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DISTRIBUTIVE TENDENCY OF ELEMENT CONCENTRATIONS IN LIMESTONE SOILS IN EASTERN CHINA

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ABSTRACT: Twenty-eight soil profiles studied were collected from the eastern China. They belong to brown soil, drab soil, yellow brown soil, brown limestone soil and red limestone soil. The concentrations of Ca and Mg in soils decrease and the concentrations of Fe, Al, Zn, Pb, Cd, and Hg increase from north to south. There is no significant correlation between the element concentrations and soil organic matter contents. Statistically there is a most significant positive correlation between the concentrations of Ca and Mg, and pH, while there is a most significant negative correlation between the concentrations of Fe, Zn and Cd, and pH, and a significant negative correlation between Al concentration and pH. There is a most significant negative correlation between concentrations of Ca and Mg, and clay content, and a most significant positive correlation between Fe, Al, Pb, Cd, Hg and clay content. The concentrations of Ca and Mg decrease, and those of Fe, Al, Zn, Pb, Cd and Hg increase in the processes of acidification and clayization with the increase in temperature and rainfall.
KEY WORDS: limestone soils, element concentration, migration and accumulation, Eastern China

Soils derived from limestone and other carbonate rocks cover an area of 2 million km^2, which make up one-fifth of the total area of China[1]. The dominant soil-forming process of limestone soils is chemical weathering, that is the limestone solution residual process. The mineral and chemical composition of rock and the texture and structure of rock layer significantly influenced the concentration, migration and accumulation of soil elements. However, the zonal factors such as temperature and rainfall are also important factors for the limestone soil-forming process. The Chinese researchers have done some studies on the soil characteristics and chemical composition of limestone soils[1-9], but the studies are limited in the tropical and subtropical regions, and the elements analysed are dominantly macroelements. The purpose of this paper is to investigate the distributive tendency of element concentrations in limestone soils and the influence of the zonal soil-forming factors on migration and accumulation.

I. SOIL TYPES AND PROPERTIES

Twenty-eight soil profiles studied were collected, among them, 3 soil profiles were from northeastern China, 4 from northern China, 3 from the middle and lower reaches of the Changjiang (Yangtze) River, 18 from Guangdong, Guangxi, southern Hunan and southeastern Guizhou. According to the soil classification system in China, the soil samples collected from southeastern Guizhou and Guangxi belong to brown limestone soil, soils from southern Hunan and Guangdong belong to red limestone soil, soils from the middle and lower reaches of the Changjiang River belong to yellow-brown soil, soils from northern China belong to drab soil and soul from northeastern China belong to brown soil.

The climatic conditions of soil formation of five soil types are different obviously. Brown soil is distributed in the south temperate wet climate region, drab soil in the south temperate semi-wet and semi-arid climate region, yellow brown soil is in the north subtropical wet climate region, red limestone soil in the tropical and subtropical wet climate region and brown limestone soil in the subtrpical wet climate region with less rainfall and longer dry season compared with red limestone soil.

The contents of organic matter and clay and pH in each limestone soil type are shown in Table 1. The highest content of organic matter was found in brown soil and the lowest in drab soil and the distributive tendency is in the order of brown soil>yellow soil>red limestone soil>brown limestone soil> drab soil. The distributive tendency of pH is: brown soil>drab soil>yellow brown soil >red limestone soil>brown limestone soil, which are decreased from north to south. Oppositely clay contents are increased from north to south, the order is: brown limestone soil>red limestone soil>yellow brown soil>brown soil>drab soil. The research result shows that there is a relationship between the organic matter, pH , clay content of limestone soils and the climatic condition of soil formation; cool wet climate favours the accumulation of organic matter and hot wet climate favours the acidification and clayization of limestone soils.

Table 1 Properties of limestone soils in eastern China(A horizon)

Soil type	Number of samples	pH		Organic matter(%)		Clay (<0.001mm)	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Brown soil	3	6.90	0.21	8.38	7.71	12.9	4.83
Drab soil	4	6.52	0.30	2.94	2.17	12.3	7.12
Yellow brown soil	3	5.94	0.17	4.83	1.12	16.9	2.01
Brown lime-stone soil	8	4.94	0.33	3.00	1.28	28.9	8.29
Red lime-stone soil	10	4.99	0.42	4.04	1.76	26.5	5.25
Total mean	28	5.51	0.84	4.14	1.65	22.7	9.02
Mean in China's soil		6.70	1.48	3.10	3.30	17.6	11.7

$\bar{x}$—mean value, SD—standard difference

II. DISTRIBUTIVE TENDENCY OF SOIL ELEMENT CONCENTRATIONS

1. Distributive Tendency of Soil Element Concentrations

Ca, Mg. The mean concentrations of Ca, Mg of limestone soil in the eastern China are 0.925% and 0.604%, which are lower than the mean concentrations of soils in China (1.54% and 0.78%)[11]. In general, the concentrations of Ca, Mg in limestone soil are higher than other soils, but most of the soil samples studied were collected from the wet climate regions and especially from high temperature and heavy rain region in the south of the Changjing River, the leaching of Ca, Mg is so intensive that the remains are very few except drab soil samples. Table 2 and Fig. 1 show that contents of Ca, Mg of limestone soil decreased obviously from north to south, it is because rainfall increased form north to south and leaching of Ca, Mg became more intensive.

Fe, Al. The mean concentration of Fe in limestone soil is 4.86%, which is mch higher than the mean concentration of soils in China (2.94%)[11] and increased obviously from north to south (Table 2, Fig. 1). The mean concentration of Al in limestone soils is 7.62%. which is also higher than the mean concentration of soils in China (6.62%)[11]. The distributive tendency of Al in limestone soils also increased from north to south (Table 2, Fig. 1).

Table 2 Concentration of elements in limestone soils in eastern China (A horizon)

Elements		Brown soil	Drab soil	Yellow brown soil	Brown limestone soil	Red limestone soil	Total mean	Mean in China's soil
		Number of samples						
		3	4	3	8	10		
Ca	$\bar{X}$	1.84	3.28	0.965	0.232	0.252	0.925	1.54
	SD	0.21	2.23	0.562	0.283	0.187	1.35	1.63
Mg	$\bar{X}$	1.09	1.02	0.723	0.384	0.430	0.604	0.78
	SD	0.699	0.174	0.583	0.303	0.297	0.445	0.433
Fe	$\bar{X}$	3.55	3.54	4.19	5.20	5.21	4.68	2.94
	SD	0.805	0.65	1.30	3.07	2.22	2.01	0.948
Al	$\bar{X}$	7.19	6.82	6.74	8.02	8.81	7.62	6.62
	SD	1.70	1.21	2.16	4.20	2.22	2.69	1.63
Zn	$\bar{X}$	59.0	58.1	78.9	128	140	109	74.2
	SD	5.33	8.95	41.8	133	106	100	32.8
Pb	$\bar{X}$	24.3	39.4	56.1	39.7	45.0	41.6	26
	SD	5.43	15.3	21.3	31.1	27.5	25	12.4
Cd	$\bar{X}$	0.265	0.098	0.731	0.649	0.740	0.570	0.097
	SD	0.245	0.025	0.438	0.791	1.21	0.854	0.079
Hg	$\bar{X}$	0.186	0.048	0.172	0.154	0.116	0.131	0.065
	SD	0.203	0.024	0.148	0.119	0.072	0.109	0.08

* Concentration unit: Ca, Mg, Fe, Al, %; Zn, Pb, Cd, Hg, mg/kg

Zn, Pb, Cd, Hg. The mean concentration of Zn in limestone soils is 109 mg/kg, higher than the mean concentration (74.2 mg/kg) in China[11]. The highest content is found in red limestone soil and Zn content of drab soil is the lowest. It is obvious that Zn concentration increases from north to south. Pb mean concentration of limestone soil is 41.6 mg/kg, much higher than the mean concentration of Pb in the soils of China (26 mg/kg)[11] and the concentration increased from north to south, but the distributive tendency is not as well as Zn. The mean concentration of Cd in limestone soils is 0.57mg/kg, it

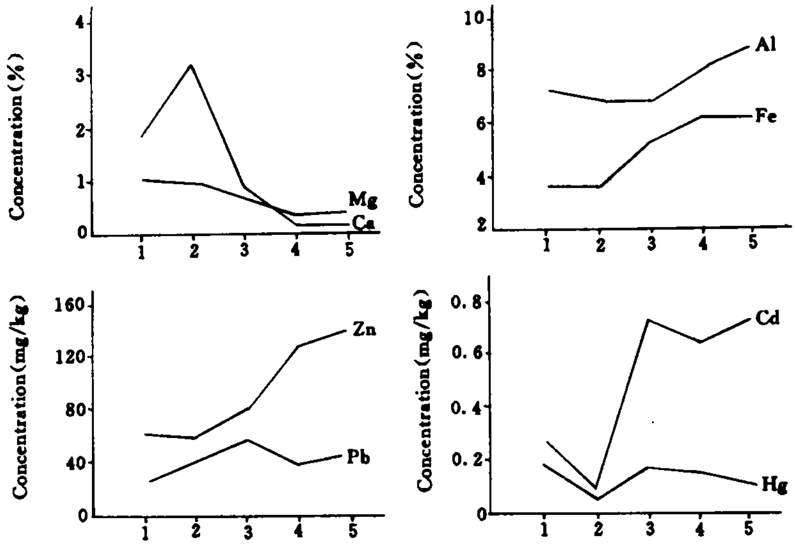

Fig. 1 Distributive tendencies of element concentrations in limestone soils in eastern China
1. Brown soil 2. Drab soil 3. Yellow brown soil
4. Brown limestone soil 5. red limestone soil

is much higher than that of soils in China (0. 097mg/kg)[11]. The content of Cd of yellow brown soil, brown limestone soil and red limestone soil in southern China are much higher than those of brown soil and drab soil in north China. The mean concentration of Hg in limestone soil is 0. 131 mg/kg, that is 2 times that the mean value of soils in China. The distributive tendency of Hg in limestone soil is not as well as other heavy metals. The highest content is found from brown soil and the lowest is in drab soil. The concentrations of Zn, Pb, Hg in limestone soils and the distributive tendency are shown in Table 2 and Fig. 1.

2. **Relationship between Distributive Tendency of Element Concentrations and Zonal Soil-Forming Factors**

In order to approach the response of element concentrations of limestone soils to zonal soil-forming factors and the relationship between the element co entrations of soils and organic matter accumulations, acidification, clayization related closely to the zonal soil-forming factors, the correlation between element concentrations and organic matter content, pH, clay content are analysed . The results show that there is a positive correlation between the concentrations of Ca, Mg and organic matter contents and a negative correlation between the concentrations of Fe, Al, Zn, Pb, Cd, Hg and organic matter contents, but all of them are not significant ($P>0.05$). Statistically there is a most significant positive correlation between the concentrations of Ca, Mg, and pH ($P<0.01$), while a most significant negative correlation between the concentrations of Fe, Zn, Cd and pH ($P<0.0$)1 and, a significant negative correlation between Al concentration and pH ($P<0.05$). There is a most negative significant correlation between the concentrations of Ca, Mg, and clay contents ($P<0.01$), whiles a most positive significant correlation between the concentrations of Fe, Al, Zn, Pb, Cd, Hg and clay contents ($P<0.01$) (Table 3).

Table 3 Relationship between concentration of elements and soil properties in limestone soil (A horizon)

		Ca	Mg	Fe	Al	Zn	Pb	Cd	Hg
pH	r	0.769	0.962	−0.678	−0.539	−0.909	−0.485	−0.702	−0.362
	P	<0.01	<0.01	<0.01	<0.05	<0.01	>0.05	<0.01	>0.05
Organic matter	*r*	0.148	0.083	−0.357	−0.446	−0.242	−0.305	−0.035	−0.123
	P	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
Clay <0.001mm	*r*	−0.648	−0.796	0.870	0.780	0.953	0.511	0.515	0.496
	P	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05	<0.05

The above analysis results show that the concentrations of Ca, Mg decreased, and Fe, Al, Zn, Pb, Cd, and Hg increased in the progresses of acidification and clayization with the increase of temperature and rainfall. Ca, Mg in limestone soil were leached severely in clayization and acidification processes so that the concentrations decreased rapidly. However, Fe, Al, Zn, Pb, Cd and Hg in limestone soils were leached very slowly and were in a relative accumulation status so that the concentrations increased obviously.

3. Influence of the Differential Soil-Forming Factors on the Mobility and Accumulation of Elements in Limestone Soils

The main sources of soil elements are from parent material, atmosphere and volcanic ash. Parent material is the most important source of elements for most of soils. The chemical composition of parent material is the initial background of elements in soil-forming process.

In soil-forming process, the differential soil-forming factors caused the different soil-forming process, which significantly influence the leaching and accumulation of elements, furthermore, change the concentrations and distribution of elements in soil profile. The distribution of limestone soils in eastern China are from temperate, through subtropical to tropical climate zones and the rainfall is quite different from north to south. In order to assess the influence of zonal soil-forming factors on the leaching and accumulation of soil elements in the process of soil-forming from parent material, drab soil and red limestone soil were selected for comparison. There is a large change in the zonal soil-forming factors between two types of soil. The drab soil is in the temperate semi-arid and semi-wet climate regions where the chemical weathering and element leaching are the most weak while red limestone soil is in the subtropical-tropical wet climate region where the chemical weathering and element leaching are the most violent among the limestone soils in eastern China.

Table 4 shows the element concentrations of each horizon in drab soil and red limestone soil. It would be found that the difference of element concentrations among A, B, C horizons is not significant. However, there is a significant difference in the element concentrations between soil and parent material (D horizon) and the varying degree is different in each element. It represents that the mobilities of rach element are variant. Ca, Mg were decreased greatly and the concentrations of Fe, Al, Zn, Pb, Cd and Hg increased greatly in the soil-forming process from parent material to soil.

For contrasting the status of the migration and accumulation of elements in drab soil with that in red limestone soil, the coefficient of element migration —accumulation were calculated, the formula is:

$$K=Cn/Cd$$

where K—coefficient of element migration-accumulation, Cn—the concentration of element in soil (mean value of horizon A, B, C), Cd—concentration of element in parent material, $K<1$ shows absolute immigration, $K>1$ shows relative accumulation.

The result shows that there is a significant differece between drab soil and red limestone soil in the element migration and accumulation. Ca, Mg are the complete migration elements in both soils, but the coefficient of migration accumulation of Ca in drab soil is much greater than that in red limestone soil, which represents the mobility of Ca increased greatly with temperature rising and rainfall increasing in the soil-forming process . The coefficients (K) of Fe, Al, Zn, Pb, Cd and Hg are more than 1, that shows that these elements are relatively accumulated in both soils. However, the K value of Hg, Zn, Fe in red limestone soils are 4. 3 to 15. 3 times that in drab soil, showing that the accumulation of these elements increased obviously with the temperature rising and rainfall increasing . The K value of Pb, Al, Cd in red limestone soil are only 1.8 to 2.0 times that in drab soil, which reflects that the increase of relative accumulation abilities of Pb, Al and Cd are much less than that of Hg, Zn and Fe under the condition of temperature rising and rainfall increasing from north to south in China.

Table 4 Comparison of concentration and coefficient of migration of elements between drab soil and red limestone soil

Elements		Drab soil					Red limestone soil				
		A	B	C	A+B+C	D	A	B	C	A+B+C	D
Ca	$\bar{X}$	3.28	2.75	2.55	2.86	28.4	0.252	0.202	0.185	0.213	31.7
	K	0.12	0.10	0.09	0.10	1	0.008	0.006	0.006	0.007	1
Mg	$\bar{X}$	1.02	0.98	0.98	0.999	5.02	0.43	0.54	0.53	0.50	3.03
	K	0.20	0.20	0.20	0.20	1	0.174	0.18	0.17	0.16	1
Fe	$\bar{X}$	3.54	4.42	4.74	4.23	1.22	5.21	6.11	6.28	5.87	0.39
	K	2.90	3.62	3.89	3.47	1	13.2	15.5	15.9	14.9	1
Al	$\bar{X}$	6.82	7.82	8.28	7.64	1.49	8.81	9.18	8.87	8.95	0.88
	K	4.58	5.25	5.56	5.13	1	10.0	10.4	10.1	10.2	1
Zn	$\bar{X}$	58.1	59.5	61.3	59.6	21.0	140	179	172	164	8.27
	K	2.77	2.83	2.92	2.84	1	16.9	21.6	20.8	19.8	1
Pb	$\bar{X}$	39.4	45.3	48.2	44.3	43.1	45.0	48.7	45.6	46.4	25.4
	K	0.91	1.05	1.12	1.03	1	1.78	1.92	1.80	1.83	1
Cd	$\bar{X}$	0.098	0.091	0.062	0.084	0.013	0.074	0.619	0.744	0.701	0.055
	K	7.54	7.00	4.77	6.44	1	13.5	11.3	13.5	12.8	1
Hg	$\bar{X}$	0.048	0.056	0.041	0.048	0.04	0.116	0.205	0.235	0.185	0.01
	K	1.20	1.40	1.03	1.21	1	11.6	20.5	23.5	18.5	1

III. CONCLUSION

The concentrations of Ca, Mg decreased rapidly but Fe, Al, Zn, Pb, Ca and Hg increased continuously from north to south in limestone soil-forming process in eastern China.

Statistically there is a most significant positive correlation between the concentrations of Ca, Mg and pH, while there is a most significant negative correlation between the concentration of Fe, Zn, Ca and pH. There is a most significant negative correlation between the concentrations of Ca and Mg and clay content, and a most significant positive correlation between the concentrations of Fe, Al, Zn, Pb, Cd,Hg and clay content.

Ca, Mg in limestone soils were migrated rapidly and Fe, Al, Zn, Pb, Ca and Hg accumulated relatively in the processes of acidification and clayization with temperature rising and rainfall increasing from north to south.

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