The Characteristics and Causes of Soil's Magnetic Susceptibility of Red Bare Lands in the Karst Region of Eastern Yunnan, China

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Abstract. We sampled and tested the magnetic susceptibility of surface soil (0~30cm) and profile soil of red bare lands in the karst area of eastern Yunnan, China. The results showed that the magnetic susceptibility of the surface soil in the 15 samples of red bare lands was lower than that of vegetated lands in the same area, which was 7~67% lower, respectively. The mean value was 994.14×10⁻⁸m³·kg⁻¹, which was 39.84% lower than that of the vegetated lands, and the variation coefficient was 36%, higher than that of the vegetated lands. The profile soil's variation coefficients of the magnetic susceptibility in the red bare lands were 5.3% and 16.8%, respectively, which were lower than those of the vegetated lands (31.5% and 25.3%). The conclusion is as follows: the soil of red bare lands is rich in magnetic minerals; the surface soil's susceptibility is lower than those of the vegetated lands in the same region and the degree of variation is higher, while the degree of profile soil's variation coefficients of the magnetic susceptibility is lower. We can conclude that there is a chemical erosion process which a large number of magnetic minerals are lost or transformed in the erosion process of red bare lands, and the acid rain may be one of its important causes.

1. Introduction
Red bare land is a kind of desertification landscapes in the karst region of eastern Yunnan, China. It is also known as “red bare soil”[1] and “naked red soil”[2] because of its visual features of long-term exposed red soil with no vegetation. The studies of the soil's physical and chemical properties and causes of red bare lands are of great significance to scientifically understand the formation mechanism of red bare lands and explore its ecological restoration measures.

Soil magnetism can synthetically reflect the magnetism of each component of the soil. Different scholars have made corresponding studies on the soil's organic matter[2], the available nutrient[3] and soil aggregates[4] of the red bare lands, but the research on its magnetic characteristics has not been published. The studies on the characteristics and causes of soil’s magnetic susceptibility in red bare lands in the karst region of Eastern Yunnan are helpful to understand the status of the soil components, especially the magnetic minerals, and to provide the corresponding scientific basis for exploring the genesis mechanism of the red bare lands.
2. Materials and methods

2.1. Study area overview
The karst region in eastern Yunnan is the source of the Pearl River and the upper reaches of the Yangtze River. The terrain is high in the northwest and low in the southeast. The difference in elevation is large, with the highest height of 4017.3m and the lowest height of 695m. There are various types of landforms, including flat massive plateau surface, high mountains, vast lake basins and karst mountains and so on. The monsoon climate is significant, with an average annual rainfall of about 1000mm. The dry and wet seasons are distinct, while the dry season is longer and the rainfall is less, the wet season is short and the rainfall is concentrated. The primary vegetation type is subtropical evergreen broad-leaved forest, but affected by cultural activities, the vegetation damage is relatively serious, the original forest is rare, small and scattered, the existing vegetation types are mostly artificial pine forest, shrub grass, etc. The red bare land is mainly distributed in the secondary vegetation area of plateau and mountains.

2.2. Sample collection and processing
In Fuyuan, Xuanwei, Shilin, Zhanyi, Luoping county(district) where red bare land more develops, representative areas was selected as sample areas for the study of surface soil magnetism, which are Liangshuijing, Huilong, Xiaohaizi, Yangjiafen, Guangshantou, Haiping, Qingshuitang, Duoletun, Guyi, Houjiadanaobao, Xize, Wude, Yuehu, Haifeng, Changdi. In each sample area,a representative sample was selected .

In accordance with the Chinese forestry industry standard LY/T 1210-1999, the collection and treatment of soil samples were conducted with a collection depth of 0~30cm. 6~20 samples were collected from each site. Collect the samples with wooden spoons and pack samples in sealed plastic bags. The check samples were collected by the same method and amounts in the vegetated lands where the landforms were similar and near the sample site.

The representative Fuyuan Haitian (red bare soil 1, vegetated land 1) and Liangshuijing (red bare soil 2, vegetative land 2) were selected as the study sample areas for the magnetic characteristics of the soil profile. Select representative plots and excavate soil profiles according to the above criteria. The section depth is 2 meters (red bare land 2) or reaches the bedrock (red bare land 1, vegetated land 1, vegetated land 2). Scrape 1~3cm of soil from the sampling surface with a plastic spoon and sample by layers (10cm/ layer) from bottom to top.

The samples were processed according to the standard LY/T 1210-1999.

2.3. The sample test
Processed samples were put into 10ml special sample boxes for weighing, and the low frequency (470Hz) magnetization rate was measured with BartingtonMS2B magnetization meter. Continuous measurement 3 times, the measured value difference is less than 5, take the middle value. If the difference value is large than 5 , then test again 3 times, the difference is small, value according to the previous method; If the difference is large, the maximum and minimum values are removed and the average value is taken. The magnetic susceptibility of the sample plot is the average value of all the samples in the sample plots.

3. Results and discussion

3.1. Magnetic susceptibility of surface soil in red bare land
According to the surface sample collection method in method 1.2 and the test method in method 1.3, the results were as follows: the average magnetic susceptibility (0~30cm) of the surface soil of the red bare land was 994.14×10^{-8}m^3·kg^{-1}, with the maximum value of 1740.1×10^{-8}m^3·kg^{-1} and the minimum value of 445.04×10^{-8}m^3·kg^{-1}. 
The magnetic susceptibility of the surface soil in the 15 samples was significantly lower than that of the vegetated soil in the same region, ranging from 7 to 67% lower (Figure 1), and the mean, maximum and minimum values were 39.84%, 26.57% and 29.95% lower, respectively.

The results of the statistical analysis of the magnetic susceptibility of the surface soil (0~30cm) in 15 samples of the red bare lands were as follows. Range: 1295.09×10⁻⁸m³·kg⁻¹, standard deviation: 353.55×10⁻⁸m³·kg⁻¹, variation coefficient: 36%. The range and standard deviation were significantly smaller than those vegetated land in the same region, and the coefficient of variation was slightly larger than the vegetated land in the same region (Table 1). It indicates that the value difference of magnetic susceptibility of surface soil in red bare land is relatively small, but the degree of variation is relatively large.

| Type of landscapes | N  | Range     | MIN   | MAX   | MEAN | SD     | CV (%) |
|-------------------|----|-----------|-------|-------|------|--------|--------|
| Red bare Lands    | 15 | 1295.09   | 445.04| 1740.13| 994.14| 353.55 | 36     |
| Vegetated lands   | 15 | 1734.51   | 635.29| 2369.80| 1652.60| 528.17 | 32     |

3.2. Magnetic susceptibility characteristics of soil profile of red bare land

The colors of the profile soil of red bare lands are same, no obvious occurrence layers, no plant roots, and no trace of large soil animals and their activities. Red bare land 1 is loose, and the soil near the bedrock becomes lighter in color with white rock weathering materials. The soil of red bare land 2 is compact. The soil profile of the vegetated lands are loose, and the soil is 0~20 cm deep with darker color and full of dense plant roots, ants, earthworms and other large soil animals. The soil below 20 cm becomes lighter in color, which tends to be consistent with the profile soil of the red bare land.

According to the sampling method 1.2 and the test method 1.3, the test results are shown in figure 2: the average soil magnetization in profile of the red bare land 1 was 749×10⁻⁸m³·kg⁻¹, all the layers were lower than that in vegetated land 1, and the amplitude of section curve was small; The average soil magnetization rate of profile of red bare land 2 is 2041×10⁻⁸m³·kg⁻¹, slightly higher than that in vegetated land 2, 0~10cm layer is lower, the amplitude of the 10~110cm layer is smaller, and that of the lower 110cm layer is larger. The amplitude of magnetic susceptibility of the two profiles were smaller than those vegetated lands in the same area.
Figure 2. Comparison of profiles Soil’s magnetic susceptibility between red bare lands and vegetated lands at the same area.

The statistical analysis of the profile soil magnetic susceptibility (Table 2) shows that the range, standard deviation and variation coefficient of the two soil profiles of the red bare land are significantly lower than those of the same region of the vegetated soil. This indicates that the difference of the magnetization of the landscape soil is relatively small in the vertical direction.

Table 2. Statistical analysis of magnetic susceptibility of soil profile of red bare lands and vegetated lands at the same area. unit: $10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$;

| Type of landscape | N  | Range | MIN | MAX | MEAN | SD   | CV (%) |
|-------------------|----|-------|-----|-----|------|------|--------|
| Red bare land 1   | 10 | 111   | 695 | 806 | 749  | 39.42| 5.3    |
| Red bare land 2   | 20 | 1291  | 3444| 2329| 2041 | 343.32| 16.8   |
| Vegetated land 1  | 20 | 1157  | 2153| 1291| 1417 | 734.97| 31.6   |
| Vegetated land 2  | 16 | 2417  | 1552| 1154| 2709 | 481.68| 25.3   |

3.3. Discussion
The 15 samples in this study are distributed in Fuyuan, Xuanwei, Shilin, Zhanyi and Luoping counties (cities and districts), with a wide geographical range, diverse environmental types, and a large number of samples, which are well representative. In addition to vegetation characteristics, the environmental similarity between the same plot and the study plot is higher, which has a good reference. Therefore, the results of this test can basically reflect the characteristics of the magnetization rate of the red bare land soil in the karst region of eastern Yunnan, that is, the surface soil magnetization rate is lower than that of the vegetated land, the regional difference is large, and the difference of the soil profile magnetization rate is small.

The main influence factor of soil magnetic susceptibility is mineral property. The magnetite and the titanium-bearing series of magnetite are the main contributors to soil magnetism. The minimum value of the magnetization rate of the surface soil (0~30cm) in the red bare lands is $445.04 \times 10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$, with an average value of $994.14 \times 10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$ and a maximum value of $1740.1 \times 10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$, it shows that the soil of red bare lands is rich in magnetic minerals. The magnetic susceptibility varies greatly in different plots, indicating that the magnetic mineral contents of red bare soil in different regions were significantly different.
There is a large soil loss in the red bare land\cite{5}. The magnetic susceptibility of the topsoil (0~30) of the 15 sample lands were significantly lower than that of the vegetated lands in the same region, indicating that in the erosion process of the red bare land, magnetic minerals were lost or changed frequently, and chemical erosion was strong. Studies have shown that under the action of acid rain, the leaching amounts of \( \text{Fe}^{3+} \) increase with the increase of acidity\cite{6}. Eastern Yunnan is the main coal-producing area. There are a large number of \( \text{SO}_2, \text{NO}_x \) and other acidic substances in the flue gas discharged by thermal power and coal burning, which will form acid rain under certain conditions. After acid rain enters the soil, it reacts with ferromagnetic metals in the soil to form water-soluble salts, which move with the flow of soil water and reduce the magnetization rate of the soil, or the magnetic minerals in the soil from high magnetic valence state to low magnetic valence state, thus reducing the soil's susceptibility.

Acid rain may be one of the reasons for the low magnetic susceptibility of surface soil in red bare land. The difference of soil magnetic mineral content and the difference of chemical erosion increased the difference of surface soil magnetic susceptibility of red bare land.

The two soil profiles of the red bare lands both have the characteristic that the difference of magnetic susceptibility is smaller than that of the vegetated land, and the upper change range of soil is smaller. In the karst area of eastern Yunnan, rock fissure and cavities develop, and soil erosion is not only caused by horizontal surface erosion, but also by vertical erosion transferred to the interior of rock mass through fissure holes. In the process of downward transport of chemical erosion solution, magnetic minerals are dissolved or precipitated along with the change of conditions, resulting in the relative equilibrium of magnetic minerals distribution, and thus the difference of soil magnetization rate in landscape profile of red bare soil decreases.

4. Conclusion

Based on the data of surface and profile soil magnetization of the red bare land and comparison with vegetated land in the karst area of eastern Yunnan, the following conclusions can be drawn from the comprehensive analysis of the environmental characteristics of the karst area in eastern Yunnan and the influencing factors of soil magnetization and related research results.

(1) The characteristics of the magnetization rate of the soil of red bare lands are as follows: the magnetic susceptibility of the surface soil is obviously lower than that of the same region, and the degree of variation is larger, and the variation degree of the magnetic susceptibility of the profile soil is small.

(2) In the erosion process of red bare lands, the chemical erosion is strong, and magnetic minerals are lost more, including horizontal erosion and vertical erosion. The effect of acid rain may be one of the important factors leading to the above characteristics of red bare lands’ magnetization.

Acknowledgments

Thanks for the support of national nature science foundation of China (41061021) and Yunnan science and technology plan(2012CA024)!

Mr. Su Huai from Yunnan normal university gave us careful guidance in the sample test. Thank you very much!

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