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Study on the Characteristics and Influencing Factors of Selenium Content in Soil of Western Hubei Province, China

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ABSTRACT

Mastering the distribution of selenium in soils is vital for the development of selenium-enriched industries. This study focuses on Xintang Township in Enshi City, western Hubei Province, known for its selenium-rich soils, analyzing 2,469 soil samples to understand selenium distribution and its influencing factors. Key findings include: 1. Selenium content in surface soils ranges from 0.14 to 25.74 mg/kg, with an average of 0.81 mg/kg, and 86.23% of the area has selenium-rich soils. 2. Soil selenium content is significantly influenced by the parent material, especially soils from the Permian black rock series, showing higher selenium levels with an enrichment factor of 3.74. 3. Soil type impacts selenium distribution, with yellow lime soil and brown lime soil showing high enrichment factors of 3.94 and 2.62, respectively.

KEYWORDS

Xintang Township; high-selenium soil; selenium content; distribution pattern; influencing factor.

1. INTRODUCTION

Selenium, a vital trace element for the human body, was first discovered by Swedish chemists in 1817 during experiments involving the extraction of sulfuric acid from pyrite[1]. China is a severely selenium-deficient country, with selenium-deficient soils covering 72% of the total soil area[2]. Consequently, regions in China have experienced endemic diseases like Keshan disease and Kashin-Beck disease due to selenium deficiency, highlighting the importance of selenium supplementation in preventing these ailments. Understanding the distribution patterns and influencing factors of selenium in surface soils is essential for selenium development and efficient utilization.

Enshi City, located in the western part of Hubei Province, China, hosts the world's only confirmed sedimentary independent selenium deposit, with abundant selenium-rich soils. Research data indicates that Enshi City's rocks, soils, and crops have reached maximum selenium concentrations of 84,123 mg/kg, 2018 mg/kg, and 3329 mg/kg, respectively, leading globally. Agriculture is a vital industry in the area, making the development of selenium-rich agriculture significant[3]. Conducting geochemical research on selenium in Enshi City's soils lays the foundation for exploiting selenium resources in the region.

This study focuses on the surface soils of Xintang Township, Enshi City, western Hubei Province, to investigate the distribution patterns and influencing factors of selenium-rich soils, aiming to provide theoretical references for the development of selenium-rich agriculture in the area.

2. STUDY AREA OVERVIEW

Enshi City is situated in the mountainous southwestern part of Hubei Province, with geographical coordinates ranging from 109°05'14" to 109°52'35" east longitude and 30°03'44" to 30°32'57" north latitude. It administratively comprises 17 townships and sub-districts, including Xintang Township, Wuyangba Sub-district, and Mufu Sub-district. Xintang Township is located in the southeast of Enshi City, covering an area of 420 km^2, and includes 13 villages and neighborhood committees such as Xintang Neighborhood Committee and Baoshuixi Village.

The geological formations in Xintang Township are rich, with exposed strata including the Silurian Luojiping Formation (S_1lr), Shamao Formation ($S_{1-2}s$), Devonian Yuntaiguan Formation, Huangjiadeng Formation, Xiejingsi Formation and interlayers (D_2y-D_3C_1x), Carboniferous Dapu Formation, Huanglong Formation and interlayers (C_2d+h), Permian Liangshan Formation, Qixia Formation and interlayers (P_1l+q), Maokou Formation, Gufeng Formation and interlayers (P_1m+g), Longtan Formation, Xiayao Formation, Dalong Formation and interlayers (P_2l-d), and Triassic Daye Formation (T_1d). The parent materials for soil formation mainly consist of weathered carbonate rocks, weathered rocks of the black rock series, and weathered clastic sedimentary rocks.

3. SAMPLE COLLECTION AND ANALYSIS

Soil samples were collected following a 1:50,000 sampling grid and density, using a combination of patch and grid methods, with representative field plots selected. The average sampling density was 6 points/km^2, employing the "five-point sampling method" to collect 0-20cm surface soil, avoiding areas with human contamination. A total of 2469 soil samples were collected, with each sample being a mixture of 4 sub-samples of equal quantity, weighing no less than 1000g. After air-drying, samples were sieved through a 20-mesh sieve, and 300g of each sample was sent for analysis, while the remaining samples were preserved in sample storage.

After thorough mixing, 80g of soil samples were sieved and ground to 200 mesh using a contamination-free planetary mill, with the leftover samples preserved as backup. Selenium elements were tested using Atomic Fluorescence Spectrometry (AFS), with a detection limit of 0.01 mg/kg. Measurement conditions included a negative high voltage of 280V, lamp current of 70mA, and an atomizer temperature of 200°C, following the relevant provisions in the "Specifications for Multi-Objective Regional Geochemical Surveys (1:250,000)" (DZ T 0258-2014)[4], meeting or exceeding accuracy and precision requirements.

4. EXPERIMENTAL RESULTS

Statistical analysis of test data from 2469 surface soil samples in Xintang Township revealed significant variation in selenium content. As shown in Table 1, the selenium content in surface soils of Xintang Township exhibited a wide range, with a content range of 0.14-25.74 mg/kg. The average selenium content was 1.50 mg/kg, with a median of 0.79 mg/kg. The calculated coefficient of variation (CV) was 141.5%, indicating an uneven distribution of selenium content in the area. After removing outliers, the background value of soil selenium was calculated to be 0.81 mg/kg, providing a solid foundation for the development of selenium-rich agriculture.

Table 1. Characteristics of Soil Selenium Content

Location	Content (mg/kg)			CV (%)	Background Value (mg/kg)
	Range	Mean	Median		
Xintang Township	0.14-25.74	1.50	0.79	141.5	0.81

This study referenced the "Guidelines for Geochemical Evaluation of Land Quality" (DZ/T 0295-2016) to classify soil selenium levels[5]. Combining the distribution characteristics of selenium in the study area, the soil was categorized into five levels: deficient, marginal, adequate, enriched, and highly enriched. Additionally, soils with selenium content greater than 0.45 mg/kg were classified as selenium-rich soils. The standard values for each level and the proportion of samples are presented in Table 2.

Table 2. Classification of Soil Selenium Levels

Indicator	Deficient	Marginal	Adequate	Enriched	Highly Enriched	Selenium-Rich Standard
Content (mg/kg)	⩽0.125	0. 125-0.175	0.175-0.40	0.40-3.00	⩾3.00	⩾0.45
Sample Count	0	5	225	1964	275	2129
Percentage (%)	0	0.20	9.11	79.55	11.14	86.23

The results indicate that over 90% of the soil selenium content in Xintang Township falls within the range of 0.40-3.00 mg/kg, with soil areas meeting the standard for selenium-rich soil accounting for 86.23% of the total area of Xintang Township. The majority of surface soils meet the criteria for selenium-rich soil. Therefore, for the study area, the development of selenium-rich agriculture holds significant geographical advantages. Conducting research on soil selenium content is of paramount importance.

5. DISCUSSION

Relevant scholars believe that factors influencing the selenium content of surface soils include parent material, soil type, and land use status, with parent material and soil type being the most significant[6] . This paper discusses the factors affecting selenium content in the study area, focusing on parent material and soil type.

5.1. Influence of Parent Material on Soil Selenium Content

This paper analyzes the factors of parent material affecting soil selenium content in the study area. The primary parent materials in the study area are carbonate rocks, clastic sedimentary rocks, and black rock series dominated by carbonaceous shale and carbonaceous siliceous rocks. Combining geological background and lithological data, the study area's surface soil regions are classified into eight categories based on parent material and geological age. These categories include areas predominantly composed of weathered clastic sedimentary rocks such as S_1lr, $S_{1\text{-}2}s$, and D_2y-D_3C_1x; areas predominantly composed of weathered carbonate rocks such as C_2d+h and T_1d; and areas predominantly composed of weathered black rock series such as P_1l+q, P_1m+g, and P_2l-d. This paper analyzes the range, mean values, and enrichment factors (EF values) of selenium content in different surface soil regions, as shown in Table 3.

Table 3. Selenium Content in Different Parent Materials

Parent Material	Selenium Content (mg/kg)		Total Sample Count	EF
	Range	Mean		
S_1lr (Weathered Clastic Sedimentary Rock Area)	0.18-1.04	0.47	65	0.55
$S_{1\text{-}2}\hat{s}$ (Weathered Clastic Sedimentary Rock Area)	0.24-1.10	0.51	178	0.61
D_2y-D_3C_1x (Weathered Clastic Sedimentary Rock Area)	0.19-2.80	0.71	431	0.84
C_2d+h (Weathered Carbonate Rock Area)	0.26-3.54	0.74	133	0.94
P_1l+q (Weathered Black Rock Series Area)	0.16-9.41	0.85	224	1.19
P_1m+g (Weathered Black Rock Series Area)	0.33-25.74	2.19	448	3.12
P_2l-d (Weathered Black Rock Series Area)	0.20-20.70	2.82	419	3.74
T_1d (Weathered Carbonate Rock Area)	0.14-23.23	1.44	571	1.71

As shown in Table 3, considering the range and mean values of selenium content in surface soils with different parent materials, the order of magnitude is as follows: P_2l-d>P_1m+g>T_1d>P_1l+q>C_2d+h>D_2y-D_3C_1x>$S_{1\text{-}2}s$>S_1lr. There are significant differences in soil selenium content developed from different parent materials.

Selenium-rich areas are predominantly developed in the P_1m+g weathered black rock series area, with an enrichment factor reaching 3.12, and the P_2l-$d$weathered black rock series area, with an enrichment factor reaching 3.74. Selenium-deficient areas are mainly developed in the S_1lr weathered clastic sedimentary rock area, $S_{1\text{-}2}s$ weathered clastic sedimentary rock area, and D_2y-D_3C_1x weathered clastic sedimentary rock area, with enrichment factors not exceeding 0.90, and the lowest value being 0.55.

5.2. Influence of Soil Type on Soil Selenium Content

Previous studies have shown significant differences in selenium content distribution among different types of soils[7]. The study area consists of seven main soil types, with their respective proportions: yellow soil (10.0%), yellow loamy soil (2.0%), dark yellow-brown soil (45.5%), yellow-brown loamy soil (7.9%), acid brown soil (21.9%), brown lime soil (7.4%), and yellow lime soil (5.3%). This paper conducts statistical analysis on selenium content in different soil types, and the statistical data is presented in Table 4.

Table 4. Selenium Content in Different Soil Types

Soil Type	Selenium Content (mg/kg)		Total Sample Count	EF
	Range	Mean		
Yellow soil	0.17-9.39	1.12	119	1.42
Yellow loamy soil	0.32-5.45	1.36	40	1.68
Dark yellow-brown soil	0.14-25.74	1.40	1228	1.80
Yellow-brown loamy soil	0.20-7.37	0.81	76	0.95
Acid brown soil	0.18-23.23	1.19	563	1.39
Brown lime soil	0.16-13.76	2.06	192	2.62
Yellow lime soil	0.34-17.70	2.67	251	3.94

According to the data in Table 4, the ranking of selenium content levels by soil type is as follows: yellow lime soil > brown lime soil > dark yellow-brown soil > yellow loamy soil > yellow soil > acid brown soil > yellow-brown loamy soil.

In the study area, most areas of yellow lime soil and brown lime soil are at the level of extreme selenium enrichment, with enrichment factors reaching 3.94 and 2.62, respectively, indicating typical enrichment characteristics. Dark yellow-brown soil, as the most widely distributed soil type, has most areas at the level of selenium enrichment, with the highest selenium content reaching 25.74 mg/kg, and an enrichment factor of 1.80. Yellow loamy soil and yellow soil generally have lower selenium levels, with enrichment factors around 1.55. Acid brown soil has a wide distribution and selenium content reaching enrichment levels, with higher maximum selenium values, but overall lower values, with an enrichment factor at the level of 1.40. Yellow-brown loamy soil does not reach the level of selenium enrichment, with an enrichment factor of 0.95.

6. CONCLUSION

The surface soil selenium content in Xintang Township ranges from 0.14 to 25.74 mg/kg, with a background value of 0.81 mg/kg. Furthermore, soil areas meeting the standard for selenium-rich soil cover 86.23% of the total area. The distribution of soil selenium is closely related to parent material, with soils developed from the Permian black rock series exhibiting significantly higher selenium content, with an enrichment factor of 3.74. Soil type also influences the distribution of soil selenium, with yellow lime soil and brown lime soil showing typical enrichment characteristics, with enrichment factors reaching 3.94 and 2.62, respectively.

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