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Uptake of radionuclide thorium by twelve native plants grown in uranium mill tailings soils from south part of China

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HIGHLIGHTS

- Screen dominant plants grown in uranium mill tailings soils.
- Quantify the content of ^{232}Th of soil samples from uranium mill tailings.
- Quantify the transfer factor, bioconcentration factor and phytoremediation factor.
- Screen out the plant species capable of remediating radionuclide contaminated soils.
- Guide the reuse of study area in future.

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ABSTRACT

The concentrations of thorium (^{232}Th) in soil from a uranium mill tailings repository in South China were analyzed. The results showed that all the soil samples were acidic and the concentrations of ^{232}Th in all the soil samples were more than the natural radionuclide content in soil of China. Through the field investigation, twelve kinds of dominant plants were discovered. The total quantity of ^{232}Th in the whole plant is highest in rice flat sedge. We also found that *Miscanthus floridulus* has the greatest transfer factor (TF) for ^{232}Th, rice flat sedge has the greatest bioconcentration factor (BF) for ^{232}Th. At the mean time, *M. floridulus* has the greatest phytoremediation factor (PF) for ^{232}Th. On the basis of the above conclusions and the definition for hyperaccumulator, rice flat sedge and *M. floridulus* could be the candidates of phytoremediation for radionuclide ^{232}Th in the soil.

1. Introduction

With the rapid development of the nuclear industry and nuclear energy, the demand for uranium (U) mining metallurgy products keeps increasing. However, extraction of uranium and ore proceeding in milling facilities produce large solid wastes (uranium mill tailings) which contain a series of long-lived radionuclides such as thorium (^{232}Th) which belongs to the family of high toxic radionuclides (Abreu et al., 2014; Favas et al., 2014; Poinssot et al., 2014). Although the uranium mill tailings are deposited in a specially designed and constructed repository, the radionuclide can still be transported to the soil covered on the repository and pose a great threat to the ecosystem, agro-system and people's health. Therefore, it is necessary to study the remediation techniques for radionuclide contaminated soils. One of the promising strategies for treating large scale radionuclide contaminated soils is the use of phytoremediation techniques (Sharma et al., 2015). In recent years, some researchers have studied the uranium mill tailings contaminated soils and the relative uptake of radionuclides such as thorium (^{232}Th) by various plant species (Li et al., 2011). However, because of its insidious chemical property and special sources, researches in this field are not enough. Also because of differences in soil types, climate, plant species, uranium ore grade, and uranium mill tailing treatment among different regions, utilizing only the applicable results to other regions would be a mistake, therefore specific local research works need to be carried out.

So the present study makes an on-the-spot investigation of the dominant plants grown in uranium mill tailings soils in southwest of China, to screen out the plant species capable of remediating radionuclide ^{232}Th contaminated soils.

2. Materials and methods

The uranium mill tailings are located in the southern part of China. The area receives regular and plentiful rainfall (1423 mm per year) during late spring and early summer. The average annual

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temperature is 18.3 °C with extreme low temperature of −2.5 °C and extreme high temperature of 40.2 °C. The average sunshine hours per year are 1443 h and the dominant wind direction is northeast. Each plant has its own ecological characteristics, growth habit and density which lead to the different distribution in the study area. So in the present study, the sampling sites extended over an area of 1500 m^2 including seven dam sections of uranium mill tailings to screen many more native plants grown in uranium mill tailing soils.

The plant samples were collected from the sampling sites. For each plant, 10 strains of intact plants were selected and then mixed to give a composite sample. All the plant samples were divided into the shoot (including seed, leaf, stalk and stem) and the root. Soil samples were taken under each selected plant from the root zone at a depth interval of 0 m down to 0.2 m by digging profiles. Collected samples of plant and soil were packed into a water-tight bag to prevent cross contamination and shipped to the laboratory.

In the laboratory, plant samples were gently washed with deionized distilled water for 2 min to remove the soils adhered. And then the plant and soil samples were kept drying at room temperature for 4 weeks to achieve radioactive equilibrium. The fresh weight of each plant sample was precisely obtained by a scale.

All the soil and plant samples were sealed in the clean polyethylene container and stored in a refrigerator for analyzing the soil physicochemical properties and the concentration of ^{232}Th at Engineering Research Center of Biomass Materials, Ministry of Education, Southwest University of Science and Technology, China. The physicochemical properties of soil samples were analyzed according to Page (1982). The traditional pipette method was used for particle size analysis.

0.05 g of soil samples and 0.10 g of plant samples including seed, leaf, stalk and stem were taken and digested with analytical reagent-grade HNO_3 and HF which were purified by sub-boiling distillation to give the low reagent blank and the corresponding low analytic limit of detection. For each sample, there are 50 replicates. That is, there are 50 tests for each sample (soil and plant).

Then the concentrations of ^{232}Th in plant and soil samples were determined by inductively coupled plasma mass spectrometry (modal-ELEMENT 2/XR, Thermo Scientific, USA). The detection limit was 0.0003 μg/L for Th. The accuracies of inductively coupled plasma mass spectrometry analyses were estimated to be better than ±5% (relative) for the elements determined.

The TF is defined as:

TF = target element concentration in the plant shoot/target element concentration in the plant root

The BF is defined as:

BF = target element concentration in the plant/target element concentration in the soil

The PF is defined as:

target element concentration in the plant × fresh weight of the plant/target element concentration in the soil.

Multivariate analysis and analyses of variance (ANOVA) were used to demonstrate differences among the sample using SPSS 19.0. Pearson correlation coefficient (PCC) was also calculated using SPSS. $P < 0.05$ was considered as significance.

3. Results and discussion

3.1. Physicochemical properties and radionuclide ^{232}Th in the soils

The uptake of radionuclide depends on various soil and plant factors like soil types, cation exchange capacity, organic matter content, soil pH as well as plant species, root development and root system. In this study, we can find that soil pH ranged from strong acidity (3.1) to faintly acid levels (5.3). Organic matter content in soils ranged from 3.07 g/kg to 7.32 g/kg. Total N and total C in soils ranged from 0.62 g/kg to 1.05 g/kg and 4.24 mg/kg to 8.55 mg/kg. The particle size distribution shows that the soil samples from the studied area have low clay content ranging from 3.6% to 5.6% with soil texture estimated to be silt loam according to soil textural triangle (Table 1).

All soil samples were acidic which might be associated with a lot of acidic ions produced during the extraction process, such as nitrate and sulfate. In fact, soil pH has great effects on the generation of soil colloid, radionuclide hydrolysis and ion exchange reaction, which in turn affect the adsorption of the radionuclide (Yan and Luo, 2015).

We can also find that the content of ^{232}Th obtained in this study was 1.10 times more than the background contents of radionuclide in soil of China: 49.1 Bg/kg for ^{232}Th (Table 1) (Sanming and Ruye, 1992). In the light of the above data, it can be concluded that radionuclide ^{232}Th concentrations in all the soil samples were more than the background value.

3.2. The select criteria for radionuclide ^{232}Th

According to the definition of the hyperaccumulator for heavy metals: first, plants can normally grow in heavy metal contaminated soil and will not appear in the heavy metal poisoning phenomenon; second, the amount of an element accumulated in plant is more than a certain critical flux; third, the concentration of an element accumulated in overground part of a plant is more than the underground part (Pollard et al., 2014).

Through on-the-spot research of the study site, we found that there are twelve kinds of plants widely distributing in the study area. They are all perennial herbaceous plants such as dog tail grass (*Setaria virdis* (L.) Beaauv.), twitch-grass (*Imperata cylindrica* (Linn. Beauv.)), dandelion (*Taraxacum mongolicum* Hand.-Mazz.), *Cibotium barometz* (*Cibotium barometz* (Linn.) J. Sm.), *Paspalum paspaloides* (*Paspalum distichum* L.), reed (*Phragmites australis* (Cav.) Trin. exSteud.), pokeberry (*Phytolacca americana*), garden sorrel (*Rumex acetosa* Linn.), *Paspalum orbiculare* (*Paspalum orbiculare* G Forstt), rice flat sedge (*Cyperus iria* L.), *Miscanthus floridulus*

Table 1
The physicochemical properties and radionuclide ^{232}Th in the soil samples.

Parameter	Min	Max	Mean	Deviation	Skewness	Kurtosis
pH	3.6	5.3	4.1	0.59	0.27	−0.84
Organic matter (g/kg)	3.07	7.32	4.91	1.22	0.13	−1.03
Total N (g/kg)	0.62	1.05	0.80	0.10	0.41	−0.64
Total C (%)	4.24	8.55	6.26	1.08	0.37	−0.05
Cation exchange capacity (cmol/kg)	8.39	10.32	9.34	0.48	0.23	−0.72
Coarse sand (%)	6.1	8.9	7.4	2.85	0.07	−0.12
Fine sand (%)	8.9	18.9	13.6	6.4	0.36	−1.11
Silt (%)	58.1	96.3	74.4	10.3	0.16	−1.01
Clay (%)	3.6	5.6	4.5	0.49	0.30	−0.57
^{232}Th (Bg/kg)	41.9	70.2	54.2	6.28	0.25	0.13