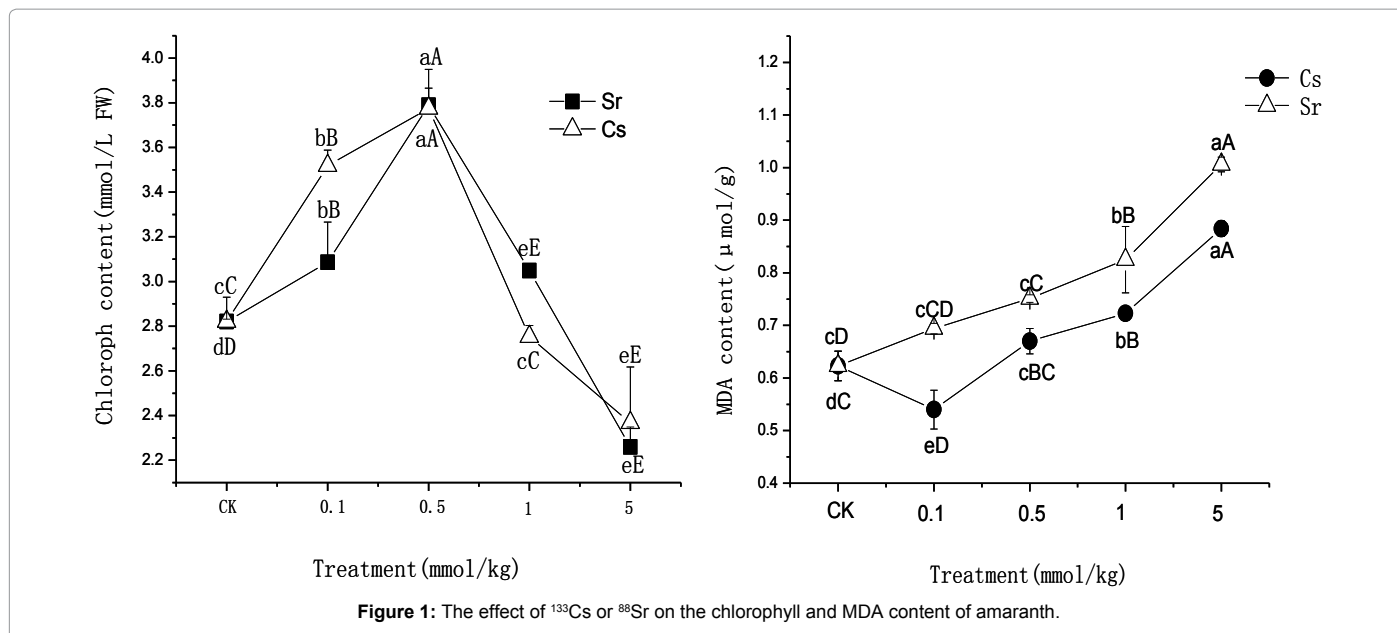


Figure 1: The effect of ¹³³Cs or ⁸⁸Sr on the chlorophyll and MDA content of amaranth.

the stress of ¹³³Cs and ⁸⁸Sr was shown in Figure 1. It can be found from the Figure 1 that the effects of ¹³³Cs and ⁸⁸Sr stress were similar, i.e. the chlorophyll content rose at first and then fell with the increasing of ¹³³Cs and ⁸⁸Sr content, it was the highest at the 0.5 mmol/kg treatment with the ¹³³Cs and ⁸⁸Sr treatment and the chlorophyll content decreased at the 1 mmol/kg treatment and it was the lowest at the 5 mmol/kg treatment. Moreover, the chlorophyll contents of all the treatments under the stress were significant difference ($p < 0.05$) comparing to the control under the stress of ¹³³Cs and ⁸⁸Sr.

Figure 1 also showed the changes of the MDA content in amaranth leaves after different ¹³³Cs and ⁸⁸Sr treatments. It can be found from the Figure 1 that the after harvesting, the MDA content rose continually with the increasing ¹³³Cs and ⁸⁸Sr treatment concentration and all was higher than the control except at the 0.1 mmol/kg ¹³³Cs treatment. For both ¹³³Cs and ⁸⁸Sr treatments, the highest values of their MDA content appeared at the 5 mmol/kg treatment. The MDA content of amaranth in ⁸⁸Sr treatments was higher than in ¹³³Cs treatments in different concentration ¹³³Cs and ⁸⁸Sr treatments. The MDA content of all the treatments was significant difference ($p < 0.05$) with the control under stress of ¹³³Cs and ⁸⁸Sr. It can be found that high concentrations of ¹³³Cs and ⁸⁸Sr strengthened the peroxidization of the membranes of amaranth.

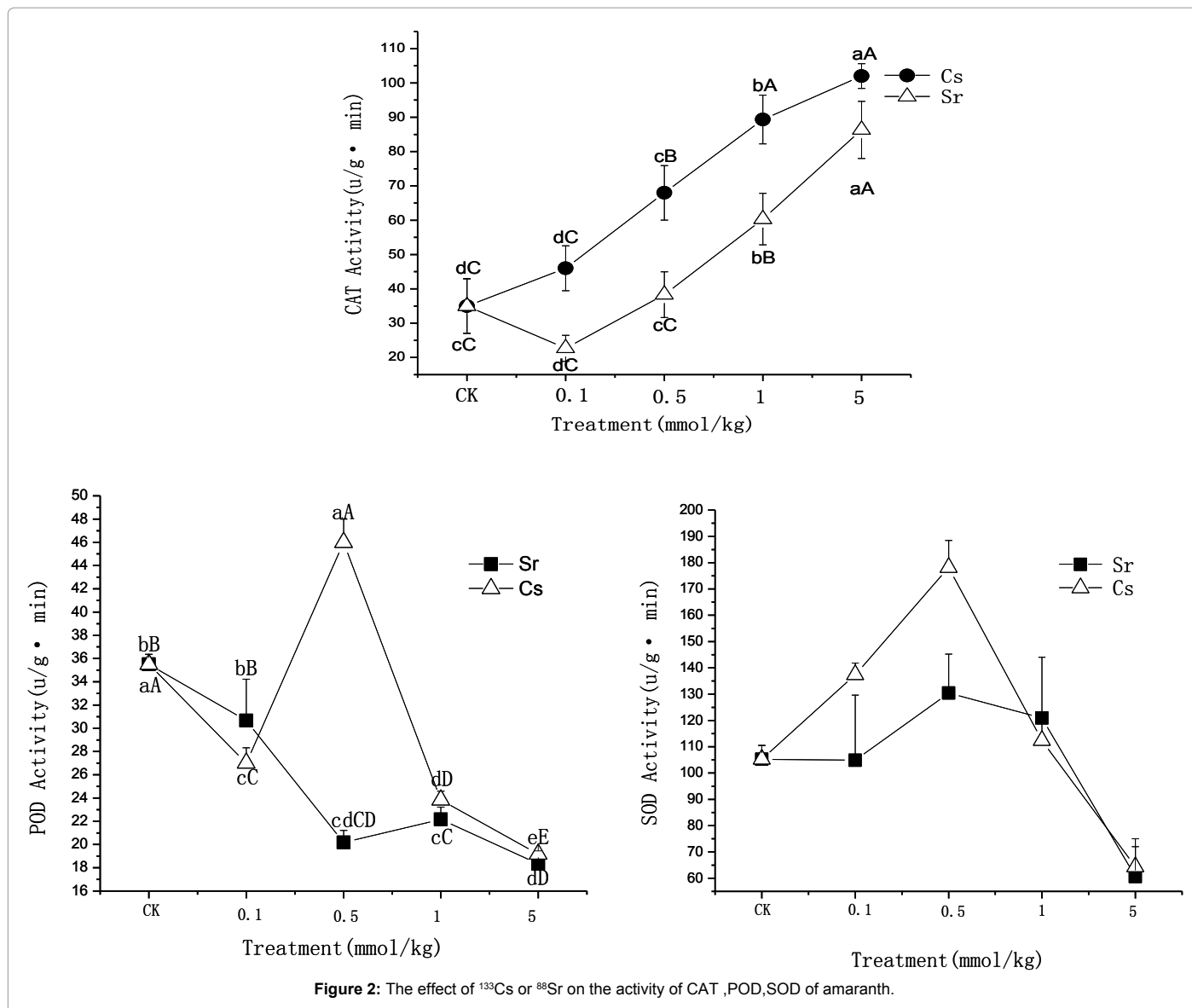
The effect of ¹³³Cs or ⁸⁸Sr on the activity of CAT, POD, SOD of amaranth: Figure 2 showed the changes of CAT, POD, SOD activity of amaranth leaves in different ¹³³Cs and ⁸⁸Sr treatments. It can be found from the Figure 2 that after the harvest, the CAT activity rose continually with the increasing ¹³³Cs and ⁸⁸Sr concentration. While the CAT activity declined firstly in ⁸⁸Sr 0.1 mmol/kg, then rose with the increasing ⁸⁸Sr concentration. Both of the highest values appeared at the 5 mmol/kg treatments, the CAT activity was 102 and 86.33 U/g min in ¹³³Cs and ⁸⁸Sr treatments, respectively, the CAT activity of the control was 35 U/g min. Except the control, the CAT activity of amaranth in ⁸⁸Sr treatments was lower than that in ¹³³Cs treatments among different concentration of ¹³³Cs or ⁸⁸Sr treatments. The result indicated that high concentrations of ¹³³Cs and ⁸⁸Sr strengthened the the CAT activity of amaranth.

As Figure 2 showed, the effects of ¹³³Cs and ⁸⁸Sr stress on POD activity were different. After the ¹³³Cs treatment, the POD activities first declined then rose and decline again. It was the highest at the 0.5 mmol/kg treatments, which was 45.1 u/g.min and the lowest at the 5 mmol/kg treatments, which was 17.2 u/g.min. For the ⁸⁸Sr treatments, the POD activities of all treatments were lower than the control, and declined continually with the increasing ⁸⁸Sr treatments concentration. Besides, the 5 mmol/kg treatment was the lowest.

Figure 2 also showed that the effects of ¹³³Cs and ⁸⁸Sr stress on POD activity were different. After the ¹³³Cs treatment, the POD activities first rose and then declined. It was the highest at the 0.5 mmol/kg treatments, which was 175.9 u/g.min and the lowest at the 5 mmol/kg treatments, it was 57.6 u/g.min and lower than the control. For the ⁸⁸Sr treatments, the POD activities of all treatments were not significantly different ($p < 0.05$) from the control, except at the 5 mmol/kg treatment, when it was the lowest.

Analysis of the correlation between the ¹³³Cs and ⁸⁸Sr contents and each physiological index

Table 5 were acquired after analyzing the correlation of the indexes including the total element content in the plant, MDA content, chlorophyll content, POD-CAT and SOD activity tested after the harvest for ¹³³Cs and ⁸⁸Sr treatments. In Table 5, the ¹³³Cs content was positively correlated with the CAT activity ($r = 0.9240$, $p < 0.05$). This means the increase of the ¹³³Cs content in the plant activated CAT activity increasing and alleviated the degree of ¹³³Cs stress to the plant. The chlorophyll content was also positively correlated to the SOD activity ($r = 0.9617$, $p < 0.01$), too. Which means the increase of SOD activity accelerate chlorophyll synthesis. The correlation between other indexes was not significant. In Table 5, the ⁸⁸Sr content was positively correlated to the MDA content ($r = 0.9697$, $p < 0.01$) and negatively correlated to the POD activity. ($r = -0.8966$, $p < 0.05$) It means the increase of the ⁸⁸Sr content in the plant activated MDA content increase and reduced the POD activity. The chlorophyll content was positively correlated to the SOD activity. ($r = -0.9094$, $p < 0.05$) and the MDA content was positively correlated with the CAT activity.



Correlation Coefficient	⁸⁸ Sr(¹³³ Cs) content in the plant	Chlorophyll content	MDA content	POD activity	CAT activity	SOD activity
⁸⁸ Sr(¹³³ Cs) content in the plant		0.3503(-0.6369)	0.9697***(0.1440)	-0.8966*(-0.8298)	0.8275(0.9240*)	-0.5047(-0.6313)
Chlorophyll content			0.5178(0.1242)	-0.0253(0.7362)	-0.6372(-0.4914)	0.9094*(0.9617**)
MDA content				-0.8394(0.1293)	0.9312*(0.4998)	-0.6418(0.2792)
POD activity					-0.7084(-0.5140)	0.1660(0.8125)
CAT activity						-0.6499(-0.4114)
SOD activity						

Note: The symbol “*” , “**” represents significant relativity at p<0. 05 and p<0.01 between the indexes ,respectively;The figures in the brackets were the correlation coefficient of the indexes of amaranth with ¹³³Cs treatment.

Table 5: Correlation coefficient of the indexes of amaranth with ⁸⁸Sr and ¹³³Cs treatment.

Discussion and Conclusion

Plants vary in their abilities to uptake, translocate and sequester radionuclides [7,18,19]. The uptakes of ¹³³Cs and ⁸⁸Sr by the plants of amaranth were different when the treatment concentrations were the same in the soil. Generally, the amaranth absorbed more ¹³³Cs than ⁸⁸Sr at the same molarity treatment in the soil. The maximum ¹³³Cs uptake

of the total plant was 3535.2 mg kg⁻¹ dw when the ¹³³Cs concentration was 5 mmol/kg (664.5 mg/kg) in the soil, and the minimum was 301.9 mg/kg.dw when the ¹³³Cs concentration was 0.1 mmol/kg (13.92 mg/kg) in the soil. The maximum ⁸⁸Sr uptake of total plant was only 639.4 mg/kg. dw when the ⁸⁸Sr concentration was 5 mmol/kg (438.7 mg/kg)in the soil, and the minimum was only 247.8 mg/kg. dw when the ⁸⁸Sr concentration was 0.1 mmol/kg (8.76 mg/kg) in the soil. The

result in this study was opposite to Dan Wang's previews reported that accumulation of ^{88}Sr was recorded higher than ^{134}Cs in radish plantlets [20]. It showed that amaranth had much stronger capacity of absorbing ^{133}Cs than ^{88}Sr . Based on the effects of the ^{133}Cs and ^{88}Sr stress on the biomass of the plants, the maximum uptake of ^{133}Cs or ^{88}Sr by amaranth reached 36.437 mg and 5.00 mg per plant, respectively. The ^{133}Cs BCF of the above-ground parts and the total plant of amaranth in different concentration treatments in the soil were higher than the ^{88}Sr BCF except in the 0.1 mmol/kg treatment. The TF trend of amaranth for ^{133}Cs and ^{88}Sr were the same and at the lower ^{133}Cs and ^{88}Sr concentration (0.1 and 0.5 mmol/kg), the accumulation of ^{133}Cs and ^{88}Sr was found higher in roots compared with when it was above-ground parts, while at higher ^{133}Cs and ^{88}Sr concentration (1 and 5 mmol/kg), ^{133}Cs and ^{88}Sr accumulation was more when it was in above-ground parts than it was in roots. The result was the same as Shradha Singh' result [6], which means the transfer capacity of ^{133}Cs and ^{88}Sr to the above-ground parts, was similar. Some researchers reported many plant species uptake more Sr than Cs when the concentration of Cs or Sr is same in the soil or hydroponic medium [6,16,20]. Which means it is more difficult to remediate Cs pollution than Sr with phytoextraction technology. The stronger uptake capacity of amaranth for ^{133}Cs in low concentration was favorable for the restoration of the soils of low level Cs pollution. The present study suggests that amaranth can be used as a potential candidate plant for phytoextraction of ^{137}Cs .

The biomass of the amaranth plants gradually decreased with the increase of ^{133}Cs and ^{88}Sr content in the soil. But it was not more obvious in the ^{133}Cs treatment than in the ^{88}Sr treatment.

The chlorophyll content in leaves is a most important physiology index in the growth and metabolism of plants. Under ^{133}Cs and ^{88}Sr stress, the chlorophyll content in amaranth firstly increase and then decreases with the increasing of ^{133}Cs and ^{88}Sr content in the soil. This means lower ^{133}Cs and ^{88}Sr contents in the soil activate the chlorophyll content and higher ^{133}Cs and ^{88}Sr content stress can decrease chlorophyll content. This can lead to lower photosynthesis ability and decrease the biomass of plants.

Malondialdehyde (MDA), one of the decomposition products of polyunsaturated fatty acids of membrane is considered as a reliable indicator of oxidative stress [13]. In this experiment, the MDA content under ^{88}Sr stress was higher than that under ^{133}Cs stress, and the activities of CAT under ^{88}Sr stress was lower than that under ^{133}Cs stress. It is the important physiological reason why amaranth has better tolerance to ^{133}Cs stress and uptake more ^{133}Cs than ^{88}Sr .

Acknowledgements

The authors gratefully acknowledge the financial support from the State Administration of Science Technology and Industry for Defence, China under the defense fundamental research projects b3120110001.

References

1. Dushenkov S (2003) Trends in phytoextraction of radionuclides. *Plant Soil* 24: 167-175
2. Lasat MM, Fuhrmann M, Ebbs SD, Cornish JE, Kochian LV (1998) Phytoextraction of radiocesium contaminated soil: evaluation of cesium-137 bioaccumulation in the shoots of three plant species. *J Environ. Qual.* 27: 65-169

3. Nriagu JO, Pacyna JM (1988) Quantitative assessment of worldwide contamination of air, water and soil by trace metals. *Nature* 333: 134-139
4. Soudek P, Tykva R, Vanek T (2004) Laboratory analyses of ^{137}Cs uptake by sunflower, reed and poplar. *Chemosphere* 55: 1081-1087.
5. Singh S, Eapen S, Thorat V, Kaushik CP, Raj K, et al. (2008) Phytoextraction of $^{137}\text{cesium}$ and $^{90}\text{strontium}$ from solutions and low-level nuclear waste by *Vetiveria zizanioides*. *Ecotoxicol Environ Saf* 69: 306-311.
6. Singh S, Thorat V, Kaushik CP, Raj K, Eapen S, et al. (2009) Potential of *Chromolaena odorata* for phytoextraction of (^{137}Cs) from solution and low level nuclear waste. *J Hazard Mater* 162: 743-745.
7. Watt NR, Willey NJ, Hall SC, Cobb A, (2002) Phytoextraction of ^{137}Cs : the effect of soil ^{137}Cs concentration on ^{137}Cs uptake by *Beta vulgaris*. *Acta Biotechnol.* 22: 183-188.
8. Chou FI, Chung HP, Teng SP, Sheu ST (2005) Screening plant species native to Taiwan for remediation of ^{137}Cs -contaminated soil and the effects of K addition and soil amendment on the transfer of ^{137}Cs from soil to plants. *J Environ Radioact* 80: 175-181.
9. Veresoglou DS, Sialtas JT, Barbayiannis N, Zalidis GC (1995) Caesium and strontium uptake by two pasture plant species grown in organic and inorganic soils. *Agr. Eco. and Environ.* 56: 37-42
10. Wirth E (1994) Transfer equations for cesium-137 for coniferous forest under storey plant species. *Sci. Tot. Environ* 157: 163-170
11. Fuhrmann M, Lasat M, Ebbs S, Cornish J, Kochian L (2003) Uptake and release of cesium-137 by five plant species as influenced by soil amendments in field experiments. *J Environ Qual* 32: 2272-2279.
12. Banuelos GS (1997) The distribution of radiocesium and potassium in spinach plants grown at different shoot temperatures. *Environ. Qual* 26: 639
13. Demiral T, Türkan I (2005) Comparative lipid peroxidation, antioxidant defense systems and proline content in roots of two rice cultivars differing in salt tolerance. *Environ. Exp. Botany* 53: 247-257.
14. Moogouei R, Borghei M, Arjmandi R (2011) Phytoextraction of stable Cs from solutions by *Calendula alata*, *Amaranthus chlorostachys* and *Chenopodium album*. *Ecotoxicol Environ Saf* 74: 2036-2039.
15. Tsukada H, Takeda A, Takahashi T, Hasegawa H, Hisamatsu S, et al. (2005) Uptake and distribution of ^{90}Sr and stable Sr in rice plants. *J Environ Radioact* 81: 221-231.
16. Soudek P, Valenová S, Vavříková Z, Vanek T (2006) (^{137}Cs) and (^{90}Sr) uptake by sunflower cultivated under hydroponic conditions. *J Environ Radioact* 88: 236-250.
17. Zou Q (2000) Guidance of plant Physiological Biochemical Experiment. Beijing: Higher Education Press, Pp: 164-165.
18. Eapen S, D'Souza SF (2005) Prospects of genetic engineering of plants for phytoextraction of toxic metals. *Biotechnol Adv* 23: 97-114.
19. von Firck Y, Rosén K, Sannerby-Forsse L (2002) Uptake and distribution of ^{137}Cs and ^{90}Sr in *salix viminalis* plants. *J Environ Radioact* 63: 1-14.
20. Wang D, Wen F, Xu C, Tang Y, Luo X (2012) The uptake of Cs and Sr from soil to radish (*Raphanus sativus* L.)- potential for phytoextraction and remediation of contaminated soils. *J Environ Radioact* 110: 78-83.